

**SEXUAL DIMORPHISM OF NORTH AMERICAN STURGEONS (*ACIPENSER*  
SPECIES)**

**A Thesis**

**Presented to**

**The Faculty of Graduate Studies**

**of**

**The University of Guelph**

**by**

**PAUL VECSEI**

**In partial fulfillment of requirements**

**for the degree of**

**Master of Science**

**November, 2000**

**© Paul Vecsei, 2000**



National Library  
of Canada

Acquisitions and  
Bibliographic Services

395 Wellington Street  
Ottawa ON K1A 0N4  
Canada

Bibliothèque nationale  
du Canada

Acquisitions et  
services bibliographiques

395, rue Wellington  
Ottawa ON K1A 0N4  
Canada

*Your file Votre référence*

*Our file Notre référence*

The author has granted a non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of this thesis in microform, paper or electronic formats.

The author retains ownership of the copyright in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de cette thèse sous la forme de microfiche/film, de reproduction sur papier ou sur format électronique.

L'auteur conserve la propriété du droit d'auteur qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

0-612-56377-4

Canada

## SEXUAL DIMORPHISM OF NORTH AMERICAN STURGEONS (*ACIPENSER* SPECIES)

Paul Vecsei

University of Guelph, 2000

Advisor:

Professor D. L. G. Noakes

I have developed a technique to determine the sex of live adult sturgeons by examination of external morphology. I analyzed four North American sturgeon species: *Acipenser transmontanus* (white sturgeon), *A. oxyrinchus* (Atlantic sturgeon), *A. medirostris* (green sturgeon) and *A. brevirostrum* (shortnose sturgeon). The opening of the urogenital duct is posterior to the anus. Males have a urogenital opening with a capital **Y**- shape while females have an **O**- shaped opening. Accuracy of sex determination was highest in live fish (82 %), but significantly lower in dead fish (29 %). Dead sturgeon usually have the rectum prolapsed via the cloaca so the urogenital opening and surrounding fleshy tissue are protruded, thus making the sexes indistinguishable. I tested this technique with naïve field personnel and observers in the laboratory. Successful application of this technique requires training of both those taking observations on the fish and those interpreting resulting photographs.

## **ACKNOWLEDGEMENTS**

This study was supported by a grant from the World Wildlife Fund of Canada - Endangered Species Recovery Fund, and an Operating Grant from NSERC Canada to David L. G. Noakes. I thank Serge Demarais, Bruce Morrison, Eugene K. Balon, Ryan Hardy, Matthew Litvak, Robert McLaughlin, Pier-Andree Pentilla, Tom Rein, Martin Hochliethner, Edward Down and Bjarni Kristjansson for discussion of this research and comments on earlier drafts of this thesis. Special thanks to all those who participated in the test of the reliability of the morphological criteria for determining sex of individual sturgeon. Thanks to Ted Neujett for allowing access to his fish and Paul Soucy of the Sturgeon Recovery Group for being instrumental in increasing my sample size of North Atlantic sturgeon and for being so well set up for urogenital examination of sturgeons. I am particularly grateful to Louise M. Porto of R L & L Consultants, Castlegar, British Columbia. She was responsible for taking the series of photographs of white sturgeon sampled during their study, and for providing additional information as to the sex and state of maturity of those individual fish. Special thanks to David Noakes whose help far exceeded the requirements of an advisor. Also, instrumental to my overall knowledge of sturgeon were D. Evgenii Artyukhin, a sturgeon ecologist and morphologist, and Martin Hochleithner, an aquaculturist who was the first to suggest that male and female sturgeon have different vent shapes making them dimorphic. Thanks also to my wife, Sarah Heaton-Vecsei who helped me net sturgeon (she set the gill nets while I manoeuvred the boat) and baiting rotted squid on hundreds of hooks while

longlining on the Columbia River. Sarah also put up with me not being around and spending too much time with sturgeon. My parents also kept lending me money for my education (interest free). One day, I will pay them back. This thesis is dedicated to all those who share my concern for the conservation and continued existence of these magnificent fishes.

## **Table of Contents**

<b>Abstract</b> .....	i
<b>Acknowledgments</b> .....	ii
<b>Table of Contents</b> .....	iii
<b>List of Tables</b> .....	iv
<b>List of Figures</b> .....	v
<b>General Introduction</b>	
<b>Chapter 1. Biology</b>	
1.1 Taxonomy and systematics of sturgeons.....	5
1.2 Review of life history, ecology and spawning behaviour of sturgeons.....	12
<b>Chapter 2. Exploitation</b>	
2.1 Sturgeon fisheries worldwide, general harvest trends .....	18
2.2 Population status, exploitation and conservation of sturgeon species....	24
<b>Chapter 3. Sexual dimorphism</b>	
3.1 Sexual dimorphism in sturgeons .....	45
<b>Chapter 4. Determination of sex of live adult North American sturgeon</b>	
From external morphology	
4.1 Introduction .....	49
4.2 Materials and methods .....	51
4.3 The study site.....	52
4.4 Recording data .....	55
4.5 Results .....	56
4.6 Discussion .....	57
<b>Chapter 5. Validation of technique for noninvasive sex determination of live adult sturgeon</b>	
5.1 Introduction .....	60
5.2 Materials and methods.....	60
5.3 Results .....	63
5.4 Discussion.....	74
<b>General Conclusions</b> .....	81
<b>References Cited</b> .....	84
<b>Appendices</b> .....	97

## List of Tables

<b>Table 1 - 1.</b> Life history table describing intervals in sturgeon development.	17
<b>Table 5 - 1.</b> Results of inter - observer reliability testing of technique to distinguish female and male sturgeons from external morphology....	72
<b>Table 5 - 2.</b> Results of double-blind test of technique to distinguish female and male sturgeons from external morphology.....	73
<b>Table A - 1.</b> Sex of adult North American sturgeons as determined by external morphology and internal gonadal examination: white <i>Acipenser transmontanus</i> , Atlantic <i>A. oxyrinchus</i> , lake <i>A. fulvescens</i> , and shortnose <i>A. brevirostrum</i> sturgeons. Green <i>A. medirostris</i> , are not included (see text for details).....	97
<b>Table A - 2.</b> Score sheet used by subjects to test inter-observer reliability of sex determination technique.....	99
<b>Table A - 3.</b> List of sturgeon species of the world, with identifying characteristics and selected life history features. Canadian species are indicated by asterisks (*).....	100
<b>Table A - 4.</b> RL& L catch summary of white sturgeon, <i>Acipenser transmontanus</i> , from Priest Rapids, Columbia River.....	103
<b>Table A - 5.</b> Sex maturity codes for white sturgeon sampled by RL&L.....	104

## List of Figures

<b>Figure 1 - 1.</b> Technical illustration of North American sturgeons studied for this thesis: (a) white <i>Acipenser transmontanus</i> , (b) green <i>A. medirostris</i> , (c) shortnose <i>A. brevirostris</i> , (d) lake <i>A. fulvescens</i> , and (e) Atlantic <i>A. oxyrinchus</i> .....	9
<b>Figure 1 - 2.</b> Technical illustrations of morphological differences among four adult shortnose sturgeon, <i>A. brevirostrum</i> , captured in the Hudson River, New York, U. S. A. during 1998.....	10
<b>Figure 1 - 3.</b> Cladogram showing phylogenetic relationships within <i>Acipenser</i> . A combination of karyological data and biogeographic information was used. (From Artyukhin 1995 and pers. comm.)...	11
<b>Figure 3 - 1.</b> Schematic diagram of internal anatomy and corresponding external urogenital region of sturgeon used for field identification of females and males by external examination.....	48
<b>Figure 5 - 1.</b> Photographic prints from color slides used to test for inter-observer reliability of technique for determination of sex by external morphological features. Species and sex of individual fish are indicated below each photograph. Arrow indicates anterior.....	65
<b>Figure 5 - 2.</b> Photographic prints of white sturgeon used for double-blind test for determination of sex by external morphological features. The code number gives information on each fish in table <b>A – 5</b> . .....	70

## General Introduction

Sturgeon are perhaps the most dramatic and enigmatic freshwater fishes. They are among the largest freshwater fishes throughout their ranges. The white sturgeon, *Acipenser transmontanus*, is the largest fish found in freshwaters of North America, and the beluga, *Huso huso*, is the largest species in Eurasian freshwaters. Most species migrate downstream from streams and rivers to the oceans where they feed and grow, then return to their spawning rivers or streams during spawning migrations (diadromy). A few species, for example the North American lake sturgeon, *Acipenser fulvescens* are not anadromous, but they still carry out extensive migrations within freshwater (see discussion of migratory behavior in Chapter 1-1.2).

Historically, sturgeon have been considered precious. In China, sturgeon were sent to emperors as a tribute (Qiwei et al. 1997). In Britain sturgeon are designated as a royal fish. In the Middle Ages, the Atlantic sturgeon, *Acipenser oxyrinchus*, took on the title of Royal fish in England when King Edward II decreed that any sturgeon caught in British waters had to be given to the Feudal Lords (Wells 1956). Unfortunately, with few sturgeons left in British waters this is now a rare occurrence.

Today, virtually every sturgeon species is threatened, endangered or of special concern (Birstein et al. 1997). The causes for the continued, dramatic declines in the populations of most sturgeon have been well documented. The flesh of sturgeon commands high prices on the commercial market and their eggs, as caviar, are among the most valuable fish products. FAO statistics show

that the worldwide catch of sturgeon from 1976 to 1983 averaged 28,911 metric tonnes. Over 90 % was taken in the USSR, 5 % from Iran, 2 % from U. S. A. waters and the rest from other parts of the world (Holcik 1989).

Sturgeons are slow growing and late maturing so they are susceptible to a host of risks before they can spawn for the first time (Kynard 1997). Their large size and predictable migrations, especially as spawning adults, make them very susceptible to capture by humans. Their dependence on spawning habitats in shallow, fast flowing rivers (Scott & Crossman 1973, Auer 1996) makes them vulnerable to a range of environmental impacts as well. Dams can block their migrations, and the regulation of water flow in rivers to generate hydro electric power can disrupt the water flow regime necessary for successful recruitment (Auer 1996).

Sturgeons are a very sensitive component of piscine ecological communities throughout the northern hemisphere. Their long life span puts them particularly at risk, exposing them to a combination of environmental degradation and fishing pressure even before they reach reproductive age. The longevity of sturgeon species has made them prime candidates as environmental indicators (LeBreton 1999 & D. Peterson pers. comm.). Nature conservation tends to focus primarily on totemic species and the science community should push to have the sturgeon recognized as such. These fishes are a unique societal and ecological resource.

Efforts to conserve or restore depleted stocks of sturgeons are in progress in a number of places (Artyukhin et. al.1999). Some, such as the slot size limits

and strict regulation of commercial harvest in the lower Columbia River, appear to have been successful in reversing the declines in population numbers (Reiman & Beamesderfer 1990). There is evidence for recruitment of lake sturgeon, *Acipenser fulvescens*, in Lake Ontario in recent years, apparently in response to improvement in spawning habitat, abundant zebra mussels as forage and restrictions on commercial and angling harvest (J. Casselman, Ontario Ministry of Natural Resources, pers. comm.). In other cases the outlook for sturgeons is bleak. The dramatic changes in the management and harvest of Caspian Sea sturgeons after the collapse of the former USSR is perhaps the saddest example. The once enormous runs of Beluga, *Huso huso*, Russian sturgeon, *Acipenser gueldenstaedtii*, and stellate sturgeon, *Acipenser stellatus*, of the Volga and Ural rivers are seriously threatened with extinction. (Artyukhin et al. 1999). Because sturgeon are so long lived, a great difficulty in the management of sturgeon stocks is that once policy is implemented and set into action, it may take up to 30 years to determine whether it was the correct course of action (D. Peterson pers. comm.).

Initial attempts at conservation, restoration, and captive breeding have been focused on classic descriptive objectives. The number of fish present, their size and age characteristics and perhaps some initial description of genetic identity of stocks are fundamental for any scientific study of population biology (Ricker 1975, Ferguson & Duckworth 1997). We now have such information for many North American sturgeon species (Birstein et al. 1997). Stock assessments are being carried out on other species and populations of sturgeons.

Researchers are now able to recommend the implementation of management policies to restore the complex multi-age structure of sturgeon stocks.

The phylogenetic and taxonomic relationships of acipenserids has received little attention. Sound conservation needs to be based on proper taxonomic identification. This aspect of sturgeon biology has been considered at length (Birstien et al. 1997).

In my thesis I address three major objectives: 1) a review of the taxonomy and systematics of extant sturgeon species, 2) an assessment of the status of the species in terms of population estimates and harvest, and 3) developing and testing a non-invasive technique for determining the sex of live adult sturgeon. I will show that the taxonomic and systematic information is relatively complete, and that the biology of most species is relatively well understood. I will also show that virtually every living sturgeon species is either threatened, or endangered, or of special concern in terms of its conservation status. I argue that the conservation needs of most, if not all, these species can be addressed by some basic theoretical and practical knowledge. I propose that one of the most important things to be developed is a simple, non-invasive technique to determine the sex of live, adult sturgeon. This would allow us to better manage sturgeon, whether in the wild or in captive populations.

## Chapter 1. Biology

### 1.1 Taxonomy and systematics of sturgeons

For proper management of fishes, a clear taxonomic division is necessary so the fishes (e.g. sturgeon) can be properly managed as a species or a population of a species distinguishable from other such units. It is therefore necessary to first get a clear understanding of the ecology and life-history of sturgeons. The complex relationship of sturgeon to their environment is an important step towards determining why fisheries for sturgeon have been mismanaged in the past.

All living and fossil sturgeons are classified within the Order Acipenseriformes (Berg 1962, Birstein et al. 1997). The Order consists of 4 genera:

*Huso* is characterized by gill membranes joined with each other and forming a free fold below the isthmus. The snout is short and tapers posteriorly. The mouth is very large, crescent shaped and projects forward. Barbels are laterally flattened and situated closer to the mouth than to the tip of the snout. Gill-rakers are rod-like. A single large median element makes up the unpaired cartilage of the palatoquadrate. Articulation between symplecticum and palatoquadrate is by means of the Meckel's cartilage. The stylohyale articulates with the anterior of the symplecticum (Findeis 1997).

*Huso* are large, pelagic, predatory fish reaching a length of up to 6 m and as much as 1, 000 kg in weight. The genus consists of two species: the beluga *Huso huso*, Linnaeus 1758, which inhabits the Ponto-Caspian watershed and is

diadromous; and the kaluga, *Huso dauricus* Georgi 1775, inhabiting the Amur watershed (Berg 1968).

**Acipenser**, characterized by gill membranes attached to the isthmus and disconnected from each other. The mouth is small, transverse and projects downward. The snout can vary greatly in shape between species but is either conical or narrow, long and flattened. The barbels are cylindrical and on some species fimbriated. The palatoquadratum connects directly to the symplecticum. The stylohyale articulates with the posterior section of the symplecticum. The palatoquadratum and the upper part of the maxillare form a straight line. The basihyalia are situated in proximity to one another along the median line of the ventral part of the head (Findeis 1997). This genus consists of 17 species: *A. nudiventris*, *A. ruthenus*, *A. persicus*, *A. gueldenstaedtii*, *A. naccarii*, *A. medirostris*, *A. brevirostrum*, *A. fulvescens*, *A. transmontanus*, *A. schrenkii*, *A. sinensis*, *A. dabryanus*, *A. mikadoi*, *A. stellatus*, *A. sturio*, *A. oxyrinchus*, and *A. baerii*.

**Pseudoscaphirhynchus** is characterized by a very wide and flat snout. Spines often present at tip of snout. No spiracle or pseudobranchia present. Caudal peduncle slightly flattened and short. The body covered by scutes and between rows of scutes, the entire body surface covered by elongated denticles. Barbels show no fimbriation, eyes are tiny (Berg 1968). This genus includes: *P. kaufmanni*, *P. hermanni*, and *P. fedtschenkoi* (*extinct*)

**Scaphirhynchus**, shares most characters of *Pseudoscaphirhynchus* except caudal peduncle is very narrow and elongated and completely covered by

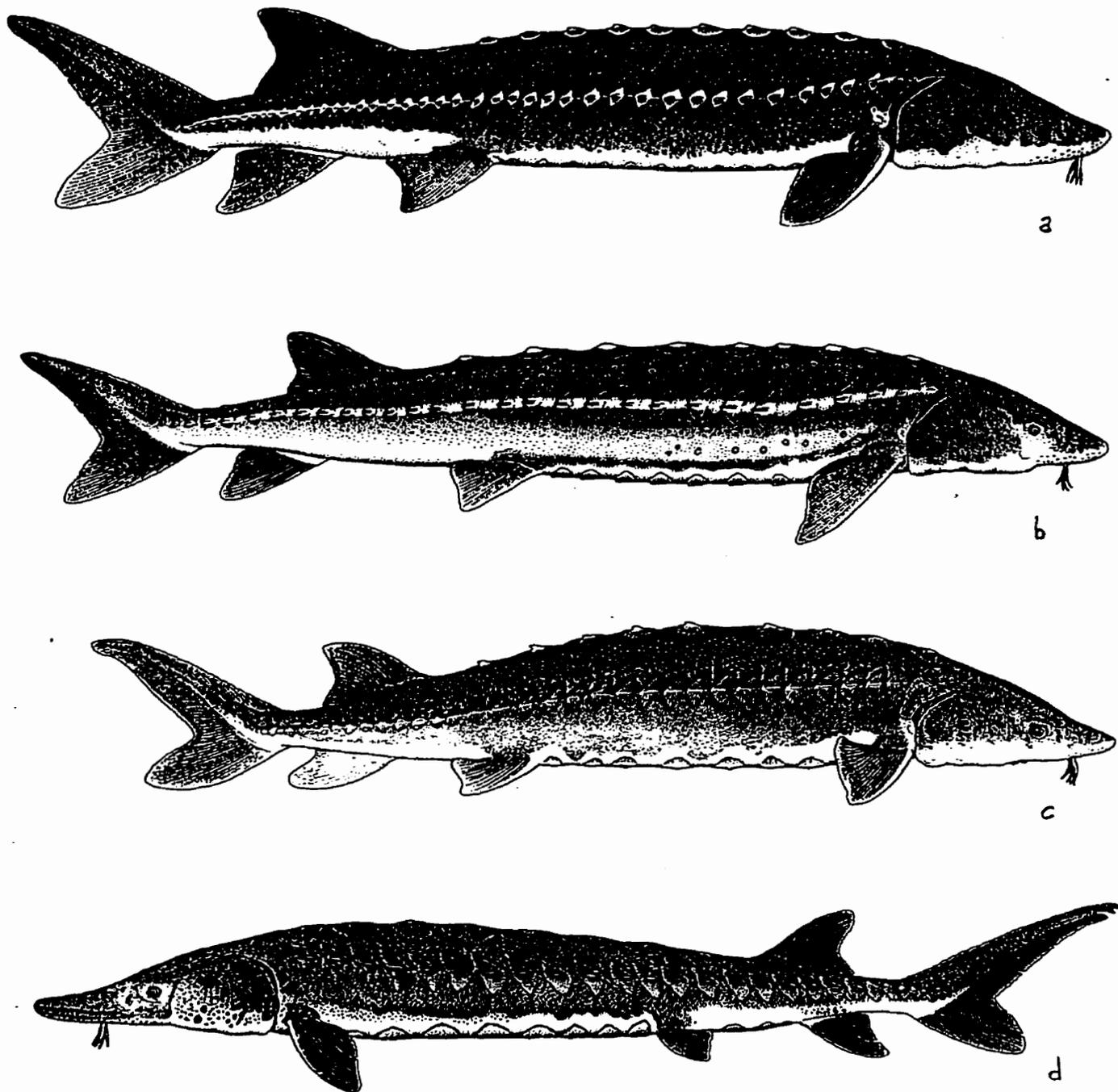
scutes. The barbels are thick and heavily fimbriated (Findeis 1997). This genus includes: *S. albus*, *S. platyrhynchus*, and *S. suttkusi*.

The Acipenseriformes originated sometime in the Lower Jurassic, approximately 200 million years ago (Bemis et al. 1997). Researchers agree that the Acipenseriformes is a monophyletic group and derived from an off-shoot of paleonisciform fishes (Bemis et al. 1997). This evolution occurred through paedomorphic reduction of the skeleton along with specialization of the feeding system (Bemis et al. 1997) According to recent findings by Findies (1997) scaphirhynchines are the derived sturgeons and *Huso* represents the most phylogenetically primitive genus within the Acipenseridae. This is contrary to earlier beliefs which postulated that scaphirhynchines represent the primitive condition of Acipenseridae (Schmalhausen 1991, Birstein et al. 1993). The more recent ideas were founded on the premise that acipenserids originated in fresh water and *Pseudoscaphirhynchus* represents a remnant of the original radiation. Also, their high degree of dermal armor was thought to be typical of ancient sturgeons. It is now suggested that acipenserids show progressive layering of paedomorphic characters in phylogeny and have evolved into fishes that are increasingly benthic. This trend towards increasingly benthic life-style in acipenserids has not achieved the benthic specializations shown by some fishes which have evolved camouflage, flattened bodies and stationary behavior. Acipenserids are cylindrical in shape, interacting with the substrate by mobile benthic foraging. Benthic cruising exhibited by acipenserids is unique in that it combines a medley of benthic and non-benthic features in terms of feeding,

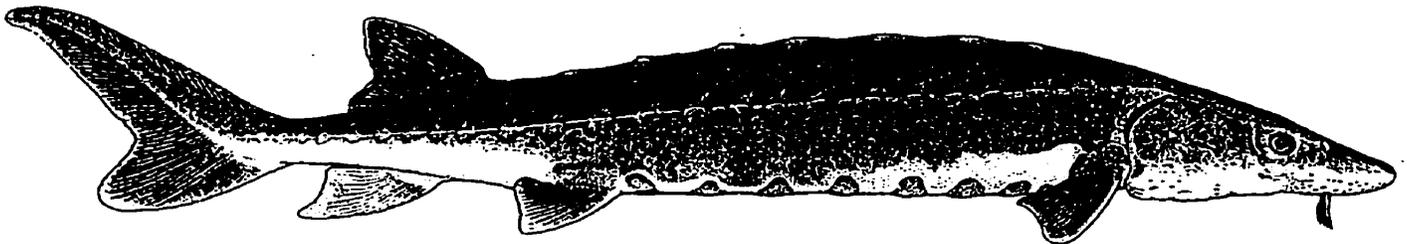
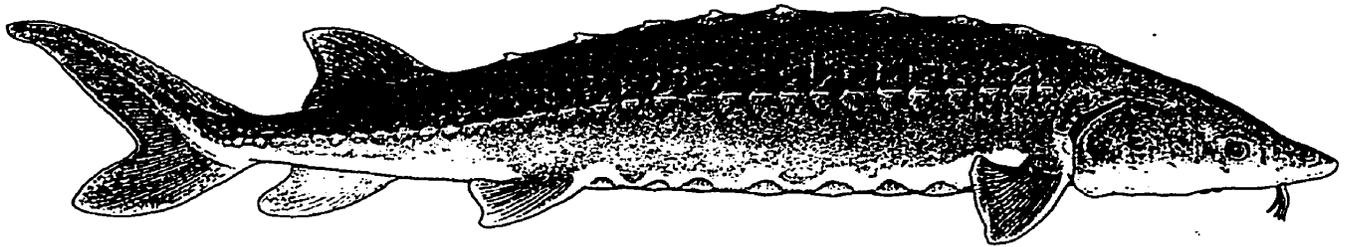
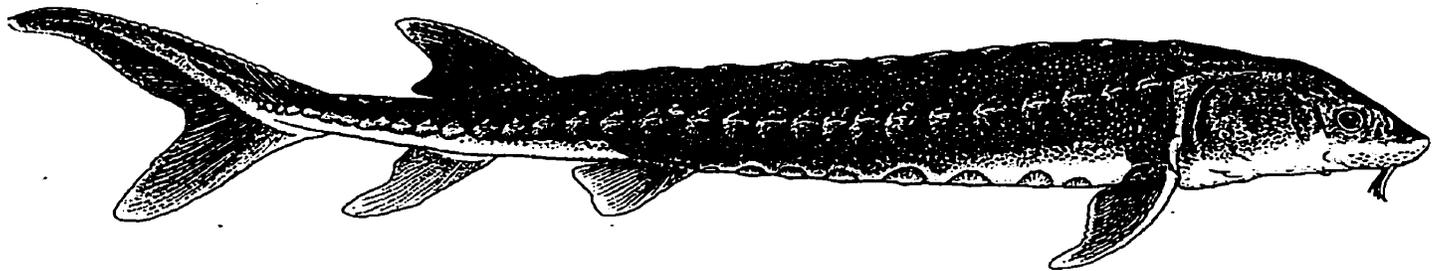
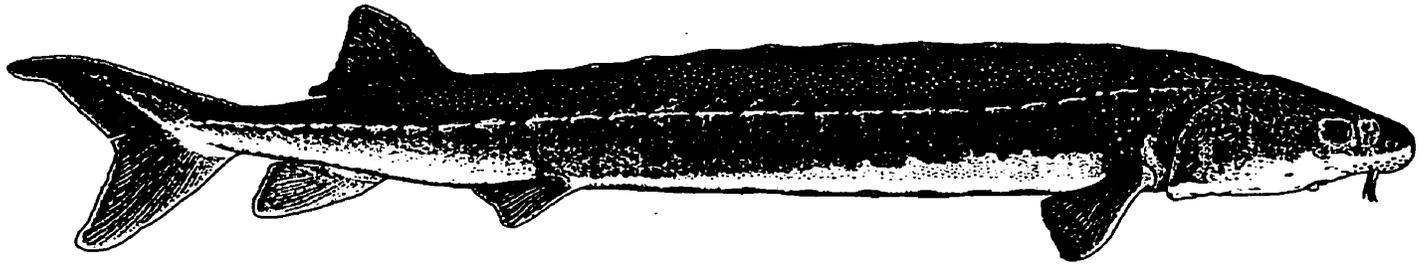
respiration, rostral expansion and head flattening, scalation and locomotion (Findeis 1997).

*Huso* has life history characteristics distinct from other acipenserids. Living *Huso* prey on fishes. Fossil *Crossopholis* have been found with their last meal of fishes fossilized within their body cavity (Grande & Bemis 1991). The early acipenseroids were pelagic piscivorous predators and like the modern *Huso*, had anterior-facing jaws. This contrasts to most of the *Acipenser* species and scaphirhynchines which consume benthic prey, predominantly mollusks and crustaceans, but also benthic fishes (Findeis 1997). *Huso* is exemplary of the primitive condition of pelagic cruising within the Acipenseridae. The opportunity for *Huso* to exploit substrate habitats was expanded upon by phylogenetically successive species of acipenserids occupying the niche of substrate habitats and prey (Findeis 1997). With their more flattened heads, ventral mouths and flatter rostrums, Acipenserines are clearly more benthically oriented than *Huso*, but the morphology of *Scaphirhynchus* represents the ultimate benthic adaptation within the Acipenseridae. With almost total dermal armor covering, wide flattened head and rostrum, and highly developed tactile barbels, the species of this genus are more ideally suited for benthic life in turbid moving waters (Findeis 1997). The North American *Pseudoscaphirhynchus* share many of the morphological characters of *Scaphirhynchus* but are not as specialized for total benthic living (Findeis 1997).

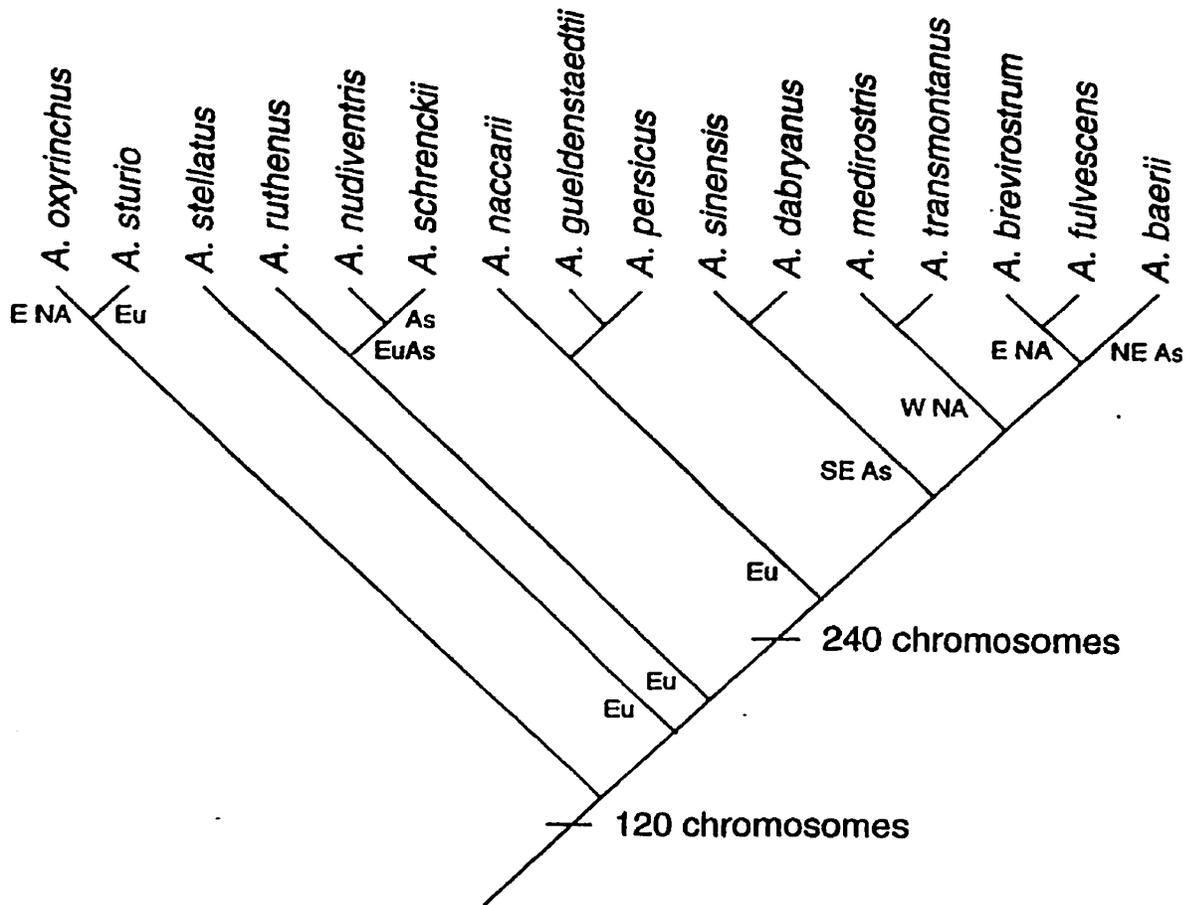
**Figure 1 - 1.** Technical illustration of North American sturgeons studied for this thesis: (a) white *Acipenser transmontanus*, (b) green *A. medirostris*, (c) shortnose *A. brevirostris*, (d) Atlantic *A. oxyrinchus*.



**Figure 1 - 2.** Technical illustrations of morphological differences among four adult shortnose sturgeon, *A. brevirostrum*, captured in the Hudson River, New York, U. S. A. during 1998.



**Figure 1 - 3.** Cladogram showing phylogenetic relationships within Acipenser. A combination of karyological data and biogeographic information was used. (From Artyukhin 1995 and pers. comm).



As: Asia  
 Eu As: Eurasia  
 Ne As: North East Asia  
 SE As: South East Asia  
 E NA: Eastern North America  
 W NA: Western North America  
 Eu: Europe

## 1.2 Review of Life History, Ecology and Spawning Behavior of Sturgeons

Migration in Acipenseriforms is primarily related to feeding and spawning. Downstream migration in juveniles and adults is linked to food abundance. The fresh/saltwater or river/lake interface is nutrient-rich and food items preferred by sturgeon are usually abundant there (Bemis & Kynard 1997). Marine (anadromous) species of sturgeon spend their time feeding in the shallow, nearshore environments. Upstream migration can be for spawning purposes, but several anadromous species make periodic forays into estuaries and lower freshwater reaches of rivers for feeding during the summer (Bemis & Kynard 1997). Sturgeons with mature gonads (spawners) enter rivers for reproductive purposes. Individuals who leave a river basin and migrate into sea or lake are termed emigrants (Bemis & Kynard 1997). They may spawn in their natal rivers or become colonizers of a new watershed. Due to their strong homing tendencies, sturgeons are classified as philopatric.

Some key terminologies are needed to describe movements of sturgeon. I follow the definitions given by McDowall (1987, 1988, 1992).

Diadromous: sturgeons that migrate between salt water and fresh water. All species fall under this category except *A. ruthenus*, *A. nudiventris*, *A. fulvescens*, *P. kaufmanni*, *P. hermanni*, *S. albus*, *S. platyrhynchus*, *P. suttkusi*.

Anadromous: diadromous sturgeon that spend all their time at sea except when spawning for which they enter freshwater. This includes all species of the genus *Acipenser* and *Huso* except those that are not categorized as diadromous.

Amphidromous: diadromous sturgeons that migrate from fresh to salt water or vice-versa, not for reproduction although spawning occurs at some point while they are in fresh water (McDowall 1988, 1992). Such migration is typical of *A. transmontanus* and *A. brevirostrum*.

Potamodromous: sturgeons that undertake migrations within a river system for spawning purposes and feeding (McDowall 1982, 1992). All species within the genus *Scaphirhynchus* and *Pseudoscaphirhynchus* fall under this category. *A. fulvescens* is almost certainly best categorized as potamodromous, since it is not capable of tolerating a high degree of salinity (LeBreton & Beamish 1997).

Within the category of anadromous, there are three kinds of migrations undertaken by sturgeon throughout their life-history: 1) the upstream migration of adults from sea into rivers for spawning, 2) the downstream movement of adult migrants after completion of spawning, and 3) the passive downstream drift of juveniles after hatching (Holcik 1989). Furthermore, returning adult migrants can be sub-divided into spring and winter cohorts (Berg 1968). The former reproduce the same year upon entering the river while the latter spend a winter in fresh water and reproduce the following spring. Winter cohort fish have developed this tactic perhaps to exploit spawning grounds at the upper extremities of a watershed. By migrating throughout the summer, they can cover the great

distance required to reach their spawning sites. Over-wintering in deep pools puts them close to the spawning areas. Therefore, they will have only a short distance to travel as water temperatures begin to rise in the spring. At the same time, the spring cohort is spawning lower downstream (Berg 1968, Bemis et al. 1997).

In all Acipenserids, there is considerable overlap of generations in the recruitment of the spawning population. These populations are characterized by an intricate multi-age structure. Historically, spawning populations of some rivers consisted of 70 age classes. Sexual maturity is attained very late in life for most Acipenserids. In many species, males first reach spawning condition at 14-16 years of age and females at 19-22 years of age (Berg 1968). There is a 3-9 year interval between spawning for adults (depending on species and latitude). For females, the ripening phase of ovaries can last 5 years and spawning would then be followed by a 4 year phase of recuperation thus adding up to more than 9 years between spawning (Goyette et al. 1988). Males appear to mature on a shorter cycle in most species (Sokolov 1989, Vlasenko et al. 1989, Qiwei et al. 1997). As a result, the sex ratios in populations of spawning adults can vary from 1:1 to 3:1 male : female. Typically the sex ratio among sexually mature adults is significantly skewed towards males, since they mature for the first time at a younger age than females, and they also mature more frequently over successive years (Holcik 1987).

Sturgeons are very fecund and numbers of eggs laid can be as high as

7, 729, 700 eggs per female (Babushkin 1964). Fecundity increases with size, as in most fishes, so larger females exhibit greater fecundity. A female beluga of 1, 228 kg captured in 1924 from the north Caspian contained 246 kg of eggs (Berg 1968). The average size of ripe oocytes in sturgeons is 3.4-4 mm, with some variation among species. There is little evidence of significant variation in size of oocytes among females.

Spawning takes place during the high water period in spring ( Berg 1968). Spawning sites are usually over stony or gravel substrate with a current velocity varying from 1 to 2 m.s<sup>-1</sup>. Spawning usually takes place at night, in water of varying depth. Fertilized eggs sink to the bottom and adhere to the bottom substrate (Dragomirov 1961). Larvae begin drifting downstream shortly after emergence from the gravel (Table 1.1). In some species (e.g. *A. gueldenstaedtii*), the majority of larvae move downstream prior to active feeding in years of high water. When water levels are low, the juveniles may remain in the river until autumn (Ambroz 1964). The sensitivity of juveniles to their habitat is further reason to implement regulations protecting the spawning sites and nursery grounds from dredging (Kynard 1997 & Taub 1990).

In the next chapter, the economic importance of sturgeons will be described by reviewing the lucrative sturgeon fisheries worldwide. Annual sturgeon harvest rates can no longer satisfy market demands. With the numerous human alterations to sturgeon habitats (especially spawning grounds) the historic trends can no longer be maintained. The impact of sturgeon harvests throughout the world has lead to a better understanding of their biology. It is an

important part of my thesis to fully comprehend the level of exploitation that surgeons have been subjected to if new management measures via sex determination are to be imposed.

Table 1 - 1. Life-history characteristics of Acipenseridae.

Interval	biological and ecological descriptions
Embryonic period: From activation of egg to exogenous feeding.	<p>In spring or summer, eggs are deposited in pebbles. Sturgeon are lithopelagophils and therefore non-guarders which are part of the ecological group of open substratum spawners.</p> <p>a) Eggs are laid among stones, pebbles or gravel  b) After hatching, free embryo is pelagic due to active movement. Free embryos are not photophobic. Limited embryonic respiratory structures.</p>
Larval period: Onset of exogenous feeding to metamorphosis giving rise to respiratory vessels, gill covers and finfolds.	<p>Almost immediately or within 2 weeks after emergence, the larvae begin downstream migration.</p>
Juvenile period: From formation of all definitive adult structures (fins fully differentiated, temporary organs replaced by definitive ones) to first maturation.	<p>The juvenile sturgeons spend several years in the estuary or delta, feeding and avoiding predators. They eventually enter the lake, sea or ocean and begin feeding on larger prey items. They remain in this environment until the onset of sexual maturity.</p>
Adult period: Starts at first maturation to period of reduction in reproductive capability and rapid decrease in growth rate.	<p>Onset of sexual maturity reached between 6-22 years of age. Sturgeons begin upstream migration to their spawning grounds. Migration varies from a few km to over 1000 km. Gonads are at various stages of development upon commencement of spawning migration. Some species have 2 forms or "races". The first migrates in summer and over winters in deep pools near spawning site until the following spring when spawning is to take place. The second migrates in early spring, soon reaching its spawning grounds at which time eggs are deposited. The spawning sites of summer migrants are situated much further upstream than spring migrants. This results in reduced competition for spawning sites.</p>

## **Chapter 2. Exploitation**

### **2.1 Sturgeon fisheries worldwide, general harvest trends**

There is a long history of sturgeon exploitation. Acipenserid species have been among the most prized and sought after fishes by aboriginal, angling and commercial fishers. There is reference to sturgeon fishing in China dating back to 1104 BC. Sturgeon were referred to as 'wang-wei' meaning 'king of fishes'. Ancient Chinese books give rich descriptions of sturgeons including their range, habits, morphology and how to catch them. Sturgeon took on the image of fishes related to god (Qiwei et al. 1997). The Scythian tribes fished for sturgeon in the Dnieper River in the northern Black Sea region as early as 2, 500 years ago (Luk'yanenko et al. 1999). In ancient Greece, no dinner party was complete without sturgeon meat (Luk'yanenko et al. 1999). The Greek port of Histria had citizens fish the Danube Delta and the catch was salted for export to Rome and back to Greece (Bacalbasa 1997). In the Middle Ages, caviar was deemed so precious that Venice and Genoa went to war over sturgeon stocks and ambassadors were sent to Moscow in hopes of securing caviar stocks (Luk'yanenko et al. 1999). In the 12th - 15th centuries, Danubian species of sturgeon were being exported as far as Poland (Giurescu 1964). In 1409, all inhabitants of villages along the Danube were ordered by the Prince of Vallachia to fish for sturgeon 3 days a year, with the catch being allocated to the court. The Italian monk Niccola Barsari, upon visiting Moldavia in 1633-1639, made

reference to fisherman buying as many as 1, 000 - 2, 000 sturgeons at the port of Chilia, from where they were exported to markets of Constantinople, Hungary and Poland (Bacalbasa 1997).

By the early 1600's, the town of Galati on the lower Danube had become an important sturgeon market center. It was strategically located for easy access by fisherman to the fishing grounds. A multitude of sophisticated sturgeon catching devices have been developed and these methods of capture did not distinguish adult from juvenile. Large portions of the Danube were fenced off using wood, with narrow gates for ships to get through. The sturgeons would get caught in cage-traps. Up to 200 people operated and maintained these corrals by living on nearby platforms on the river (Bacalbasa 1997). By blocking large sections of river or side channels in such a manner, 14 of these installations caught up to 2, 000 sturgeons daily near Chilia on the Danube. These installations were also erected near the town of Ismail in the Danube Delta and for decades accounted for huge captures of migrating sturgeon (Bacalbasa 1997).

By the early 1800's, various sturgeon stocks began showing signs of over-exploitation. The prized beluga, *Huso huso*, had become much less abundant in the Danube River (Giurescu 1964). The natural flow regime of the Danube had been greatly altered by dredging for shipping channels and by construction of embankments and hydroelectric dams built in the 1950's. The European common sturgeon, *Acipenser sturio*, underwent drastic declines in numbers by the latter 19<sup>th</sup> century and is now close to extinction. Tributaries to the Baltic and North Sea

have been dammed and polluted, and the Elbe and Rhine River have had their common sturgeon stocks completely fished out (L. Debus pers. comm.).

In Russia, the Caspian Sea historically represented the principal fishery for several sturgeon species. Early human settlements caught sturgeon during their annual spawning migrations up the Volga River. In the early 1900's, the Azov, Black and Aral seas contributed 50% to the Russian total catch, the rest originating from the Caspian basin (Luk'yanenko et al. 1999). The decline in water quality coupled with overfishing associated with the Black Sea and Aral Sea, lead to increased importance of the Caspian fishery and by the 1960's, the Caspian catch represented up to 90% by weight of the global catch of sturgeons. Due to strict management policies and numerous hatcheries, the Caspian sturgeon population enjoyed a golden age following the Second World War. Catches rose from 3, 200 tons in 1944 to 18, 000 tons by the early 1970's (Khuzhin 1964). This was maintained for approximately 15 years and represented a triumph of long-term management of a fishery. But it soon became apparent that natural recruitment is vital in maintaining stocks of sturgeon in the Caspian Sea. Once the Volga flow became regulated in 1959, annual harvest decreased from 7, 500 metric tonnes in 1960 to 3, 000 tonnes by 1981. Over 80 % of their original spawning grounds were no longer accessible due to the Volgograd dam. By the early 1990's, natural reproduction was 830 metric tonnes and continues to decline.

By the early 1980's the ecological conditions of the Caspian deteriorated considerably and primarily affected survival of juvenile sturgeon as well as the

physiological condition of all age classes of all acipenserid species (Artyukhin et al. 1999). Since the 1990's, Iran has set up a modern aquaculture network and is supplementing the poor natural stocks of its waters by farming several species of acipenserids for massive stocking in the south Caspian. In the early 1990's, an annual production of 300 tonnes was achieved but this slowly began dropping and in 1999, barely 100 tonnes were produced. Iran has a history of producing the finest caviar (De Meulenaer 1996). In recent years, this holds especially true because of the break up of the Soviet Union which closely controlled caviar production. Now, with the rampant poaching and pseudo - regulated fisheries, caviar has become a black market family - or gang - operated business. Quality control is lacking and facilities are non - hygienic. Freshness of the catch is not monitored and cold storage of fish prior to butchering is rarely possible. The situation in Iran is quite different. The country nationalized caviar production and distribution in 1950 through the state-owned Shilat. Shilat is now responsible for annual sturgeon quotas as well as the allocation of caviar to trading companies (De Meulenaer 1996).

In the last decade, the Danube River sturgeon stocks have undergone a drastic decline. The causes are similar to those affecting Russian stocks: conflicting fisheries legislation between nations, widespread poaching of spawning adults and heavy pollution (Bacalbasa et al. 1999). The Romanian sturgeon hatchery infrastructure is insignificant when compared to the Russian effort (Bacalbasa et al. 1999).

In North America, sturgeon do not have as long a history as a commercial species. At first, European settlers concentrated on more valued species such as salmon (*Oncorhynchus* spp. and *Salmo salar*) (Scott & Crossman 1973). As native fish stocks began collapsing by the late 19<sup>th</sup> century, many commercial fisherman switched their attention to various sturgeon species for which markets were now growing. Along the Atlantic coast and particularly in the Hudson River, landings of Atlantic sturgeon, *Acipenser oxyrinchus*, peaked by the early 1900's and thereafter declined steadily (Smith & Clugston 1997).

Along the west coast of North America, the primary fishing sites for sturgeon were the large rivers in which white sturgeon, *Acipenser transmontanus*, undertook spawning migrations. Among native tribes, the Coast Salish were the primary fishers of sturgeon. They caught these fish in the summer in the sloughs of the Fraser River, using fence weirs, set nets, trawl nets and harpoons. In 1864, Sir Arthur Birch, Colonial Secretary at Government House in New Westminster described how he watched the natives fishing in the Fraser. The natives would use their canoes to drift downstream with the current, 30 boats abreast. They would poke the bottom with very long spears and when a sturgeon was felt, the tip was thrust into the fish, detaching from the long pole but remaining attached to the canoe by a strong rope (Stewart 1977). By the 1800's, enormous fish wheel traps and gill nets were catching large numbers of sturgeon, often as by-catch during the salmon fisheries.

While sturgeon have evolved numerous efficient functional mechanisms for adapting to tolerate and prosper under a wide range of environmental

fluctuations, they have proven ill-adapted to human modifications to their environment and above all else, large scale commercial exploitation. Next, I will discuss the current population status of sturgeons on a continental basis and a detailed history of the exploitation of each species, culminating with their status as a rare or endangered species.

## **2.2 Population status, exploitation, and conservation of sturgeon species**

### ***General***

Sturgeons are at great risk of extinction and all populations of all species have undergone drastic declines (Ivanov et al. 1999). Their sensitivity to overfishing and dependence on large and now polluted rivers for spawning makes the future grim for the long term prospect of survival. Throughout much of their ranges, hatchery stocking has been the answer to maintaining stocks but the wisdom of this approach is being questioned (Ivanov et al. 1999, Khoderevskaya et al. 1997). In Russia, the large runs of sturgeon in the Volga were predominantly made up of hatchery-produced fish. The fragility of this approach is now apparent. With the economic hardship following decentralization, many hatcheries have closed and production of juveniles has been greatly curtailed (Ivanov et al. 1999, Khoderevskaya et al. 1997). For species whose existence depended on this human intervention in the form of artificial propagation, the consequences have been catastrophic. The few remaining hatcheries can not stock enough juveniles to ensure the survival of the species. (E. Artyukhin pers.comm.).

### ***North America***

The fishery for salmon (*Oncorhynchus* spp.) along the west coast also caught white sturgeon, *Acipenser transmontanus*, as part of the by-catch but it wasn't until 1880 that sturgeon were intentionally targeted (Galbreath 1985). By 1892, a peak harvest of 2, 500 tonnes was landed. Towards the end of the

1890's, the fishery collapsed and it wasn't until strict seasonal regulations and a size slot limit (allowing harvest of individuals only between 81-178 cm) was introduced in 1950 that the sturgeon population slowly recovered (Galbreath 1985).

The history for the Fraser River is similar to that of the Columbia. Prior to 1880, there was a small subsistence fishery practiced by aboriginal groups living along the river. Once the salmon fishery was well established, large numbers of white sturgeon were also being caught. By 1894, they were being exported to eastern North American markets. Landings of white sturgeon peaked in 1897 when 5,500 tonnes were taken from the lower Fraser River. Annual catches soon declined despite gear restrictions being imposed (Scott & Crossman 1973). Following a period of commercial extinction, a limited fishery took 5 - 25 tonnes annually. Because of the continued pressure from the by-catch during the in-river native salmon fishery and a huge sport fishery which harvested over 15 tonnes annually, the Department of Fisheries and Oceans has now implemented a total ban on sturgeon harvest from the Fraser River. Angling is still permitted but no fish may be kept (E. Down, B. C. Ministry of Fisheries, pers. comm.).

The east coast fisheries for Atlantic sturgeon, *Acipenser oxyrinchus* began in the 1600's and was well established by the 19<sup>th</sup> century. Gent (1675) reported Atlantic sturgeon as being abundant enough in some New England rivers that they represented a serious hazard to small boat navigation. In 1888, a single dealer on the Delaware River shipped 50 tonnes of Atlantic sturgeon eggs to buyers in Germany (Scott & Crossman 1973). Around that time, the United

States Fish Commission considered the commercial importance of *A. oxyrinchus* as second only to the American lobster, *Homarus americanus* (Taub 1990). Similar to the early days of exploitation of *A. fulvescens*, a variety of products were obtained from various organs of Atlantic sturgeon.

In the mid 1800's, some commercial fisheries targeting Atlantic sturgeon abruptly collapsed (Goode 1887). By the end of the 19<sup>th</sup> century, the Delaware River fishery employed 978 fisherman, 80 shoremen and 45 transporters. In 1890, approximately 3,500 tonnes were landed which contrasts starkly with the 46 tonnes landed in 1987. Artificial propagation was first attempted in 1875 on the Hudson River but it proved difficult to obtain simultaneously ripe male and female sturgeon (Harness & Dymond 1961). This may attest to the prolonged spawning period of sturgeons or that the males are ripe longer than females. Some recent stocking has been undertaken but has encountered stiff resistance from biologists who are concerned it will compromise the genetic integrity of stocks. The entire fishery for Atlantic sturgeon has been closed in the United States. At present the only viable fishery for *A. oxyrinchus* remains the Saint John River in New Brunswick and the St. Lawrence estuary (Caron 1999). The St. Lawrence fishery is based entirely on juvenile Atlantic sturgeon (Caron 1999).

The Laurentian Great Lakes fishery for lake sturgeon, *A. fulvescens*, had an inglorious start. Lake sturgeon was considered a nuisance fish which destroyed nets set for other species (Scott & Crossman 1973). Prior to 1860, sturgeon were an incidental catch and were either used as pig feed, discarded, or used as fertilizer. At Amherstburg, Ontario, dead sturgeon were stacked like

cordwood on the dock and used to fire the boilers of steamboats traveling the Detroit River. Indigenous people utilized sturgeon as a food source (Needs - Howarth 1999) but for Europeans, even the exquisite roe was thought to be fit only for hogs or to be used as bait for more desired species. The oil extracted from sturgeon by boiling was used in paints (Scott & Crossman 1973).

In the decades following 1860, North Americans were swept by a sturgeon craze. Suddenly every part of this animal was considered to be extremely useful as a result of expertise gained by German settlers in Sandusky, Ohio. The flesh was smoked or sold fresh, the eggs were processed into fine caviar at Sandusky, the gelatin of the swim bladder (isinglas) was extracted and used as a clarifying agent in the making of wine and beer and as cement in pottery (Scott & Crossman 1973, Lytwyn 1990). Even sturgeon skins were tanned and made into a rough leather. The momentum of this now profitable fishery grew exponentially until stocks collapsed not only in the Great Lakes but also other inland waters. Lake Erie was the most productive fishery and an annual landing of 2.2 million tonnes was reduced to 500 tonnes by 1895. In Lake of the Woods there was a 90 % decline in landings of sturgeon between 1893-1900. Today, only Lake St. Clair has a commercial fishery for sturgeon in the Great Lakes and it operates on an annual quota system (D. Peterson, pers. comm.).

Lake sturgeon are distributed throughout the North and South Saskatchewan rivers in Alberta. Because of over exploitation since the turn of the century, a closure on harvesting lake sturgeon was implemented in 1940.

Originally, lake sturgeon in Alberta were part of a large mid-western population. With the construction of hydro-electric dams at Squaw Rapids in 1962 on the Saskatchewan River, and at Gardiner in 1967 on the South Saskatchewan River, the population of lake sturgeon became fragmented (McLeod et al. 1999). In 1968, the fishery was reopened to hook-and-line. In 1900, the fishery from Lake Winnipeg, Manitoba peaked at 445 tonnes but dropped to a mere 13 tonnes in 1910 and the fishery was closed (Houston 1987).

The St. Lawrence River lowlands (from Cornwall to Lake St. Pierre) has the largest remaining population of lake sturgeon. In recent years, the commercial harvest has been approximately 100 tonnes annually (Dumont et al 1987). Such high levels of harvest are not thought to be sustainable (G. Gaie pers. comm.). Large populations still exist in the northern rivers of Ontario and to a lesser extent, a few areas in south-western Quebec. In Ontario, the rivers of the Hudson and James Bay drainage such as the Severn, Winiski, Attawapiskat, Albany and Moose all have substantial numbers of lake sturgeon (Ferguson & Duckworth 1997). American populations of *A. fulvescens* are very fragmented and the species is considered rare everywhere in United States except Wisconsin. Lake sturgeon are classified by CITES as Vulnerable throughout their range (Birstein et al. 1997).

The shortnose sturgeon, *Acipenser brevirostrum*, was exploited by fisherman in the Delaware River during the 19<sup>th</sup> century who considered the flesh of better quality than that of the Atlantic sturgeon and it commanded a higher price. By the 1900's, shortnose sturgeon were being caught by gill nets and set

lines. Much of the New England and Canadian catch ended up in markets in New York. The huge American shad, *Alosa sapidissima*, fisheries along the east coast of North America has taken a high toll on *A. brevirostrum* through incidental capture (Scott & Crossman 1973). Many rivers inhabited by this species had small populations which quickly collapsed under poaching and commercial fishing. Anthropogenic impacts such as loss of spawning grounds due to dams, river flow regulation and pollution have created a situation where many of the rivers now inhabited by shortnose sturgeon consist of populations made up of no more than a hundred or more fish. This falls well below the suggested minimum population abundance of 1, 000 individuals (Kynard 1997). Because of their amphidromous nature, each river has its distinct population of shortnose sturgeon and these stocks do not mix with that of neighbouring watersheds. Thus, unlike the anadromous stocks, the shortnose cannot benefit from adult straying during spawning migrations. In the USA, *A. brevirostrum* has been listed under the Endangered Species Act of 1973 and is also considered Endangered in Canada (Birstein et al. 1997).

### ***Eurasia, Arctic drainage***

The Siberian sturgeon, *Acipenser baerii*, has until recently benefited from the remoteness of its native range, spanning Siberia's large rivers. The Ob River population was the largest and had been historically exploited by indigenous people of Siberia's arctic as well as Russian commercial fisherman (Ruban 1997). Between 1932-1938, annual landings ranged from 895 to 1, 400 tonnes. By 1979, the catch had decreased to 152 tonnes (Ruban 1997). This drop was

caused by the compounding anthropogenic factors and years of overfishing. Dam construction in the late 1950's cut off access to 40 % of the Siberian sturgeon's spawning grounds (Votinov et al. 1975). Poaching has also been on the rise and while the legal catch for 1994 was 9.2 tonnes for the entire Ob watershed, poachers accounted for roughly 250 - 300 tonnes of Siberian sturgeon (Ruban 1997). A recent trip to the Ob River by Russian scientists gave further firsthand account of the dwindling stocks. Fishing with legally licensed fisherman produced very few fish (Ruban 1996). Histological analysis revealed serious gametogenesis anomalies. Several fish were even sterile. Ruban (1996) suggest that the Ob River population of *A. baerii* is Extremely Endangered and under CITES it has received the Endangered listing as well.

The Lake Baikal sub-species, *A. baerii baicalensis*, was once very abundant in the area of the Selenga River Delta and Barguzinskii and Chivyrkuiskii bays. During the spawning migration, these Siberian sturgeons traveled up to 1, 000 km up the Selenga River, often entering tributaries such as the Chikoy, Orhan, Tula and Delger-Muren rivers (Yegorov 1961, Sokolov & Shatunovsky 1983). This sub-species has suffered primarily from overfishing and is now so rare that it has been included in the Red Data Book of the Russian Federation (Kolosov 1983). This sub-species is presently listed by CITES as vulnerable. The third sub-species is the Siberian sturgeon (*A. baerii stenorhynchus*) inhabiting the Yenisey and Lena basins. In the Yenisey, there exists a migratory and a non-migratory stock, the former occurring from the delta to river km 2, 450. Several tributaries are also populated by this non-migratory

form including the Angara, Nizhnyaya, Podkamennaya and Tunguska rivers. While not as depleted as the other members of the *A. baerii* complex, this subspecies has been greatly reduced in number and range in recent times. This subspecies is classified as Endangered by CITES (Birstein et al. 1997).

### ***Eurasia, Aral Sea Basin***

The three Central Asian shovelnose sturgeon species belonging to the genus *Pseudoscaphirhynchus*, are characterized by their small size and unique morphology (Berg 1948). Together with the three North American members of the genus *Scaphirhynchus*, they make up the subfamily Scaphirhynchinae (Bemis et al. 1997). Historically, there were two species of *Pseudoscaphirhynchus* inhabiting the Amu Darya River watershed. They were the large Amu-Dar shovelnose, *P. kaufmanni* Bogdanov, 1874, and the small Amu-Dar shovelnose *P. hermanni* Kessler, 1877 (Berg 1968).

*Pseudoscaphirhynchus kaufmanni* was endemic to the entire Amu Darya River from the headwaters to the mouth (Nikolskii 1973). It also occurred in the small irrigation channels connected to the river and in the Karakum Canal system (Salnikov 1995). Since the 1960's, the environmental conditions of the area have undergone drastic alterations. The irrigation required for Russia's vast cotton fields has diverted the flow of the Amu-Darya to the extent that the river no longer reaches the Aral Sea (Zholdasova 1997). Average water salinity has gone from a 1960's average of 10.3 to 38 parts per thousand. The sea's water volume has decreased by more than 3 times from the original surface area of 68.4 to 30.0 thousand km<sup>3</sup> (Zholdasova 1997). *P. kaufmanni* is now found primarily in the

middle reaches of the Amu-Darya. *P. hermanni* was never as abundant as *P. kaufmanni* (Nikolskii 1938, Berg 1948) but none has been captured since 1982 and it was even considered extinct. In 1996, an expedition sponsored by the Sturgeon Society and the National Science Foundation Division of Environmental Biology and International Programs surprisingly caught three individuals of this species in the Amu-Darya (Salnikov 1996). Although evidently not extinct, it should be considered extremely rare. Both species are currently listed as endangered in the Uzbek SSR Red Data Book (1983), USSR Red Data Book (1984) and Turkmen SSR Red Data Book (1985). In 1996, the Red List of Threatened Animals of the IUCN (The World Conservation Union) had *P. kaufmanni* proposed as Endangered and *P. hermanni* as Critically Endangered (Birstein et al. 1997).

### **Europe**

The European common sturgeon, *Acipenser sturio*, was once widely distributed throughout Europe. It was common in the Baltic Sea, entering rivers along Poland's and Germany's coast, and the North Atlantic along the coast of France and Spain. *A. sturio* was also native to the northern coast and rivers of the Mediterranean Sea and Black Sea (Holcik 1989).

The common sturgeon was always highly esteemed for its flesh. The roe was processed into caviar and collagen extracted from the gas bladder was used in the optics industry (Cacutt 1979). The history of this species' exploitation dates back to the first human settlements along the Black Sea and Europe. By medieval times, the common sturgeon was well established as a gourmet fish

throughout Central and Western Europe. *Acipenser sturio* belonged to the king or a representative of the king in form of some local authority. Fisherman were allowed to keep a small amount of meat under terms of “hunters’ rights” or they would be substantially compensated by authorities for handing over the fish (Kinzelbach 1987). In the 16<sup>th</sup> century, *A. sturio* was so abundant throughout the Rhine River that even very small individuals were harvested for food in large numbers (Kinzelbach 1987). Even at such rates of exploitation, the European common sturgeon was still an economically viable species at the end of the 19<sup>th</sup> century. In Hamburg, Carl Hagenbeck, a fish trader purchased up to 5, 000 sturgeons annually from commercial fisherman (Hagenbeck 1908). At the beginning of the 20<sup>th</sup> century, the annual catch of *A. sturio* was 200 metric tonnes.

In the following 50 years, *A. sturio* became rare everywhere in Europe. The huge Elbe River stock underwent drastic decline, as did catches along the Dutch coast. After the Second World War, the only remaining exploited population of *A. sturio* was that of the Gironde Estuary in France where 50 tonnes were landed annually. The growing demand for caviar increased the fishing pressure on spawning adults while juveniles continued to be exploited for their flesh. Suitable sites for reproduction decreased due to gravel extraction, and dams limited how far the sturgeon could migrate upstream in search for spawning beds. By the 1970’s, it was no longer economically viable as a species and by 1980’s, it became clear that unless both habitat and sturgeon were protected, *A. sturio* faced extinction. At present, it is difficult to even catch enough mature adults to initiate an artificial reproduction program. *A. sturio* is

now included as Endangered in the New York Convention for Species (IUCN) and Critically Endangered under the Washington Convention for Species Protection (CITES) as well as being on the priority list for species protection with the EU. Today, the common sturgeon population of the North Sea is classified as “not self-sustaining” and that of the Baltic Sea is termed “missing”. Rarely, *A. sturio* is caught in the Elbe in Germany or in the Gulf of Finland and Lake Ladoga (Debus 1995, Kudeerskij 1983). *A. sturio* was once common in the Guadalquivir River, Spain but with the completion of a dam 100 km from the river mouth, sturgeon were prevented from reaching their spawning grounds. During that same year, a sturgeon processing plant was opened in the vicinity of the dam and rampant fishing followed. The species is now likely extinct with the last female being caught in the river mouth in 1982 (Elvira et al. 1992). The only self sustaining wild stock persists in the Rioni River on the Eastern Black Sea, Russia (Ninua & Tsepkin 1984).

### ***Eurasia, Ponto Caspian region***

The Russian sturgeon, *A. gueldenstaedtii* is one of the most highly sought sturgeons. This species ranks first in terms of numbers caught with most coming from the Caspian Sea followed by the Azov-Black Sea.

In the Caspian Sea, the fishery for *A. gueldenstaedtii* is situated in the northern portion of the sea. Although exploited for hundreds of years by local indigenous groups, an intensification in the exploitation of this species began in the end of the 19<sup>th</sup> century. From 1898 to 1913, between 4, 600 to 10, 000 tonnes of *A. gueldenstaedtii* were caught on an annual basis (Korobochkina 1964b). By

1941, most individuals were being harvested from the sea and signs of collapse were beginning to show. After 1941, all harvesting of any acipenserids during their time at sea was forbidden and the fishery was targeting returning adult spawners in the Volga and Ural rivers. In the 1960s, under strong centralized government and strict enforcement, the banning of fishing at sea came into effect. The population recovered and catches of *A. gueldenstaedtii* reached a high of 13,800 tonnes in 1980 (Khodorevskaya et al. 1997). In 1994, less than 2,000 metric tonnes were landed and the downward trend continues. To compensate for the downward trend in recruitment, hatcheries situated along the Volga have been stocking large numbers of juveniles. In the 1960's, the input of juvenile *A. gueldenstaedtii* oscillated around 10 million fish and this reached a high of 60 million fish in the late 80's and early 90's (Khodorevskaya et al. 1997). In the Black Sea, the Danube Delta situated at the north-western coast is the primary fishing grounds for *A. gueldenstaedtii*. The Romanian records show that the average annual harvest from 1924 to 1940 was 170 tonnes. From 1941 to 1956, the harvest dropped to an annual average of 33.6 tonnes. The Sea of Azov has historically proven very productive for Russian sturgeon. In 1939, over 1,000 tonnes was harvested (Korobochkina 1964a). In 1952, the Don River was dammed and because this river system represented the principle spawning grounds for *A. gueldenstaedtii*, numbers of returning spawners began falling. The Kuban River was also a major spawning river for Russian sturgeon. With the construction of the Fedorovskaya dam, followed 6 years later by the Krasnodar dam, the flow regime of the river was so altered that no natural spawning takes

place (Chebanov & Savalyeva 1999). In the Krasnodar area near the Kuban River, five sturgeon hatcheries have released between 5 to 10 million juveniles annually. At present, these hatchery originating fish account for 90 % of the harvest of Russian sturgeon in the Azov basin (Chebanov & Savalyeva 1999). While hatchery sturgeon make up a larger portion of the overall *A. gueldenstaedtii* population, it has not been able to compensate for the decrease in natural spawning and heavy poaching of spawning migrants. All populations of the Russian sturgeon are classified as Endangered under CITES.

The population status and rate of exploitation is similar for the Persian sturgeon, *Acipenser persicus* except that this species is more common in the south Caspian Sea while *A. gueldenstaedtii* predominates in the north. Catch statistics for *A. persicus* were never kept for the huge Volga fishery since they were lumped under *A. gueldenstaedtii* and it is only recently (1986) that they have been given species rank (Artyukhin et al. 1986). In the Volga, *A. persicus* has historically made up a small proportion of the overall number of migrants but this species dominates in the Kura, Terek and Sefid Rud rivers. Because the Kura run is almost completely *A. persicus*, and *A. gueldenstaedtii* are rare, reliable catch statistics are available. From 1974 to 1978, between 90 to 220 tonnes of *A. persicus* was landed (Kazanchev 1981). Hatchery propagation in Iran has put millions of juvenile Persian sturgeon into the south Caspian Sea but overall stocks, especially in the north Caspian remain low. The population of *A. persicus* in the Black Sea is listed as Endangered while that of the Caspian is ranked vulnerable under CITES (Birstein et al. 1997).

Ship sturgeon, *Acipenser nudiiventris*, is scarce relative to other sturgeons. It is one of the only sturgeon species which has been successfully introduced into another water body. In 1933-34, 289 adult ship sturgeon were introduced from the Aral Sea into the Ili River, a tributary of Lake Balkhash. These fish successfully acclimatized to their environment and began reproducing. A prosperous commercial fishery flourished in ensuing years but is now verging on extinction due to lowering water levels and increased salinity (Bond et al. 1992). The parent stock from the Aral once supported a fishery which reported landings of 4,000 tonnes per year prior to World War Two (Zholdasova 1997). *A. nudiiventris* has become extinct recently due to increased salinity, lack of access to spawning grounds; all anthropogenic factors brought on by the ecological disaster which has befallen the region.

This species was once endemic to the Danube watershed, remaining year round in freshwater, dams and dredging have caused the extirpation of this species throughout Europe. The ship sturgeon is also verging on extinction in the Azov-Black Sea. In the Caspian Sea, the annual catch during the 1950's and 60's was in the range of 7,000 individuals. In the Caspian basin, the Kura River was the principle spawning river for this species. With the construction of the Mingechar Dam in 1954, prime spawning grounds became inaccessible and the population underwent a drastic decrease. By the end of the 1980's, as few as 1 to 4 adults were seen on the spawning grounds (Makarova et al. 1991). The Ural River remains undammed but poaching has pushed this already rare species near extinction. All wild stocks are now maintained by artificial propagation. All

populations of ship sturgeon are listed as Endangered or Critically Endangered under CITES (Birstein et al. 1997).

The stellate sturgeon, *Acipenser stellatus*, is of enormous economic importance throughout its range and hence heavily exploited. The primary fishing grounds for stellate sturgeon is the Caspian Sea basin. In the north Caspian, over 13, 000 metric tonnes were landed in 1977 but there is now a steady decline of *A. stellatus* landings, dropping from 5, 700 metric tonnes in 1990 to 1, 700 metric tonnes by 1994 (Khodorevskaya et al. 1997). To make up for the decrease in natural recruitment and heavy poaching, hatcheries in the Caspian Sea basin have released over 10 million juveniles into the Volga River Delta (Artyukhin et al. 1999).

The Sea of Azov ranks second only to the Caspian Sea in population size of *A. stellatus*. Prior to the damming of the Kuban River, approximately 80, 000 stellate sturgeon spawned in the upper reaches, some 300 km from the mouth (Musatova 1973). Flow regulations caused a dramatic decline in the population and today, artificial propagation has replaced natural recruitment. Fish lifts built alongside the dams have not proven successful (Chebanov et al. 1999). The hatcheries along the Kuban River in the Krasnodar region have released approximately 25 million juveniles on an annual basis since 1976 (Chebanov et al. 1999). Other than the Caspian population which is listed as Vulnerable, all populations of *A. stellatus* are listed as Endangered under CITES (Birstein et al. 1997).

The sterlet, *Acipenser ruthenus*, is a very important commercial species throughout its entire range. Sterlet are wide ranging and occur within the Ponto-Caspian region and also throughout Siberia in the Arctic drainage. Historically, a large number of sterlet were caught in the Volga River watershed. This species accounted for approximately half of the sturgeon catch in most villages along the river and its tributaries (Sokolov & Tsepkin 1971). From 1935 to 1939, up to 800 tonnes of sterlet were landed annually, 90 % of which came from the USSR (Lukin 1949). At present, the largest sturgeon fishery is that of the Danube River where this species occurs in potamodromous form. A high of 117 tonnes was landed in 1963. Sterlet now occupy only particular areas of the Danube. They are extirpated from the German section of the Danube (Balon 1995) and endangered in the Austrian section (M. Hochleithner pers. comm.). Even the Slovakian section of the river has a reduced population of sterlet. In Russia the sterlet is nowhere near as abundant as at the turn of the century but in parts of the Danube (river km 1, 749 and 1, 762), this species has made somewhat of a resurgence (Balon 1995). The upper middle population of the Danube and lower Morava River is now further threatened by construction and expansion at the Gabčíkova Dam (Hensel & Holcik 1997). This species has been extensively used in aquaculture and sold for its meat. It has been hybridized with the beluga, *Huso huso*, to produce a fast growing - early maturing sturgeon. All populations of sterlet are listed as Vulnerable under CITES (Birstein et al. 1997).

### ***Asia, Far-East***

The Kaluga, *Huso dauricus*, is endemic to the Amur Basin. In the late 1800's, catches of up to 595 metric tonnes were recorded annually. Most of these fish came from the middle-Amur where *H. dauricus* are concentrated (Krykhtin & Svirskii 1997). Since fishing pressure was curtailed in the estuary since 1976, the estuary population is now the largest, having increased by one third. Individuals over 100 kg increased by 2.5 times compared to the early 1970's (Krykhtin 1979). By the end of the 1980's, there was estimated to be over 70, 000 *H. dauricus* over 1 year old and 5, 000 of these were thought to be in excess of 100 kg (Krykhtin 1997). The effects on the population of Kaluga by a growing illegal fishery have proven extremely detrimental. By 1993, the number of spawning aged adults was reduced by at least 30 % and now it is thought that the population consists of only 2 % of adults. (Krykhtin 1997). The pressure on this species by the legal and illegal fishery on both the Russian and Chinese side will continue to reduce the already depleted stock. The high price of caviar will continue to bring pressure on the spawning migrants since they are particularly attractive to poachers. China has been exporting caviar made from kaluga, the major markets being the US and Japan (Taylor 1996). Specific regulations have been issued by the Chinese Heilongjiang Government in 1982 but due to insufficient fisheries law enforcement officials, quotas and gear restrictions are not being implemented (Wei et al. 1996). Russia has had annual closures to the Kaluga during certain periods and seasonal quotas which are loosely enforced at best. The Kaluga is listed as Endangered under CITES (Birstein et al. 1997).

The Amur sturgeon, *Acipenser schrenkii*, is the only other sturgeon species endemic to the Amur basin. Unlike the kaluga which exists as an anadromous form and freshwater form, *A. schrenkii* is restricted to freshwater. The Amur sturgeon in the lower river section is made up of approximately 95,000 fish of age 2 or older while the middle Amur population of *A. schrenkii* is double that. Tributaries of the Amur such as the Zeya and Bureya rivers have extremely small numbers of *A. schrenkii* and now verge on extinction. In 1891, the annual catch of *A. schrenkii* reached 607 metric tonnes (Krykhtin & Svirskii 1997). If the Khinganski Dam project is revived by the Chinese authorities, then *A. schrenkii* will have little remaining spawning grounds. The Amur sturgeon is listed as Endangered under CITES (Birstein et al. 1997).

*Acipenser dabryanus* and *Acipenser sinensis* are endemic to China. The Dabry's sturgeon is a freshwater species ranging in the mid and upper reaches of the Yangtze River (Qiwei et al. 1997). By the 1960's, the Dabry's sturgeon was of great commercial importance, and in the 1970's up to 5 tonnes were caught each spring in the Yibin reach of the Yangtze. This species has declined drastically in recent years due to overfishing, pollution and habitat destruction (Wu 1990). It is particularly rare below Gezhouba Dam. The reasons behind the demise of this species is principally due to fishing methods. The size of the net mesh used became so small that juveniles in the range of 50 g made up the bulk of the catch in some areas (Qiwei et al. 1997). In the Neijiang area of the Tuo River, over 2,000 fishing boats worked a stretch of river that had only 500 boats in the 1950's. Industrial pollution and agricultural effluent is a major concern and the

Gezhouba Dam has prevented this species from reaching the spawning grounds (Wu et al. 1991). Commercial harvest of this species has been prohibited since the early 1980s when it received special protection under the state's special category 1 as an endangered species (Qiwei et al. 1997). The Chinese sturgeon occurs in the Yangtze and Pearl Rivers. Prior to 1972, official statistics were not kept but between 1972 and 1980 an annual average of 517 individuals were landed (77, 550 kg). Commercial fishing for this species has been banned since 1983 and scientific captures for artificial breeding averages 100 individuals per year (Qiwei 1997). An average of 25, 000 larvae and juveniles are released into the Yangtze River annually. Public awareness is growing and many fisherman cooperate by releasing any sturgeons they happen to catch (Qiwei et al. 1997). This species has been listed as a state protected animal in class I (Qiwei et al. 1997).

While stocking has been initiated as a measure to save many of the Acipenser species, it represents at best a stopgap. For sturgeons and other late maturing fishes, even the most massive artificial spawning and stocking efforts cannot keep a species being industrially harvested from going extinct before long. The Russian experience has shown that astronomical numbers of juveniles need to be stocked merely to prevent a heavily harvested species of late maturing fish from going extinct. In order to preserve the global diversity of sturgeons, increased international awareness, better regulation and stricter enforcement are necessary (Birstein et al. 1997). The prognosis for most

sturgeon species is very bleak and it may take many years before we see the results from today's conservation measures.

For wild stocks where artificial propagation is not being used as a means of aiding recruitment, Goodyear (1993) suggests maintaining the levels of spawning stock biomass per recruit that are at least 20% of the maximum (when  $F = 0$ ). Boreman et al. (1984) claim this level should be 50% if stocks are to rebuild rather than simply maintain themselves at present low numbers (Boreman 1997).

The U. S. Fish and Wildlife Service has put forth new regulations meant to curtail the illegal trade of sturgeons and to help protect remaining stocks. In 1997, the U.S. and 142 countries belonging to the Convention on International Trade In Endangered Species (CITES), proposed to halt the decline of remaining sturgeon stocks through the control of caviar trade. The U. S. accounts for roughly 30 % of the world caviar market and is thus a major importer but also has several species of sturgeons, some of which are harvested for domestic consumption and caviar. Most caviar sold in the U.S. is imported, with 70% originating from Russia (Taylor 1996). Germany and the U. S. undertook measures to put all species of sturgeons not previously listed, to be placed under Appendix II with CITES. Such a listing will now set in motion trade controls which would eliminate the influx of illegally processed black market caviar (De Meulenaer & Raymakers 1996, Fisher 1998). Since April 1, 1998, all imported caviar to member countries must have valid CITES export permits from their

country of origin. Furthermore, the exporter country must have a CITES export permit.

Biologists with the U. S. Fish and Wildlife Service in Oregon have developed a method of DNA analysis allowing for species identification of any batch of caviar in question (Fisher 1998). Inspectors can thus remove a small quantity of caviar from a shipment which would then be sent to the forensic laboratory for analysis. If the species is determined not be the species on the caviar label, the shipment would be seized and the importer prosecuted for violation of Federal wildlife laws (Fisher 1998).

In chapter 3, I introduce a novel concept to sturgeon management. The ability to sex individuals by a non-invasive method based on external morphology. This technique would add greatly to our ability to selectively harvest, culture and release sturgeons (typically females) in programs to enhance the recovery of depleted populations or the sustainability of existing harvests.

## **Chapter 3. Sexual dimorphism**

### **3.1 Sexual dimorphism in sturgeon**

Sexual dimorphism in adult fishes is an example of secondary sexual characteristics. These characteristics are more often displayed in males and may be permanent dimorphic sexual features, or may be morphological changes brought on prior to or during spawning (Jobling 1995). Fishes with specialized reproductive behavior can have secondary sexual characters as obvious as different coloration, body shape, fin size or the presence of nuptial tubercles. For example, many salmonids have marked seasonal sexual dimorphism. Mature males typically develop enlarged jaws and bright colors (Groot et al. 1991, Scott & Crossman 1973, Pauley 1991). Fishes such as the poeciliids and elasmobranchs are permanently dimorphic because of the modified anal or pelvic fins of males used as intermittent organs (Hamlett 1999). The males of many cyprinids and catostomids develop breeding tubercles at sexual maturity (Scott & Crossman 1973, Trautman 1968).

Sexual dimorphism may be inconspicuous or absent in other species. In species of Gobiidae the sexes can be differentiated only by relatively minor differences in morphology and coloration ( Balon & Bruton 1994). Some investigators have shown that even apparently monomorphic species, such as some cichlids, can be differentiated at sexual maturity by small but consistent differences in the size and shape of the urogenital openings of females and males (Guerrero 1982). There are, however, a number of species such as

clupeids, chaetodontids, and sturgeon which are believed to exhibit no external sexual dimorphism (Berg 1962, Holcik 1989, Helfman et al. 1998). The evolution of sexual dimorphism is commonly thought of as the result of sexual selection where variation in the traits in one sex results in greater reproductive success either through preferences present in the other sex, or because of direct competition for the other sex among members of one of the sexes (Galis 1998). Sturgeon are known to spawn in relatively turbid waters where visibility is often poor so any visual component to mate choice is unlikely. Alternatively, it is also possible that sexual dimorphism does not reflect the results of sexual selection, and instead is a consequence of the reproductive function of each sex.

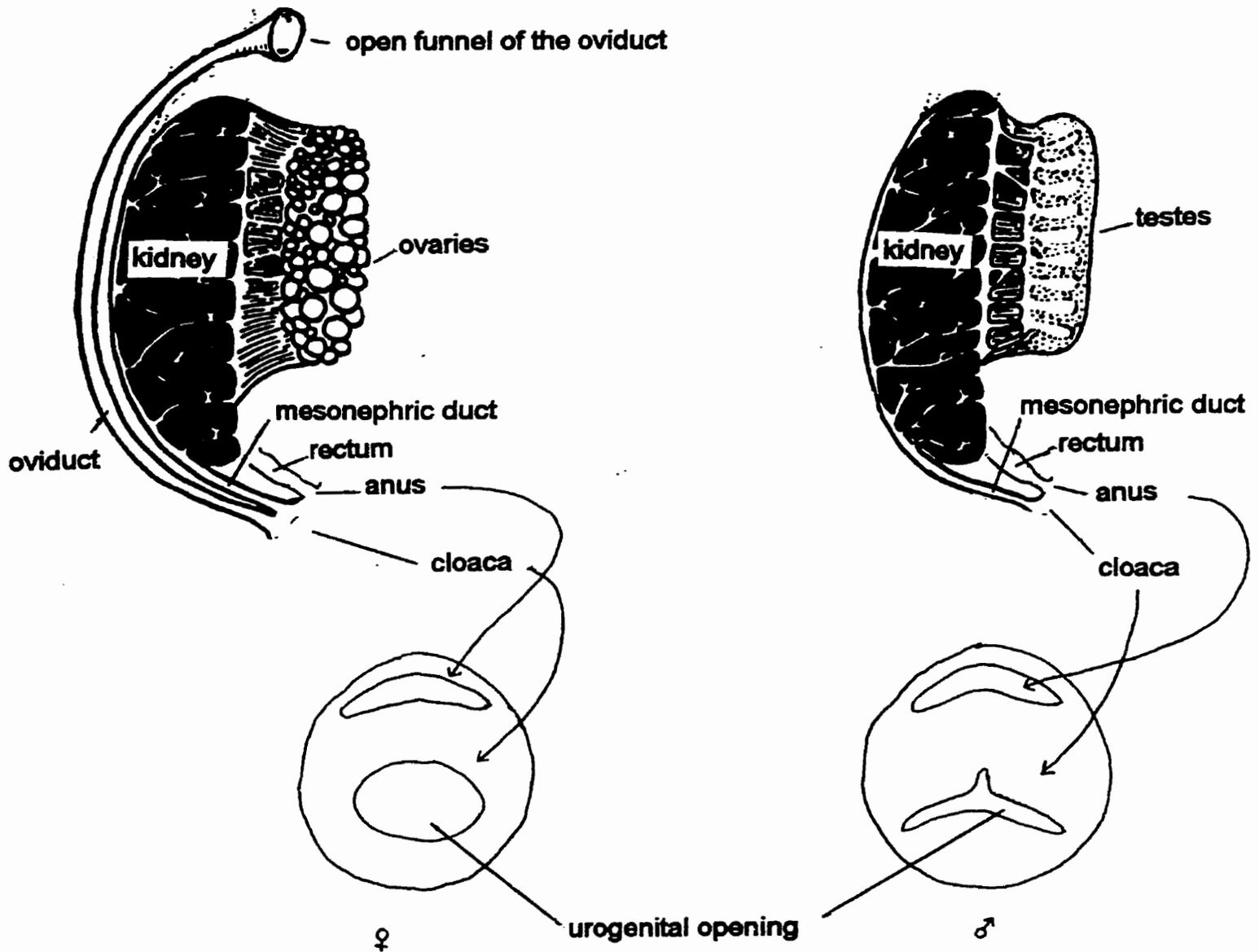
The question of secondary sexual characters and sexual dimorphism can be viewed from the perspective of the fish, as well as from that of the human observer. There is no doubt that fishes can distinguish between sexes within their own species. Fish likely use a variety, or combination, of signals and stimuli, including chemical, electrical, tactile and auditory, as well as visual. Human observers are usually limited to visual features. It is such visual features we want to identify so as to be able to discriminate between females and males.

In sturgeons, the ovaries are paired, longitudinal and suspended by a pair of mesenteries. Eggs are shed into the body cavity since the ovarian capsule is not joined to the oviduct. The eggs enter the funnel of the oviduct, known specifically as the Mullerian duct. Thus a female sturgeon has 3 ducts leading to 2 external openings. Most anterior is the intestinal tract leading to the anus. The Mullerian duct is situated posteriorly to the anal opening. The Mullerian duct is

anterior to the mesonephric duct, both of which connect internally and lead to a single opening, the urogenital opening. The testes of male sturgeon are paired and lie close to the kidneys. The male sturgeon also has two ducts opening into the cloaca. The anal opening is anterior, as in the female. The posterior opening consists only of the mesonephric duct. Internally the testes drain through a complex network of tubules into the mesonephric duct near the kidneys.

For example, Guerrero (1982) reports that experienced technicians can distinguish female and male tilapia by differences in the appearance of the urogenital papillae with a success rate of about 80%. The need for this discrimination is related to the intensive culture and production of tilapias. Since tilapias could be sexed by external morphology, it thought it may be possible to do the same for sturgeon. Based on this, I hypothesize that 1) sexually mature sturgeon are dimorphic, and 2) it is possible to determine the sex of adult sturgeon based on external morphology of the urogenital opening (fig. 3-1). To test this, I looked at adults of North American acipenserids in situations where I could also verify the sex of individuals.

**Figure 3 - 1. Schematic diagram of external urogenital region of sturgeon used for field identification of females and males by external examination (adapted from Hoar 1957).**



## **Chapter 4. Determination of Sex of Live Adult Sturgeon From External Morphology**

### **4.1 Introduction**

Sturgeon spawn over rock and gravel substrate (Balon 1975, Auer 1998). No complex courtship involving display or aggression takes place and researchers have concluded that there is no external sexual dimorphism among sturgeons (Men'shikov 1937, Shmidtov 1939, Berg 1948, Vlasenko et al. 1989, Scott & Crossman 1973). Certain authors (Vladykov 1931) have noted slight differences in the size of the paired fins in sterlet, *Acipenser ruthenus*, but such morphometric criteria are statistical and can only emerge through comparing the mean fin lengths of many fish of each sex. There is apparently no reliable method for determining the sex of individuals in any of the Acipenseridae from external morphology.

Suggestions that concentrations of steroid hormones in the blood circulation of sturgeons could be used to determine sex have not proved to be feasible, despite earlier demonstrations of the utility of this technique in Atlantic salmon (Idler et al. 1981). The procedure requires restraint and invasive sampling of blood from the fish, followed by a rather sophisticated sequence of analytical procedures to measure specific hormones. Attempts to use this procedure have provided results ranging from inconclusive to successful but it remains a costly method to provide unambiguous sex determination of individual fish and is not feasible for field determination of sex (G. J. Van Der Kraak, pers. comm., G. Feist, pers. comm.).

Recently, some researchers have begun using fiber optic probes inserted into the abdominal cavity of adult sturgeon to determine the sex of individuals (B. Kynard, pers. comm.). This technology has certain advantages. Sex can be successfully determined by direct visual examination of the gonads and, furthermore, stage of maturation of the gonads can be gauged in some cases. This not only provides data for determining sex ratios but also provides information concerning female brood stock productivity (fecundity). Of course this technique also requires that sturgeon be immobilized and subjected to anesthesia and handling, perhaps on repeated occasions. While this may be a useful tool for fisheries researchers, fiber optic probes are not generally accessible to aquaculturists, conservationists, anglers and commercial fisherman. Nor are these individuals likely to be able to immobilize sturgeon for the time required to carry out this internal examination. It is possible to confirm the sex of live sturgeon by gonad biopsy. However, this procedure requires that fish be immobilized by anesthesia, while a tube is inserted through an incision to remove a sample of gonadal tissue. A part of any stock assessment and population structure study involves correct sexing of any potentially mature spawner. Biopsies are performed to sex these fish but this intrusive procedure can be very stressful on fish and human operators. Non invasive sexing would enhance sturgeon survival by greatly minimizing handling time out of water. It is these individuals, that I hope to assist by developing a simple, reliable, noninvasive method of sexing individual fish without resorting to expensive or sophisticated equipment and invasive procedures.

Such an approach requires finding some external morphological trait characteristic to each sex. In a discussion of this problem Martin Hochliechner, a European sturgeon aquaculturist, suggested that the shape of the urogenital vent might be a distinguishable character differing between the sexes.

The experimental test of the prediction that it indeed is possible to sex sturgeon by external morphology is the basis for my thesis. I conducted a detailed analysis of selected North American sturgeon species to address this important question.

Sex of fish was judged by examination of the anal/urogenital vent (=cloacal) region. My prediction was that the female urogenital opening would be larger and more circular, and the male opening would be smaller and less prominent. In most cases this external examination was carried out while the fish were still alive, but this was not possible in all cases. Sex was confirmed by examination of gonads following dissection of fish after they were killed by commercial fishermen.

## **4.2 Material and Methods**

I conducted my study of sexual dimorphism in sturgeon on North American watersheds where there are significant commercial harvests of four different species, *A. medirostris*, *A. brevirostrum*, *A. transmontanus* and *A. oxyrinchus*. While lake sturgeon, *Acipenser fulvescens* is the most common North American sturgeon species, I had great difficulty in sampling anything but juveniles despite sampling over 2 years in northern Lake Michigan. I had to be able to confirm the sex of the individual sturgeon by internal examination of gonads and that is

possible only if fish are killed and dissected after external examination. By definition, a study of endangered and threatened species such as sturgeon will always limit sample sizes because of the possibly lethal nature of the sampling process and the small population size. There were few locations, and few opportunities to obtain sufficient numbers of fish to make this study possible.

To further increase my sample size and to determine whether my sexing technique can be used by others working with sturgeon, we asked biologists with RL & L Consultants to photograph the anal/urogenital vent region of all adult white sturgeon they caught during their summer 2000 field season on the Upper Columbia River, British Columbia. This part of my study was a double blind test of my hypothesis. I instructed L. M. Porto (R L & L consultant) as to which region of the fish to photograph, but did not give any indication as to what features were to be examined, or how they might be used to distinguish females from males. These photographs were then shown to a series of observers at the University of Guelph, to test their ability to identify the sex of individual fish.

### **4.3 The study sites**

I chose the Saint John River, New Brunswick, Canada and the Columbia River , Oregon, U.S.A. as my study sites. The former site has the only commercial harvest for Atlantic sturgeon, *A. oxyrinchus*, and scientific sampling for shortnose, *Acipenser brevirostrum*, is done on an ongoing basis. There is a commercial harvest and scientific sampling for white, *A. transmontanus*, and green, *A. medirostris*, sturgeons on the Columbia River. R L & L Consultants

sampled white sturgeon on the Columbia River, Priest Rapids, near Wanapum Lake, approximately 500 km inland from Vancouver, British Columbia.

The Saint John River has its source in the northwest region of New Brunswick. Sturgeon migrations can not go beyond the Mactaquac Dam below Fredericton but historically most spawning took place downstream of this site so the dam's effect on successful recruitment is probably minimal. The lower reaches of the Saint John River, primarily the estuary, are highly productive and support a large population of shortnose sturgeon. These fish overwinter in the tidal zone and move upstream in spring to their feeding grounds. Atlantic sturgeon are seasonal migrants, feeding and growing in the ocean, with individuals in reproductive condition entering the river in late June (M. Litvak, pers. comm.). Atlantic sturgeon, *Acipenser oxyrinchus*, is subject to an intense commercial fishery in July and August during the spawning migration from the Bay of Fundy to the mid-upper reaches of the river. Because the commercial fisherman are in close collaboration with the Sturgeon Conservation Organization, several fish are purchased for artificial propagation. Since all fish are potential candidates, they are kept alive in the water after capture in 33 cm mesh gill nets. This procedure gave me the opportunity to examine several adult specimens. This would have been impossible anywhere else throughout the range of this species because stocks have collapsed and there is no commercial harvest or any significant scientific survey (Caron & Tremblay 1999). For example, the next most productive system, the Hudson River produced only one

adult female during an intense biological sampling survey during the entire 1998 spawning season ( D. Peterson, pers. comm.).

Shortnose sturgeon are captured in the Saint John River in gill nets in the upper estuary as they migrate upstream to spawn. They are held alive until they become sexually mature, when they are stripped by hand. While these fish were not killed to confirm our sexing from external characters, I was able to confirm their sex by the release of eggs or sperm from individuals.

The Oregon Department of Fish and Wildlife conducts an annual stock assessment of white sturgeon on the Columbia River. While once a free flowing river from the headwaters in southeast British Columbia, the Columbia River is now a series of impoundments and dams. Anadromous sturgeon have access upstream as far as the Bonneville Dam. All other populations throughout the watershed are landlocked. The impounded waters above Bonneville Dam support a large population of white sturgeon. While over 340 white sturgeon were captured, tagged and released in August 1999, the vast majority were sexually immature juveniles. I examined the few adults that were caught. A 12 hour commercial harvest was allocated to zone 6 in the estuary of the Columbia. These fish were all brought into the processing plants in Astoria and were measured and sexed by opening the body cavity.

A sample of 50 green sturgeon caught in the estuary of the Columbia River during the 12 hour sturgeon fishery on August 3, 1999 was purchased by the Oregon Department of Fish and Wildlife from the fish processing plant in Astoria.

#### 4.4 Recording data

I used fine grained film (Fujichrome 50 and 100 ASA) to photograph the cloaca (anus and urogenital opening) of sturgeons. All photos were taken with a Nikkor 24-120 Aspherical zoom lens set at 120 mm focal length to minimize parallax distortion. I tried to restrict the image size to the area immediately around the cloaca but light levels often forced me to back away further. The lighting of the subjects was impossible to control and sometimes affected the clarity of detail. A variable output flash (Image MBZ-1500) was sometimes used but was found to over-expose out detail so natural light was used whenever possible. I projected the cloaca slides onto a Linetech illustration board, then traced the contour detail using a Koh-I-Nor Radiograph technical pen (0.25 mm tip point).

I analyzed my data with a combination of chi-square and binomial tests, the former for sample sizes greater than 15, the latter for smaller sample sizes. I tested whether I was more likely to sex females or males correctly using external morphology, for sturgeon either alive or dead at the time of external examination. Analyses were performed for the four species, as well as for all species combined.

Each species was broken down into the following categories: a) total sample size for species in question, b) number correctly sexed, c) number incorrectly sexed, d) number of males, e) number of females. The correctly and incorrectly sexed categories (b and c) were further broken down into sub categories of: correct : incorrect male, and correct : incorrect female. This included the total of all species combined and *A. oxyrinchus* as an individual

species. A binomial test was performed for sample sizes fewer than 15 fish to determine whether there was a significant difference in determining the sex of fish, whether dead or alive. This included *A. brevirostrum* and *A. transmontanus*.

#### 4.5 Results

All fish examined were sexually mature. Testes of all the males were enlarged, clearly visible upon dissection, and uniformly beige or cream-white in color. All females had eggs clearly developing in their ovaries ( Holcik 1984, Doroshov 1987). The state of maturity of the testes and ovaries varied among individuals, but was clearly identifiable.

My success in determining the sex of fish from external morphology was 71 % for all species combined, 71.4 % for shortnose, 73.6 % for Atlantic, 67 % for white, and 0 % for green sturgeon (Table A-1). If I categorize my results according to whether the fish were alive or dead at the time I examined external morphology, a clear pattern emerges. My success rate for determining sex based on external morphology was 82 % for fish examined alive but only 29 % for fish examined after death. This difference is highly significant ( $p < 0.01$ , chi-square test). There was no significant difference in the success at sexing of male versus female sturgeons ( $\chi^2_{(1)} = 0.11$ ,  $p > 0.05$ ) for all species combined, or ( $\chi^2_{(1)} = 0.01$ ,  $p > 0.05$ ) for *A. oxyrinchus*. There was a significant difference in sexing live versus dead fish of all species combined ( $\chi^2_{(1)} = 6.18$ ,  $p < 0.05$ ). Results were significant for live white sturgeon ( $p < 0.05$ ) but not significant for white sturgeon when data for both live and dead fish were aggregated, or when dead white sturgeon were examined independently ( $p > 0.05$ , binomial test). The binomial test

was non-significant for shortnose sturgeon ( $p > 0.05$ ). While all green sturgeon were dead before I examined them, the small opening of their urogenital vent makes them poor candidates for external morphological sex determination. Furthermore, it seemed both male and female green sturgeon have small circular urogenital openings. An alternative explanation cannot be ruled out, however, that green sturgeon could not be sexed because all were dead and had prolapsed cloacae.

#### **4.6 Discussion**

These results indicate that it is possible to successfully determine the sex of live adult sturgeon from external morphology. This contrasts with earlier reports stating sturgeon are sexually monomorphic. This also contrasts with previous attempts, even using concentrations of steroid hormones circulating in the blood, to determine the sex of live sturgeon (Dumont et al. pers. comm.) .

Postmortem prolapsis of the rectum, with subsequent distortion of the adjacent urogenital openings, is common in large elasmobranchs (Berra 1997) and the coelacanth, *Latimeria chalumnae* (Balon et al. 1988). This has been observed in sturgeons, and thus limits the application of my external examination to living individuals. Under appropriate conditions, it is possible to confirm the sex of live sturgeon by gonad biopsy. However this procedure requires that fish be immobilized by anesthesia and that a tube be inserted through the incision to remove a sample of gonadal tissue (Doroshov et. al. 1983)

The confirmation of my non-invasive procedure has far-reaching potential for the management of sturgeon. The harvest of Atlantic and shortnose sturgeon

in the Saint John River is primarily for their flesh. Most females caught are still in early stages of ovarian maturation. Thus they do not yield any caviar and so are of no additional commercial value compared to males. Males outnumber females in the spawning runs, as is common in other sturgeon species, so there is no economic advantage to harvest females. There is typically a preponderance of males among spawning adults of sturgeons (Holchik 1989). This is almost certainly because males have an earlier age of initial sexual maturation than females and they mature at shorter intervals after their initial maturation (Berg 1962). The present quota for commercial harvest of sturgeon in the Saint John River is an annual total weight limit. In this situation the annual quota could be satisfied by a harvest heavily skewed towards males. Females could be identified externally while still alive, and released to complete their spawning migration. Even more importantly, size quotas on females could be implemented, calling for the release of smaller first time returning females.

The external identification of the sex of any sturgeons on the Columbia River would be important primarily for scientific studies. External identification of the sex of any sturgeon would be a significant advantage, whether for conservation, stocking or other management procedures. Commercial aquaculture production of sturgeon depends significantly on whether fish are to be produced for caviar only, flesh only, or some combination of these two products (Logen et al. 1995). Similarly, the production of hatchery brood stock would be greatly enhanced if the sex of individual fish could be verified. By determining the sex of sturgeon prior to maturation, any excess males could be removed thus saving money.

The stocking of fish for restoration or rehabilitation would also be enhanced if the sex of individual fish were known.

The validation of this technique in other sturgeon species, and the application to management and conservation of sturgeons should now take the highest priority.

## **Chapter 5 . Validation of Technique for Noninvasive Sex Determination of Live Adult Sturgeon**

### **5.1 Introduction**

An advantage of this morphological means of external sexing of sturgeon is the potential simplicity of the technique. Unlike other methods which involve expensive equipment or complicated laboratory analysis, my method of external sexing relies on the observational skills of the investigator.

To establish whether other people unfamiliar with sturgeon morphology could also sex fish based on my criteria, I had independent observers view my slides and apply my criteria for sex determination. The photos sent by RL & L Consultants were also viewed by independent observers as a separate double blind test. This latter test is particularly important, as it not only tests the applicability of this technique, but also tests some more subtle aspects of the training and ability required to successfully apply this technique.

### **5.2 Materials & Methods**

This part of my thesis was the practical application of my non-invasive sexing method. I designed a questionnaire to test whether people ranging from students, to professional ichthyologists were able to successfully sex individual fish after being introduced to the morphological differences in shape of the urogenital opening. This is a test of the inter - observer reliability of the technique, a procedure commonly used in validating such procedures (Siegel 1956, Martin & Bateson 1993). Inter - observer reliability is used to measure the extent of similar

results between several observers (Martin & Bateson 1993). In this manner, I tested for agreement between different observers all looking at the same part of the sturgeon.

I administered the following test procedure. All subjects were informed of the background to this study and the basis for my technique. They were first shown a black and white line drawing (Figure 3-1) to demonstrate the identification procedure. The subjects were then shown 13 color photographic slides of male and female sturgeon from three species (*A. transmontanus*, *A. brevirostrum* and *A. oxyrinchus*) included in this study. The fish were identified only by slide number. Because the fish were not present and the orientation of the body not obvious, I indicated anterior and posterior directions for each slide.

Each subject had a printed score sheet, with one row for each specimen (photographic slide). Test subjects were asked to determine the sex of each sturgeon shown based on the appearance of the urogenital opening. Once the subjects had judged the sexed each sturgeon, they were asked to rate the level of confidence in their judgment on a numerical scale of 1 to 5. A value of 1 indicated the subject was strongly confident of her / his judgment while 5 indicated a low level of confidence (Table A-2).

Subjects were tested in groups of 5 or less and in all cases made their judgments independent of each other. No communication was allowed among subjects tested in groups. The least experienced subjects ranged from secondary school students with minimal fisheries skills to senior undergraduate university students with at least one formal undergraduate course in fish biology. More

experienced subjects included postdoctoral researchers (professional ichthyologists) and technicians with several years' experience handling and identifying various fish species.

A similar procedure was used for the photographic prints taken by RL & L Consultants but subjects were tested on an individual basis and the degree of certainty was scored from 1 to 3 rather than 1 to 5. Respondents were given a schematic illustration of what to look for in terms of sexing based on the shape of the urogenital opening. The photos sent by RL & L Consultants were color prints of photographs they had taken of the urogenital vent regions of adult white sturgeon. Each photograph included a coded alphanumeric sequence to identify the PIT tag they implanted in each fish, and hence provided a unique identification for each fish. The RL & L biologist also provided, on a separate sheet, the list of PIT tag codes, with corresponding information as to the size, sex and gonadal maturity of each fish. They determined sex and sexual maturity by gonadal biopsy at the time of capture. They released all fish after their sampling. They took these photographs during their larger study of population biology of white sturgeon.

The photographs were shown to individual observers with no knowledge of the sex of the fish. The test was administered by another individual (D.L. Noakes), who was also ignorant of the identification or sex of the individual fish. Observers were given a printed sheet to instruct them on the features to be used to distinguish females from males. Each observer was then allowed to view the photographs (Figure 5 -1), identified only by arbitrary numerical code numbers.

Each observer scored each photograph as to whether they judged it as a female or male, and also indicated their degree of certainty (1 = most certain, 2 = somewhat uncertain, 3 = uncertain) with assignment of sex . I also took this test, under exactly the same circumstances (double blind) as others. I summarized these individual data sheets (Table 5 - 2), and only then read the data sheet provided by R L & L (Table A - 4 and A - 5).

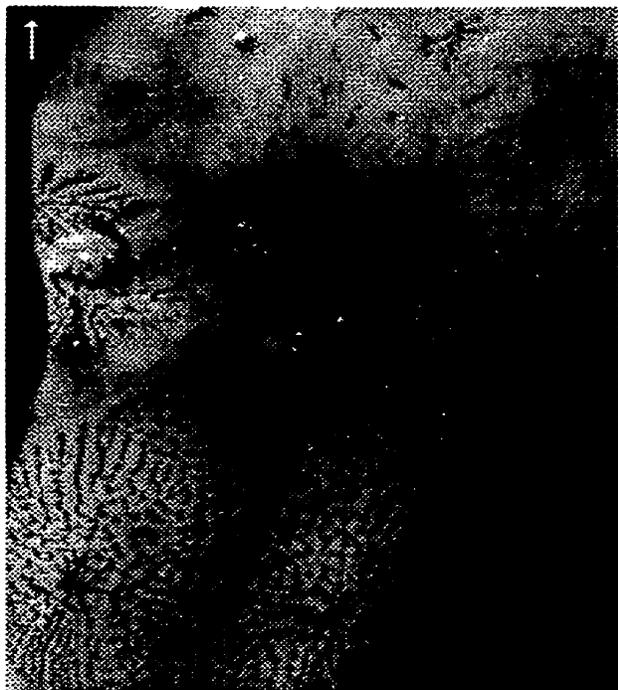
Some individual observers participated in both tests, and always in the sequence with the double blind test last. No observer was given any indication of her/his record of identification of slides or photographs in relation to the actual sex of individual sturgeon until both tests had been completed and all data summarized.

### **5.3 Results**

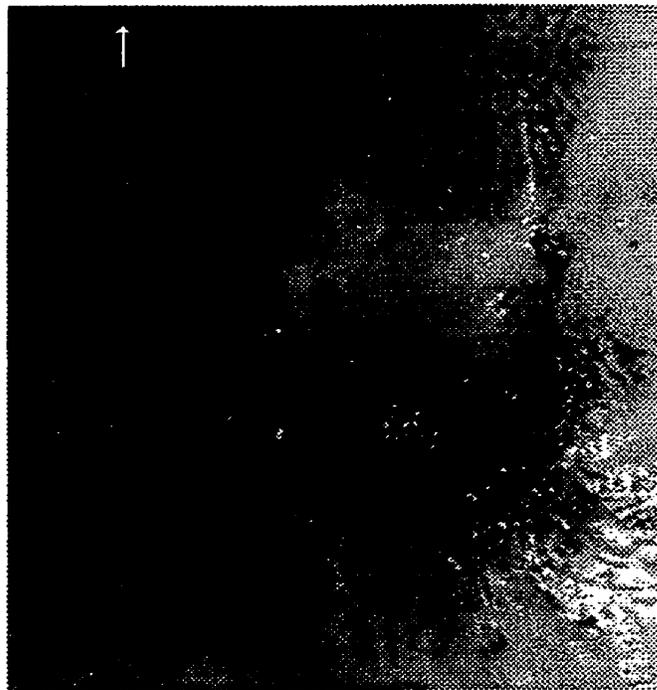
The scores of observers for presentation of my slides are presented in Table 5 - 1. A total of 20 observers viewed the slides and scored them as to whether they were from female or male sturgeon. The pattern of correct sexing was similar among candidates. That is to say, certain slides were apt to give difficulties to all respondents. Two slides proved most difficult to determine for sex and were wrongly determined by 75% and 95% of respondents. Out of the 13 slides, one was judged correctly by every respondent taking the test. The rest were all judged correct more often than not except for the two which were wrongly sexed more often than correctly. Out of a possible 260 right answers among 20 respondents (20x13), there were 70 wrong (26.9%) answers and 190 (72.2%)

correct answers. Males proved to be more difficult to sex than females with 30.7% of males being incorrectly sexed as opposed to only 23.1% for females.

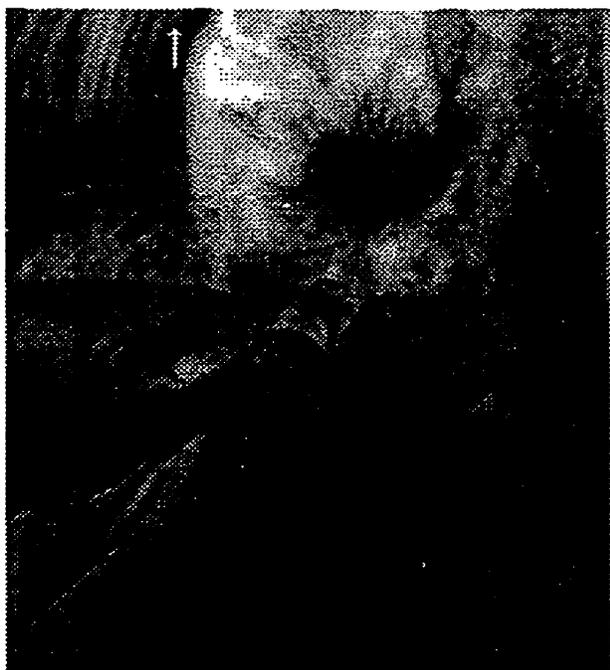
**Figure 5 - 1.** Photographic prints from color slides used to test for inter-observer reliability of technique for determination of sex by external morphological features. Species and sex of individual fish are indicated below each photograph



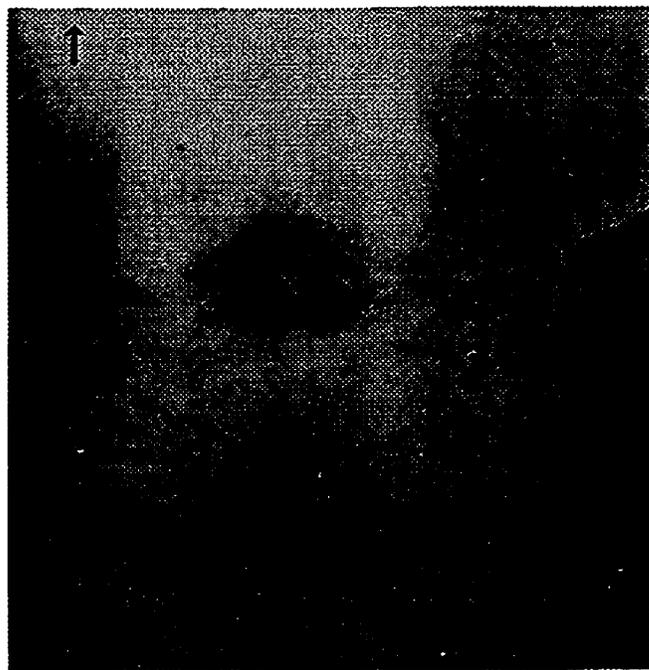
***A. oxyrinchus* (female)**



***A. oxyrinchus* (female)**



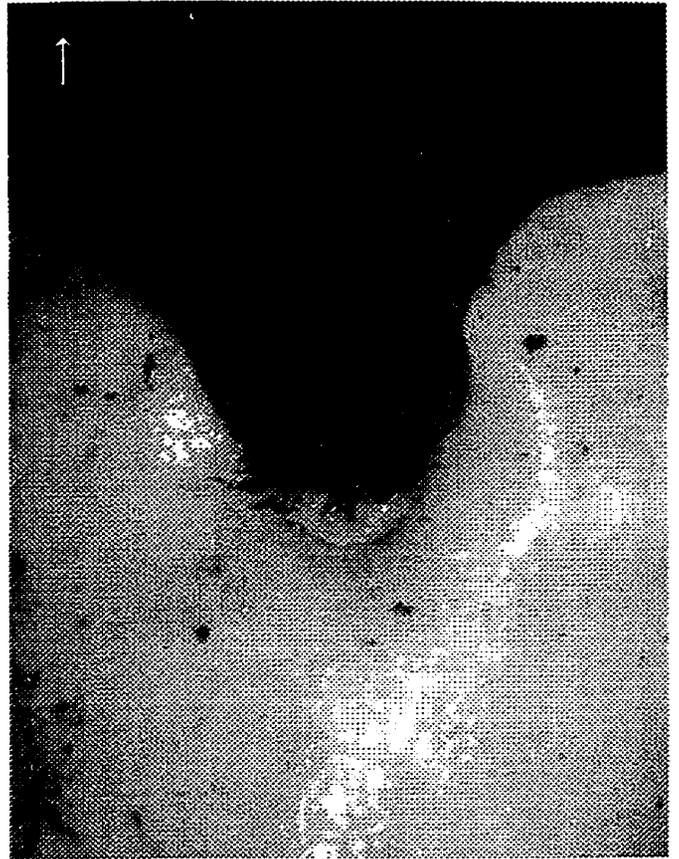
***A. oxyrinchus* (male)**



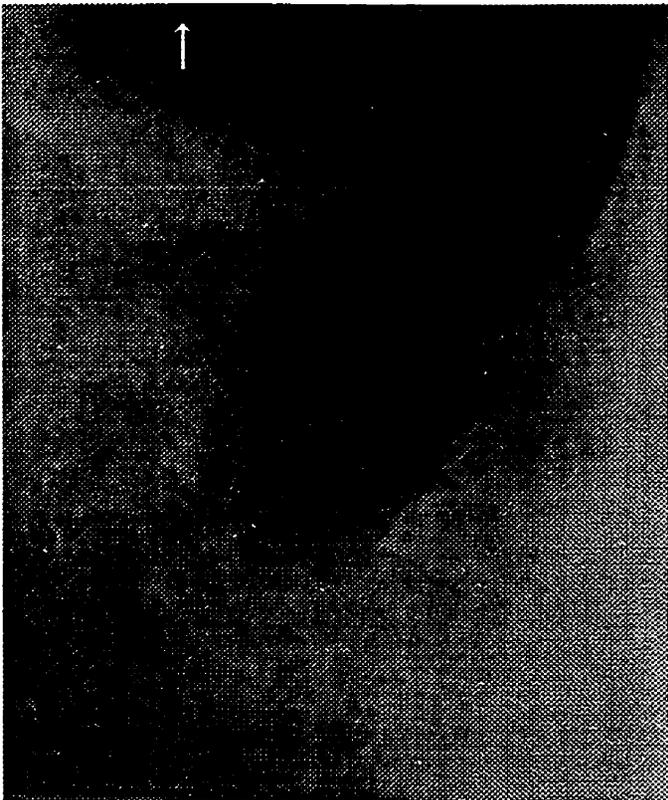
***A. brevirostrum* (female)**



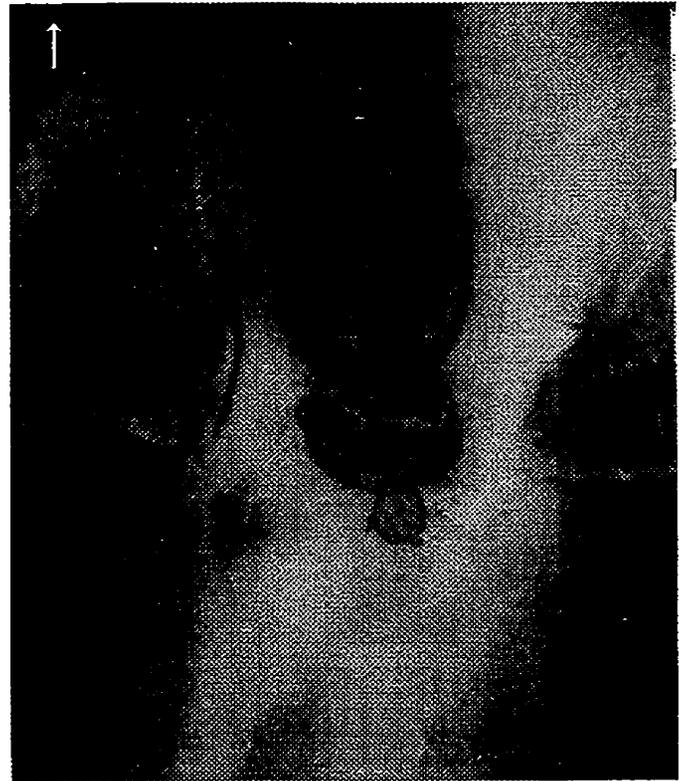
***A. brevisrostrum* (male)**



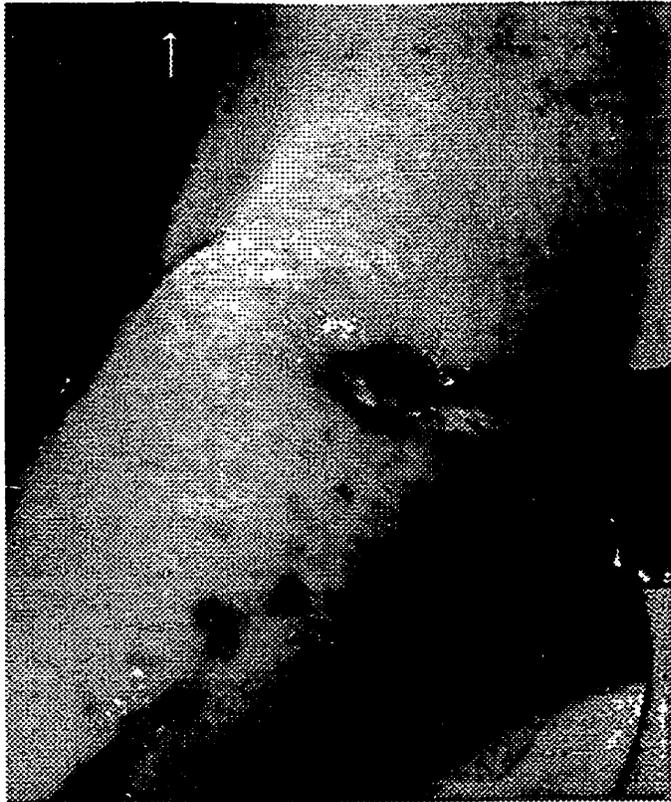
***A. transmontanus* (male)**



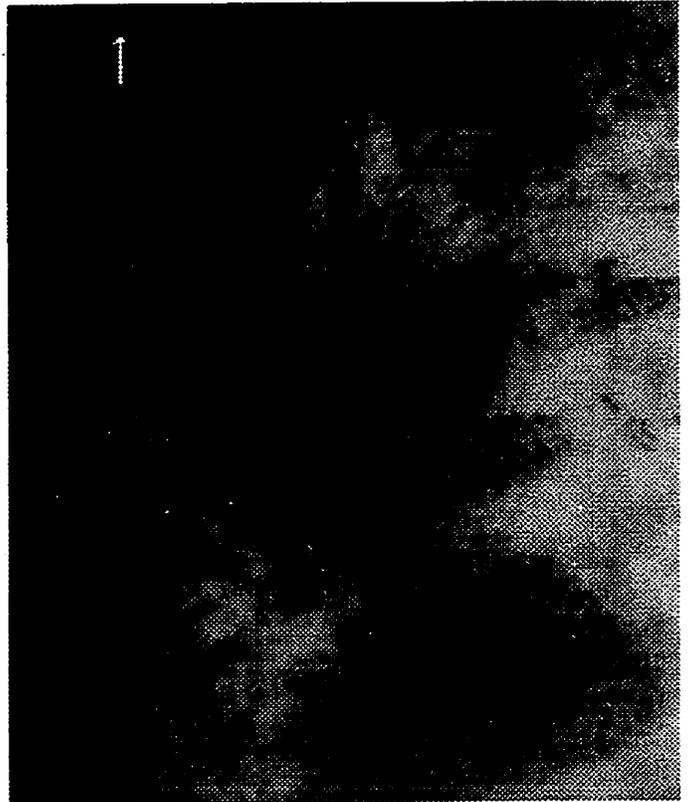
***A. transmontanus* (female)**



***A. brevisrostrum* (female)**



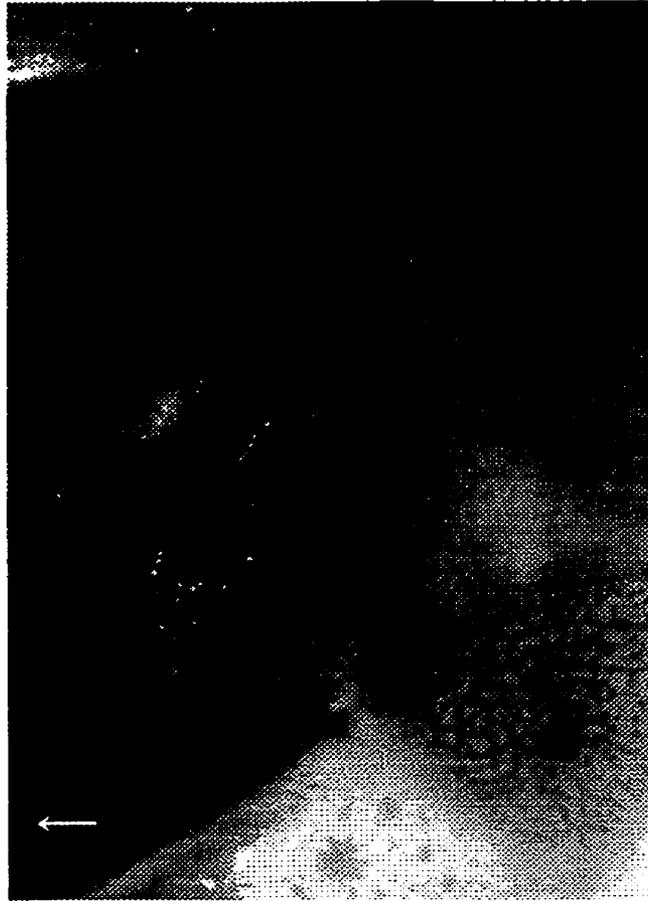
***A. transmontanus* (female)**



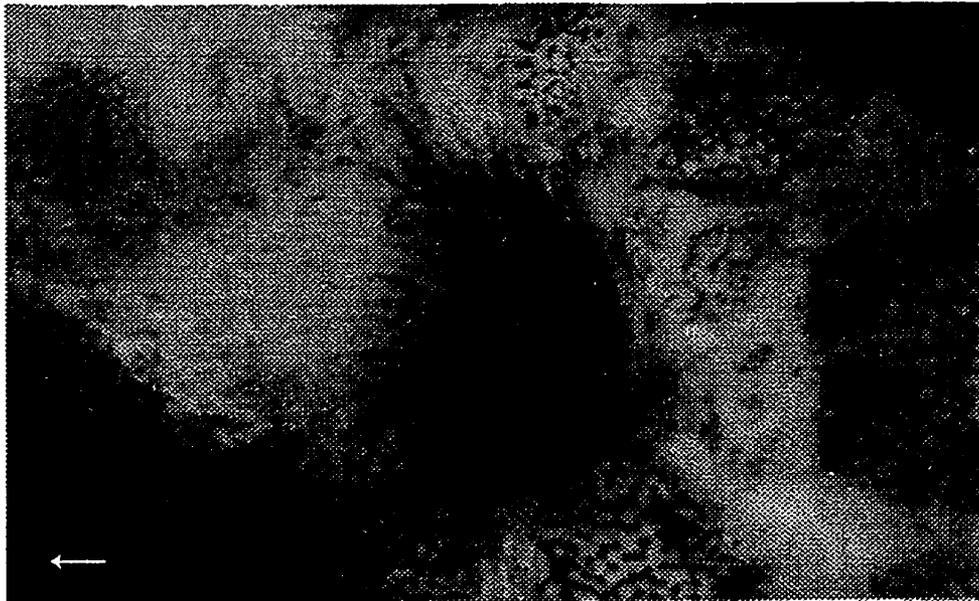
***A. oxyrinchus* (male)**



***A. brevirostrum* (male)**

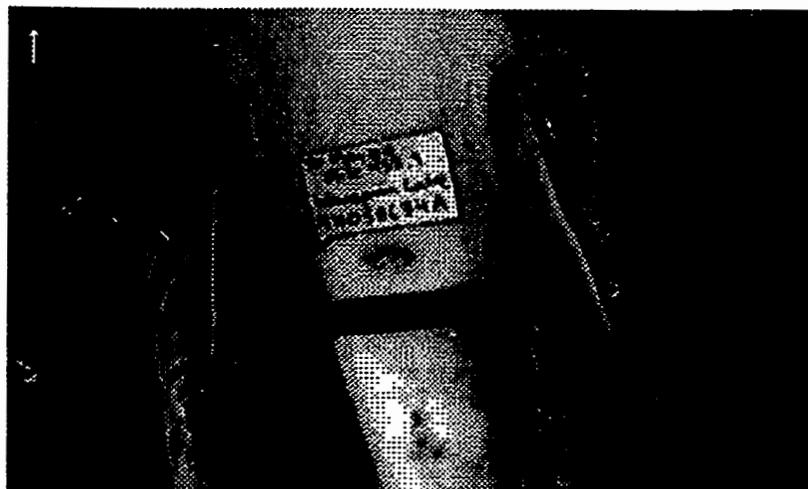
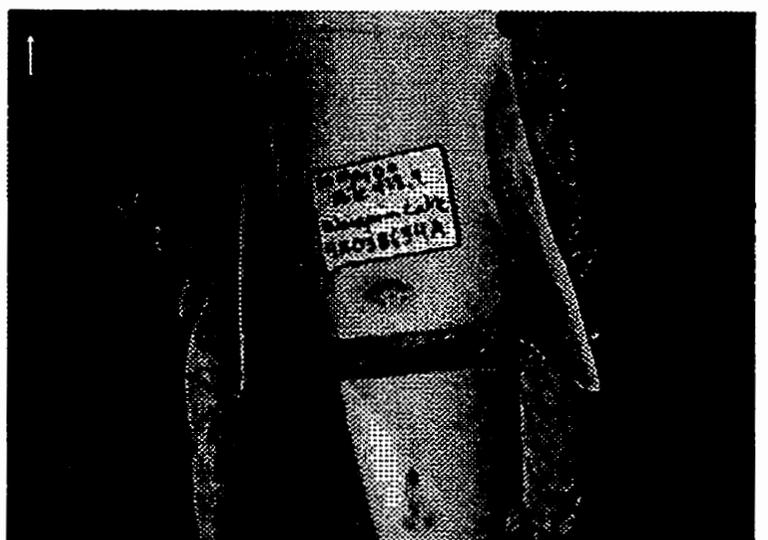
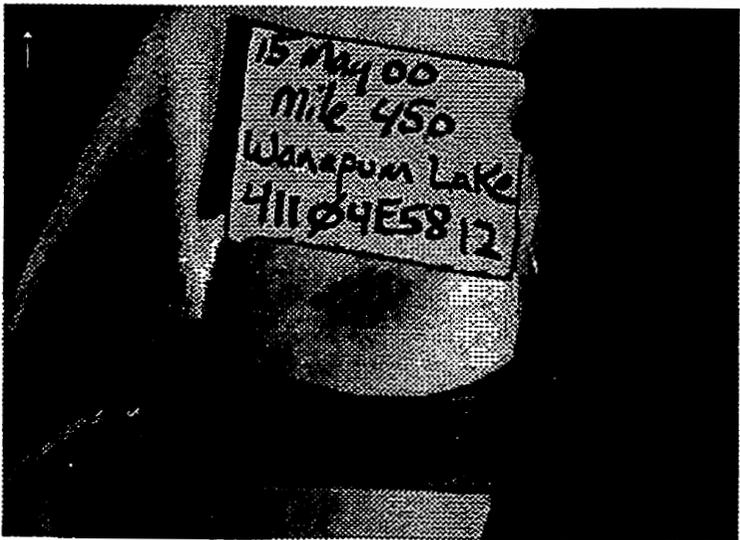
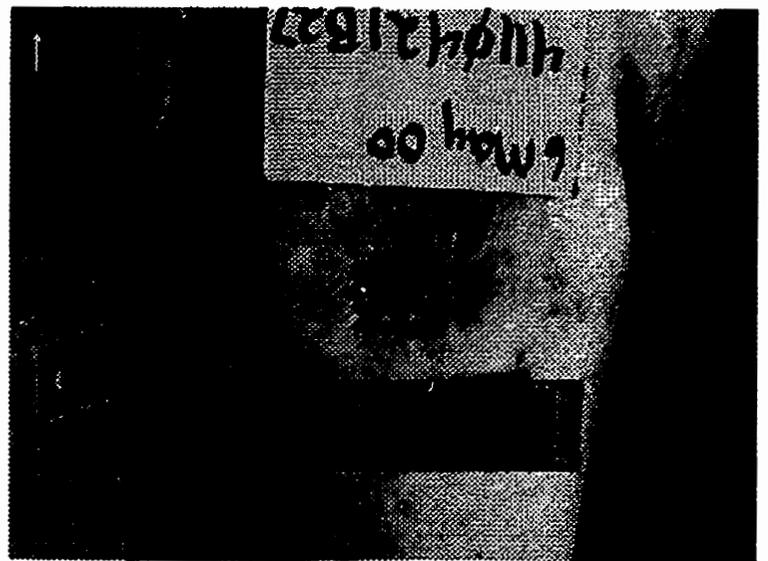


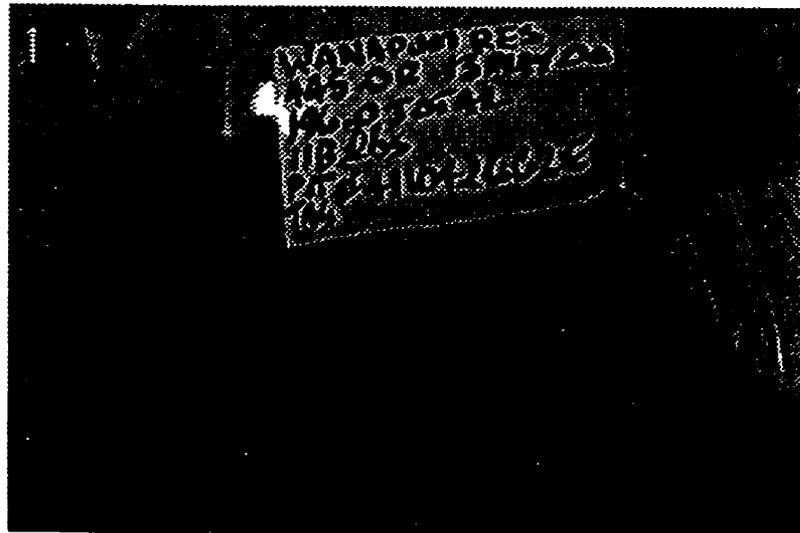
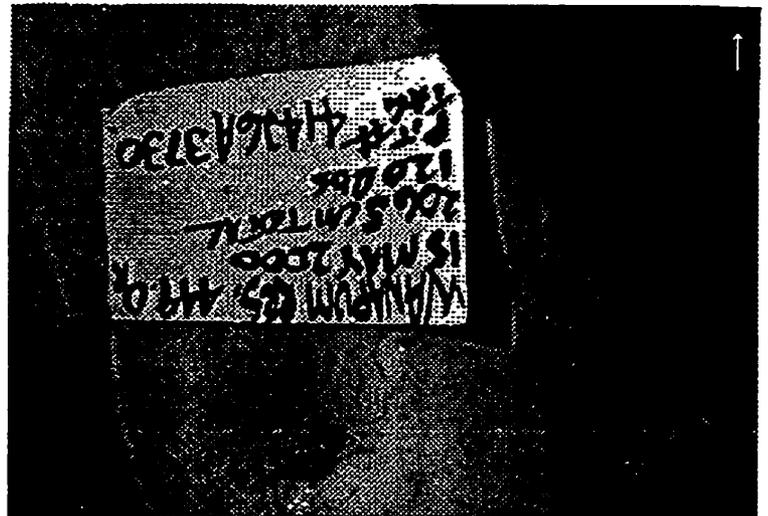
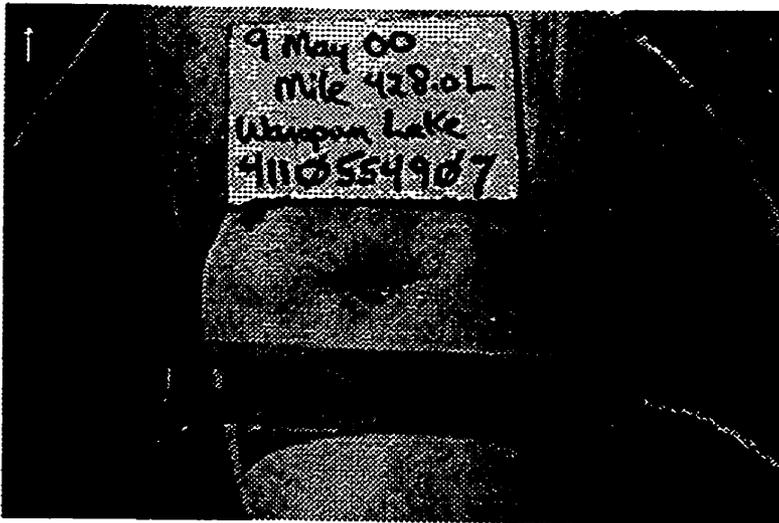
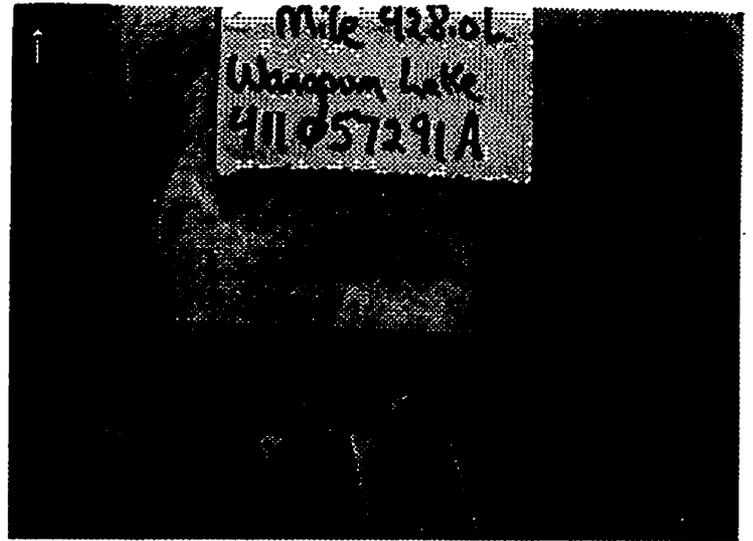
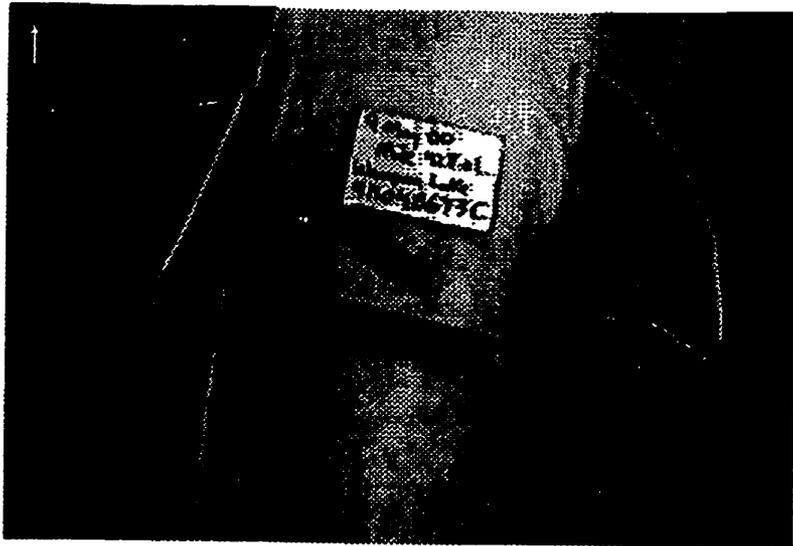
***A. oxyrinchus* (female)**

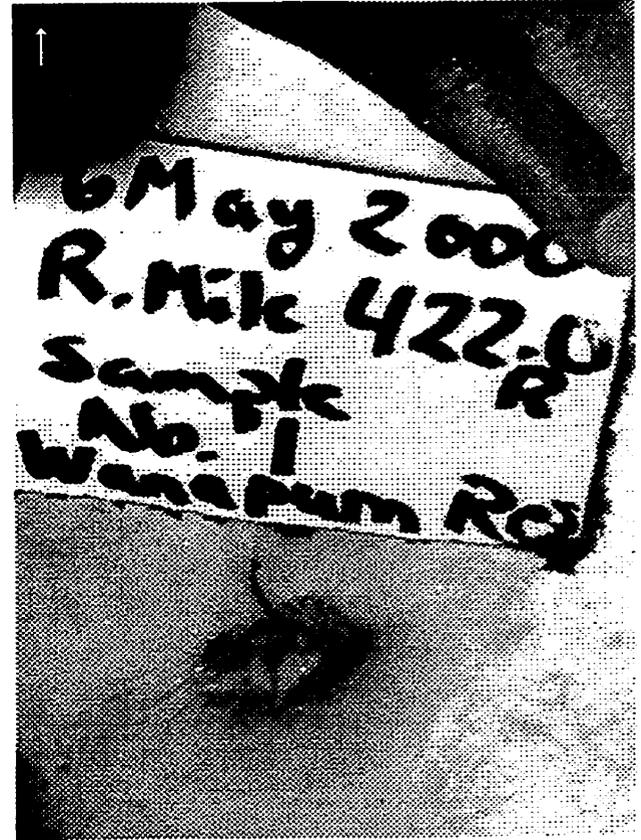
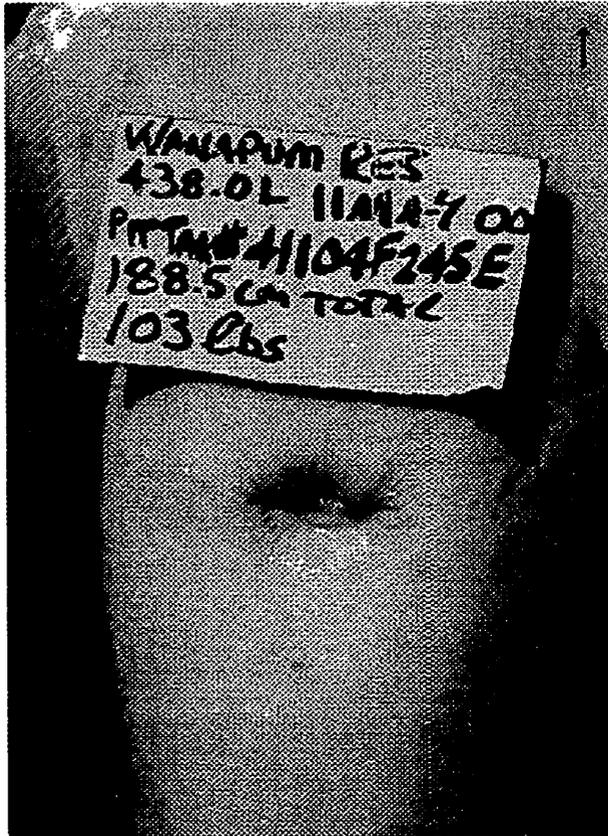
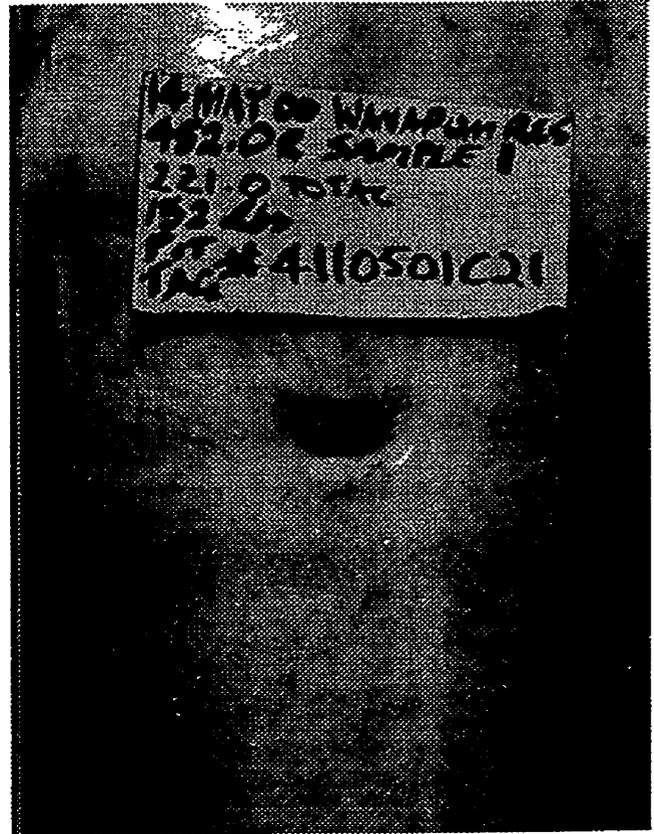
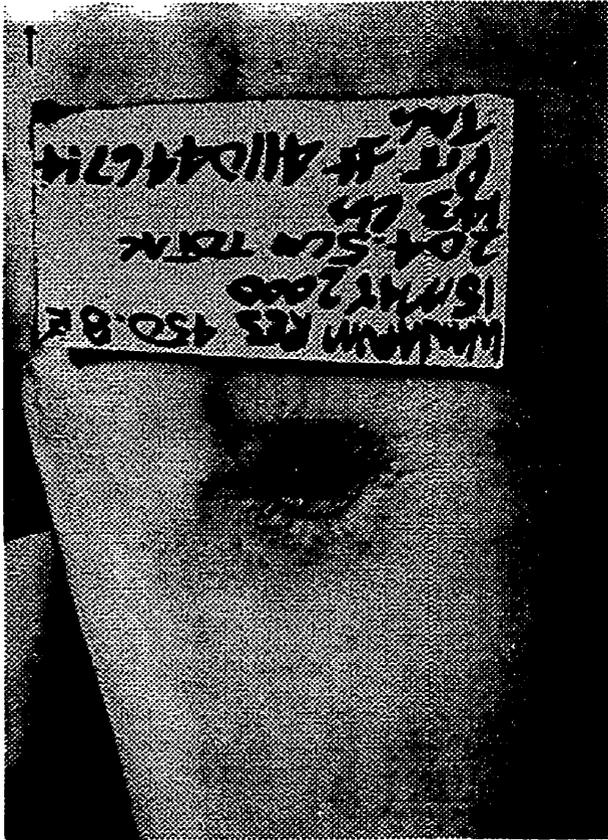


***A. oxyrinchus* (male)**

**Figure 5 - 2.** Photographic prints of white sturgeon used for double-blind test for determination of sex by external morphological features. The code number gives information on each fish in table







**Table 5 - 1. Results of inter-observer reliability testing of technique to distinguish female and male sturgeons from external morphology using photos by the author.**

Slide Number	Sex	# Correct/Incorrect	Certainty mean 1 most certain, 5 least certain
1	F	17 2	2.3
2	M	19 0	1.0
3	F	18 1	1.5
4	M	14 5	3.0
5	F	18 1	1.9
6	F	15 4	2.3
7	M	17 2	2.2
8	M	12 7	2.4
9	M	5 14	2.2
10	M	12 7	2.0
11	F	15 4	1.7
12	F	18 1	1.3
13	F	1 18	1.8

Table 5 - 2. Results of double blind test of technique to distinguish female and male white sturgeon from external morphology.

Photo Number	Sex	Correct/Incorrect		Certainty mean
				1 most certain 3 least certain
1	F	1	27	1.1
2	M	13	15	1.9
3	M	1	27	1.1
4	F	4	25	1.5
5	F	3	24	1.6
6	F	1	27	1.2
7	M	3	25	1.3
8	F	4	24	1.3
9	F	20	8	1.7
10	F	16	12	2.3
11	M	27	1	1.7
12	F	1	27	1.3
13	F	24	4	2.0
14	M	9	19	2.1

The results of observers scores of the R L & L photographs are summarized in Table 5 - 2. A total of 28 observers participated in this test. In general, observers' scores of the photographic prints sent by RL & L Consultants differed drastically from tests I conducted with my slides. I scored 35.7% of the photographs correctly, 23.3% correct for females and 60% correct for males. Other subjects scored only 30.8% of the photographs correctly. Of these, 37.5% of the females were correctly sexed and 40% of males were correctly sexed. I tested for concordance in the scores of all observers with a Kappa statistic test (Siegel & Castellan 1989). There were no significant differences in the assessments of individual fish by different observers for the first test using my slides, ( $z=1.20$ ,  $p=0.11$ ). However, in the test using photos supplied by RL & L, there was significant disagreement among respondents, ( $z=1.65$ ,  $p=0.05$ ).

#### **5.4 Discussion**

The results from the three different tests of my hypothesis initially appear somewhat confusing, but a clear pattern does nonetheless emerge. It is important to understand that there are two different, but related questions to be resolved concerning my hypothesis. The first is whether or not it is possible to determine the sex of sturgeon using the technique I propose. Only if the answer to the first question is "yes", can the second question be addressed. The second question is how generally can the technique be applied.

The results of my observations of live and recently dead sturgeon under field conditions show that it is indeed possible to determine the sex of live adult sturgeon. However, the probability of assigning the correct sex to a given

individual appears to be significantly influenced by whether or not the animal is alive at the time of examination. There may also be some differences in the probability of successfully identifying sex of individuals in different species (size being a factor), but that effect is clearly less important than whether the fish are alive or dead at the time of examination. Overall, it is clear that the technique is successful, and therefore potentially useful. The sex of live adult sturgeon can be determined with a high degree of certainty by non invasive examination of the external urogenital opening.

It could be argued that my direct examination of live and recently dead sturgeon in the field is susceptible to several potential sources of bias. My judgment of the sex of a given individual could be influenced by the overall size of the fish, the apparent degree of distention of the body cavity, body coloration, or any of a host of potential cues. I could also be influenced by the comments or opinions of others` working with me in the field. I could also tend to balance numbers of females and males in my estimates, on the presumption that both sexes would be more or less equally represented in the catches. This does not assume that I have any conscious bias, it simply presumes that I could be subject to any of those influences. So although the data show clearly that I have a high degree of success in judging the sex of live adult sturgeons in the field, the question remains as to how generally this technique can be applied. The fact that I had a very low probability of successfully determining the sex of recently dead sturgeon in the field argues against these biases. In any event, I have the results of two additional tests of my hypothesis, and my methodology.

The general applicability of my technique can be addressed by testing the procedure with other observers. The results of the first test using my photos confirm that indeed the technique can be used to judge the sex of sturgeon, even from slides. However, the probability of successfully judging the sex of individual sturgeon by other observers was not as good as when I examined live fish. There are several possible reasons for the lower success rate by other observers. First, none was experienced as I am in terms of capturing, handling and examining sturgeon. Therefore they might have a lower success rate than I for this reason alone, even if they were to examine live sturgeon. Second, they were only viewing slides, and those slides may have been less perfect than the real fish in terms of displaying the differences between males and females. Alternatively this indicates that I am cueing in on other traits unknowingly. Nonetheless, these results argue that not only can the technique be applied successfully, it apparently can be applied by people with relatively little knowledge or experience of sturgeons, with minimal instructions.

The second test of the applicability of my technique was a double blind test and relied on photos provided by others. The field biologists who photographed the white sturgeon had no knowledge of the features to be examined, nor the purported differences between males and females. They were also not given any special instructions for displaying the urogenital opening or for taking of pictures. The photographic prints shown to the observers were identified only by code numbers, and showed only the immediate area surrounding the urogenital opening of the fish. Thus, the observers could not possibly be biased

by any other features of the fish, or their surrounding or the conditions of their capture. I also acted as a subject in this double blind test, to compare my responses to those of (more or less) naïve observers.

My score on the double blind test gave a slightly higher probability of successfully assigning sex of individual sturgeon than that of more naïve observers. However, even my success rate was significantly below that of observers judging my slides, and far below my success rate when observing live fish in the field. The probability of successfully identifying the sex of individual sturgeon by other observers in the double blind test was very low, even less than would be predicted on the basis of guessing (assuming that the actual sex ratio of fish in the sample was 1:1). These results lead me to the following conclusions.

My non invasive technique to determine sex of adult sturgeon is successful, and can be applied under field conditions but only by an experienced observer. Photographic records (in this case slides) taken from live fish under field conditions can be used to judge the sex of the fish, but with less certainty than for live fish. However, to use photographs, particular care must be taken to fully expose the urogenital opening of each fish in the photograph, and if possible to displace the anal opening anteriorly. This will maximize the exposure of the urogenital opening and accentuate the features characteristic of females and males. It would be a matter for judgment in each case to decide if the probability of successfully judging the sex of sturgeon from careful photographs is acceptable in particular circumstances.

My conclusions are further strengthened by the detailed results of the double blind test. As an experienced observer I had a higher probability of successfully identifying the sex of sturgeon than did the naïve observers, but the probability was significantly lower than for slides I had taken myself, and very much less than for my direct observations of live fish. Again, it would be a matter of judgment to decide if this lower probability of successfully assigning sex of individuals would be acceptable in a particular case. There could be several reasons for accepting a lower success rate in particular circumstances. Photographs could be taken by a number of field personnel, and then judged at some later date by one experienced observer. The time, effort and cost to train or hire experienced observers could be traded against a decreased probability of success in judging sex. There might well be other such reasons for accepting a lower probability of successfully judging the sex of sturgeon from photographs, but I need not detail them here. They would have to be justified in each case, and the reduced certainty of determination of sex of the fish would have to be carefully weighed against any possible benefits to be gained.

From the results of my double blind test, it becomes evident that it is not acceptable to have untrained personnel taking the original photographs, and to have untrained observers judging the resulting photographs. As we have seen, this combination is the worst case scenario. The probability of successfully judging the sex of individual sturgeon under those circumstances is far below chance, and is unacceptable under any conditions.

The conclusions to be drawn from this, however, are potentially informative and constructive. My preliminary results suggest that this technique can be applied successfully only to live sturgeon, or photographs of live sturgeon. The best possible situation is to have a trained, experienced observer in the field to observe live sturgeon. The next best situation is to have good photographs of live sturgeon, taken by an experienced photographer who also knows the features of the urogenital region to be shown in the photographs. Photographs, or slides, should be viewed and judged by an experienced observer to give the highest possible probability of success in judging sex of the fish. Any departure from these “best practices” will result in reduced probabilities of success in judging the sex of live sturgeon.

The training required for observers is relatively straightforward, and would have to include repeated testing and practice with live fish, or photographs, of fish of known internal sex. This training could be repeated until the observers reached some specified criterion of success in judging sex of known individual fish. The training required for photographers, or observers in the field would be similar, except that photographers obviously need to be competent in the basic mechanics of taking photographs under demanding field conditions. The photographic prints provided by Louise Porto for my double blind test were of uniformly high technical quality. All were clearly in focus, illumination was uniform and sufficient detail could be observed. Even modern “point and shoot” cameras are sophisticated enough to ensure a high enough standard of pictures. Thus it would seem that it is not a major task to train field biologists to take acceptable

photographs of sturgeons during routine field sampling. The only significant limitation of those photographs was how small the urogenital opening appeared on some of the photos and exposure of the details of the urogenital openings of the fish. It would take some additional training to produce photographs that allowed an acceptable probability of success in assigning sex to individual fish. Again, this could be determined empirically, and testing of the training procedure would be straightforward. Thus, there are 2 aspects to good photos: 1) mechanics of the picture, 2) preparation of the specimen.

## **General Conclusions**

The possibility of sexing sturgeons based on external morphology provides numerous opportunities for management and conservation. So far, the technique yielding greatest accuracy would seem to be fiber optic probe inserted into the fish. While this technique is termed minimally invasive, any struggle during the procedure may damage the delicate endoscope and associated equipment (Murray et al. 1998). It is thus recommended to use the anesthetic tricaine methanesulfonate (MS-222). The disadvantage to MS-222 is that one of its compounds, tricaine which is inherently acidic in the aqueous solution. While there is enough buffering capacity in sea water to ameliorate the effects, when used in freshwater, a buffer must be used in order to avoid substantial irritant effects to the gills. It is possible to over anesthetize a fish and the application of this procedure requires the confines of a laboratory is not a 'field-friendly' approach. In gravid females, there is much less working space for the endoscope, therefore care must be taken to avoid damaging the ovary or the ventrally displaced colon (Murray et al. 1998). The overall cost of endoscopes and related instruments is approximately \$10, 000 and is thus not part of the hardware possessed by anyone except a few universities and researchers (M. Taylor pers. comm.). Other concerns about MS-222 include high cost (Keene et al. 1998). It has not been approved for exposure to humans, especially in food, so fish exposed to MS-222 cannot be used for human consumption for several weeks thereafter.

Laboratory analyses of sturgeon blood plasma can be highly accurate depending on the source population and the fish's maturity (G. Feist, pers. comm.). This too is a very expensive procedure and requires highly qualified personal. This technique is also not possible under field conditions requiring rapid identification of sex in large samples. Work with chemistry of sturgeon urine also holds promise as a non-invasive technique but this procedure will likely involve laboratory analysis and specialized equipment not amenable to field conditions.

A means of sex determination based on external morphology that can be deployed in the field on a real-time basis has obvious advantages. No sturgeon would be subjected to the trauma of being handled out of water, often at very high temperatures. External sexing requires no incision through the body wall, nor any expensive equipment.

With a high rate of success in identifying the sex of sturgeons via visual means, a selective means of harvest would be possible. The introduction of upper size limits followed by slot size limits in the harvest of white sturgeon on the Columbia has aided greatly in rebuilding stocks (Rieman & Beamesderfer 1990). To ensure a greater survival of females, a slot size or numbers quota could be introduced for females. Based on the results from the questionnaire done by volunteers, it seems this method has the potential of a high degree of accuracy, and demonstrates that this method of sexing fish is easily taught. Posters can be handed out to all registered commercial fisherman and in areas where there is sturgeon angling, information charts can be included in fishing

regulations or with annual licensee purchases. In areas where sturgeon are caught by anglers or are subject to commercial exploitation, fisheries biologists can assess the sex ratio and population structure of each sex. Using this non-invasive sex determining technique would allow collection of data from fish which are not necessarily killed. Information concerning this non invasive sexing techniques can be posted electronically on the World Wide Web.

## References cited

- Ambroz, A. I. 1964. Osetry severo-zapadnoi chasti Chernogo morya. Trudy VNIRO. 52: 287-347. Cited in: Holcik, J. (ed.) 1989. The freshwater fishes of Europe. Vol. 1, part II. General introduction to fishes Acipenseriformes. AULA-Verlag Wiesban.
- Artyukhin, E., I. A. Barannikova & A. G. Romanov. 1999. Russian strategies for conservation and reproduction of rare and common Caspian sturgeon species. Journal of Applied Ichthyology 15: 191-192.
- Artyukhin, E. & Z. G. Zarkua. 1986. On the problem of taxonomic rank of the sturgeon from the Rioni River (the Black Sea basin). Voprosy Ikhtiologii 26: 61-67. In: Holcik, J. (ed.) 1989. The freshwater fishes of Europe. Vol. 1, part II. General introduction to fishes Acipenseriformes. AULA-Verlag Wiesban.
- Artyukhin, E. & P. Vecsei. 1999. On the status of Atlantic sturgeon: conspecificity of European *Acipenser sturio* and North American *Acipenser oxyrinchus*. Journal of Applied Ichthyology 15: 35-37.
- Auer, N. B. 1996. Response of spawning lake sturgeon to change in hydroelectric facility operation. Transactions of the American Fisheries Society. 125: 66-77.
- Babushkin, N. Y. 1964. Biologiya i promysel kaspiskoi belugi. Trudy VNIRO 52: 183-258. Cited in: Holcik, J. (ed.) 1989. The freshwater fishes of Europe. Vol. 1, part II. General introduction to fishes Acipenseriformes. AULA-Verlag Wiesban.

- Bacalbasa-Dobrovici, N. 1997. Endangered migratory sturgeons of the lower Danube River and its delta. *Environmental Biology of Fishes* 48: 201-207.
- Balon, E. K. 1977. Reproductive guilds of fishes: a proposal and definition. *Journal of the Fisheries Research Board of Canada* 32: 35 - 37.
- Balon, E. K. 1995. The common carp, *Cyprinus carpio*: its wild origin, domestication in aquaculture, and selection as colored nishikigoi. *Guelph Ichthyology Reviews*. 3: 1-55.
- Balon, E. K. & M. N. Bruton. 1994. Fishes of the Tatinga River, Comoros, with comments on freshwater amphidromy in the goby, *Sicyopterus lagocephalus*. *Ichthyological Explorations in Freshwaters*. 5: 25-40.
- Balon, E. K., M. N. Bruton & H. Fricke. 1988. A fiftieth anniversary reflection on the living coelacanth, *Latimera chalumnae*: some new interpretations of its natural history and conservation status. *Environmental Biology of Fishes*. 15: 243-271.
- Balon, E. K., D. L. G. Noakes & M. T. Rush. 1999. Principles of Ichthyology. 6<sup>th</sup> Edition. Institute of Ichthyology, College of Biological Science, University of Guelph. 400 pp.
- Beamish, F. W. H., J. Jebbink, A. Rossiter & D. L. G. Noakes. 1996. Growth strategy of juvenile lake sturgeon, *Acipenser fulvescens*, in a northern river. *Canadian Journal of Fisheries & Aquatic Sciences* 53: 481-489.
- Bemis, E. W., E. K. Findeis & L. Grande. 1997. An overview of Acipenseriformes. *Environmental Biology of Fishes*. 48: 25-71.

- Bemis, E. W., & B. Kynard. 1997. Sturgeon rivers: an introduction to acipenseriform biogeography and life history. *Environmental Biology of Fishes*. 48: 167-183.
- Berg, L. S. 1962. *Freshwater fishes of the U. S. S. R. and adjacent countries*. Israel Program for Scientific Translations, Jerusalem. 504 pp.
- Berra, T. M. 1997. Some 20<sup>th</sup> century fish discoveries. *Environmental Biology of Fishes*. 50: 1-12
- Binkowski, F. P. & S. I. Doroshov. (ed.) 1985. *North American sturgeons: biology and aquaculture potential*. Dr. W. Junk, Dordrecht. 163 pp.
- Birstein, V. J., Poletaev, A. I. & Goncharov, B. F. 1993. DNA content in Eurasian sturgeon species determined by flow cytometry. *Cytometry*. 14: 377-383.
- Birstein, V. J., W. E. Bemis & J. R. Waldman. 1997. The threatened status of acipenseriform species: a summary. *Environmental Biology of Fishes* 48: 427-435.
- Bond, A. R., P. P. Micklin & M. J. Sager. 1992. Lake Balkhash dwindling, becoming increasingly saline. *Post-Soviet Geography*. 33: 131-134.
- Boreman, J. 1997. Sensitivity of North American sturgeons and paddlefish to fishing mortality. *Environmental Biology of Fishes* 48: 399-405.
- Brennan, J. S. & G. M. Cailliet. 1989. Comparative age - determination techniques for white sturgeon in California. *Transactions of the American Fisheries Society* 118: 296-310.

- Cacutt, I. 1979. British freshwater fishes. Croom Helm, London. In: Holcik, J. (ed.) 1989. The freshwater fishes of Europe. Vol. 1, part II. General introduction to fishes Acipenseriformes. AULA-Verlag Wiesban.
- Caron, F. & S. Tremblay. 1999. Structure and management of an exploited population of Atlantic sturgeon (*Acipenser oxyrinchus*) in the St. Lawrence Estuary, Quebec, Canada. *Journal of Applied Ichthyology*. 15: 153-156.
- Chebanov, M. S. , E. A. Savelyeva. 1999 New strategies for brood stock management of sturgeon in the Sea of Azov basin in response to changes in patterns of spawning migration. *Journal of Applied Ichthyology* 15: 183-190.
- Conte, F. S., S. I. Doroshov, P. B. Lutes & E. M. Strange. 1988. Hatchery manual for the white sturgeon *Acipenser transmontanus* Richardson with application to other North American Acipenseridae. Number 3322 from ANR Publications, Department AQ, 6701 San Pablo Avenue, Oakland, California. 120 pp.
- Debus, L. 1995. Zur Systematik der Stoere. *Fischer & Teichwissenschaften*. 8: 281-285.
- De Meulenaer, T. & C. Raymakers. 1996. Sturgeons of the Caspian Sea and the international trade in caviar. TRAFFIC International, Cambridge. 71 pp.
- Doroshov, S. I., H. Clark Jr., P. B. Lutes, R. L. Swallow, K. E. Beer, A. B. McGuire & M. D. Cochran. 1983. Artificial propagation of white sturgeon, *Acipenser transmontanus* Richardson. *Aquaculture* 32: 93-104.

- Dragomirov, N. I. 1961. Ekologo-morphologicheskie osobennosti lichinocnogo razvitiya belugi *Huso huso* (L.). Trudy Instituta morfologii zhivotnykh Akad. Nauk SSSR 33: 72-93. Cited in: Holcik, J. (ed.) 1989. The freshwater fishes of Europe. Vol. 1, part II. General introduction to fishes Acipenseriformes. AULA-Verlag Wiesban.
- Dumont, P., R. Fortin, G. Desjardins & M. Bernard. 1987. Biology and exploitation of the lake sturgeon (*Acipenser fulvescens*) in the Quebec waters of the Saint-Laurent River. pp 57-76. In: C. H. Olver (ed.) Proceedings of a workshop on Lake Sturgeon (*Acipenser fulvescens*). Ontario Fisheries Technical Report Series No. 23
- Ferguson, M. M. & G. Duckworth, 1997. The status and distribution of lake sturgeon, *Acipenser fulvescens*, in the Canadian provinces of Manitoba, Ontario and Quebec: a genetic perspective. Environmental Biology of Fishes. 48: 299-309.
- Fernandez-Pasquier, V. 1999. *Acipenser sturio* L. in the Guadalquivir river, Spain. Water regulation and fishery as factors in stock decline from 1932 to 1967. Journal of Applied Ichthyology 15: 133-135.
- Findeis, E. K. 1997. Osteology and phylogenetic interrelationships of sturgeons (Acipenseridae). Environmental Biology of Fishes. 48: 73-126.
- Galis, F. & J. A. J. Metz. 1998. Why are there so many cichlid species? Trends in Ecology and Evolution. 13: 1-2.
- Giurescu, C. C. 1964. Istoria pescuitului si a pisciculturii in Romania. Editura Academiei Rep. Pop. Rom. Bucuresti. pp 281-390. Cited in: Holcik, J.

- (ed.) 1989. The freshwater fishes of Europe. Vol. 1, part II. General introduction to fishes Acipenseriformes. AULA-Verlag Wiesban.
- Goode, G. B. 1884-87. The Fisheries and Fishery Industries of the United States, 7 vols. Washington, Government Printing Office.
- Goyette, D, S. Guenette, N. Fournier, J. Leclerc, G. Roy, R. Fortin, & P. Dumont. 1988. Maturité sexuelle et périodicité de la reproduction chez la femelle de l' esturgeon jaune (*Acipenser fulvescens*) du fleuve Saint-Laurent. Rapport de travaux 06-02. Service Aménagement Exploitation Faune. 77 pp.
- Guerrero, R. D. III. 1982. Control of tilapia reproduction. Pp. 309-316. In: R. S. V. Pullin & R. H. Lowe, McConell (ed.). The biology and culture of tilapia. ICLARM, Manila.
- Grande, L. & W. E. Bemis. 1991. Osteology and phylogenetic relationships of fossil and recent paddlefishes (Polyodontidae) with comments on the interrelationships of the Acipenseriformes. Journal of Vertebrate Paleontology 11. Suppl. Soc. Vert. Paleontol. Mem. 1: 121 pp.
- Groot, C. & L. Margolis (ed.) 1991. Pacific salmon life histories. University of British Columbia Press, Vancouver. 564 pp.
- Hamlett, W. C. (ed.) 1999. Sharks, Skates, and Rays. The biology of elasmobranch fishes. The Johns Hopkins University Press. 516 pp.
- Harkness, W. J. K. & J. R. Dymond. 1961. The lake sturgeon. The history of its fishery and problems of conservation. Ontario Department of Lands Forests, Fish Wildlife Branch. 121 pp.

- Helfman, G. S. , B. B. Collette & D. S. Facey. 1998. Diversity of fishes. Blackwell, New York. 528 pp.
- Hensel, K. & J. Holcik. 1997. Past and current status of sturgeons in the upper and middle Danube River. *Environmental Biology of Fishes* 48: 185-200.
- Hochlechner, M.1999. The sturgeons and paddlefishes (*Acipenseriformes*) of the world. Aquatech Publications, Vienna. 163 pp.
- Holcik, J. (ed.) 1989. The freshwater fishes of Europe. Vol. 1, part II. General introduction to fishes Acipenseriformes. AULA-Verlag Wiesban. 469 pp.
- Houston, J. J. 1987. Status of the lake sturgeon (*Acipenser fulvescens*) in Canada. *Canadian Field-Naturalist* 101: 171-185.
- Idler, D. R., S. J. Hwang, L. W. Crim & D. Reddin. 1981. Determination of sexual maturation stages of Atlantic salmon (*Salmo salar*) captured at sea. *Canadian Journal of Fisheries and Aquatic Sciences*. 38: (4) 405-413
- Ivanov, V. P., A. D. Vlasenko, R. P. Khodorevskaya & V. M. Raspopov. 1999. Contemporary status of Caspian sturgeon (*Acipenseridae*) stock and its conservation. *Journal of Applied Ichthyology* 15: 103-105.
- Keene, J. L., D. L. G. Noakes, R. D. Moccia & C. G. Soto. 1998. The efficacy of clove oil as an anaesthetic for rainbow trout, *Oncorhynchus mykiss* (Walbaum). *Aquaculture Research*. 29: 89-101.
- Keenlyne, K. D. 1997. Life history and status of the shovelnose sturgeon, *Scaphirhynchus platyrhynchus*. *Environmental Biology of Fishes* 48: 291-298.

- Khodorevskaya, R. P., G. F. Dovgopol, O. L. Zhuravlena & A. D. Vlasenko. 1997. Present status of commercial stocks of sturgeons in the Caspian Sea basin. *Environmental Biology of Fishes* 48: 209-219.
- Kinzelbach, R. 1987. Das ehemalige Vorkommen des Stors, *Acipenser sturio* (Linnaeus, 1758) im Einzugsgebiet des Rheins (Chondrostei: Acipenseridae). *Zeitschrift f. Angewandte Zoologie* 74: 167-200 Cited in: Holcik, J. (ed.) 1989. The freshwater fishes of Europe. Vol. 1, part II. General introduction to fishes Acipenseriformes. AULA-Verlag Wiesban.
- Krykhtin, M. L. 1979. The modern state and perspectives of development of the sturgeon fishery in the Amur River Basin. Pp. 68-74. In: *Biological Foundations of Development of the Sturgeon Fishery in the Water Bodies of the USSR*, Nauku Press, Moscow
- Krykhtin, M. L. & V. G. Svirskii. 1997. Endemic sturgeons of the Amur River: *Huso dauricus*, and Amur sturgeon, *Acipenser schrenkii*. *Environmental Biology of Fishes* 48: 231-239.
- Kynard, B. 1997. Life history, latitudinal patterns, and status of the shortnose sturgeon, *Acipenser brevirostrum*. *Environmental Biology of Fishes* 48: 319-334.
- Lane, E. D. 1991. Status of the white sturgeon, *Acipenser transmontanus*, in Canada. *Canadian Field-Naturalist* 105: 161-168.
- LeBreton, G. T. O. 1999. Lake sturgeon growth chronologies. Ph.D. Dissertation, University of Guelph, 255 pp.

- Le Breton, G. T. O. & F. W. H. Beamish. 1998. The influence of salinity on ionic concentrations and osmolality of blood serum in lake sturgeon, *Acipenser fulvescens*. *Environmental Biology of Fishes*. 52: 477-482.
- Logan, S. H., W. E. Johnston & S. I. Doroshov. 1995. Economics of joint production of sturgeon (*Acipenser transmontanus* Richardson) and roe for caviar. *Aquaculture* 130: 299-316.
- Lytwyn, V. P. 1990. Ojibwa and Ottawa fisheries around Manitoulin Island: historical and geographical perspectives on aboriginal and treaty fishing rights. *Native Studies Review*. 6: 1-30.
- Martin, P. & P. Bateson. 1993. *Measuring behavior. An introductory guide*. Second edition. Cambridge University Press. 222 pp.
- Mayden, R. L. & B. R. Kuhajda. 1997. Threatened fishes of the world: *Scaphirhynchus albus* (Forbes & Richardson, 1905) (Acipenseridae). *Environmental Biology of Fishes* 48: 420-421.
- McDowall, R. M. 1987. The occurrence and distribution of diadromy among fishes. *American Fisheries Society Symposium*. 1: 1-13.
- McDowall, R. M. 1988. *Diadromy in fishes. Migrations between freshwater and marine environments*. Croom Helm, London. 308 pp.
- McDowall, R. M. 1992. Diadromy: origins and definition of terminology. *Copeia* 1992: 248-251.
- McLeod, C., L. Hildebrand & D. Radford. 1999. A synopsis of lake sturgeon management in Alberta, Canada. *Journal of Applied Ichthyology* 15: 173-179.

- Murray, M. J., B. Schildger & M. Taylor. 1998. Endoscopy in birds, reptiles, amphibians and fish. Endo Press, Tuttligen. 86 pp.
- Needs – Howerth, S. J. 1999. Native fishing in the Great Lakes – A multidisciplinary approach to zooarchaeological remains from precontact Iroquoian villages near Lake Simcoe, Ontario. Doctoral Thesis. Groningen University.
- Pauley, G. B. 1991. Anadromous trout. In: Trout. J. Stolz & J. Schnell (eds.) Stackpole Books. 370 pp.
- Qiwei, W., F. Ke, J. Zhang, P. Zhuang, J. Luo, R. Zhou & W. Yang. 1997. Biology, fisheries, and conservation of sturgeons and paddlefish in China. *Environmental Biology of Fishes* 48: 241-255.
- Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. *Bulletin of the Fisheries Research Board of Canada*. No. 191.
- Rieman, B. E. & R. C. Beamesderfer. 1990. White sturgeon in the lower Columbia River: is the stock overexploited? *North American Journal of Fisheries Management* 10: 388-396.
- Rien, T. A. & R. C. Beamesderfer. 1994. Accuracy and precision of white sturgeon age estimates from pectoral fin rays. *Transactions of the American Fisheries Society* 123: 255-265.
- Ruban, G. I. 1997. Species structure, contemporary distribution and status of the Siberian sturgeon, *Acipenser baerii*. *Environmental Biology of Fishes* 48: 221-230.

- Ruban, G. I. 1996. The Siberian Sturgeon, *Acipenser baerii baerii*, population status in the Ob River. *The Sturgeon Quarterly* 4: 8-10.
- Salnikov, V. B., V. J. Birstein & R. L. Mayden. 1996. The contemporary status of the two Amu-Darya River shovelnose sturgeons, *Pseudoscaphirhynchus kaufmanni* and *P. hermanni*. *The Sturgeon Quarterly* 4: 10-14.
- Schmalhausen. O. I. 1991. Prelarval development of *Pseudoscaphirhynchus kaufmanni*. *Soviet Journal of Developmental Biology*. 22: 296-302.
- Scott, W. B. & E. J. Crossman. 1973. *Freshwater fishes of Canada*. Bulletin 184, Fisheries Research Board of Canada, Ottawa. 966 pp.
- Siegel, S. 1956. *Nonparametric statistics for the behavioral sciences*. McGraw-Hill Kogakusha, 304 pp.
- Sokolov, L. I. & Berdichevskii, L. S. 1989. Acipenseridae Bonaparte, 1831. The freshwater fishes of Europe. pp 285-293. J. Holcik ed. Vol. 1, part II. General introduction to fishes Acipenseriformes. AULA-Verlag Wiesban.
- Sokolov, L. I. & M. I. Shatunovsky (ed.) 1983. *Fishes of the Mongolian Peoples Republic*. Nauka Press, Moscow. 277 pp. Cited in: Holcik, J. (ed.) 1989. The freshwater fishes of Europe. Vol. 1, part II. General introduction to fishes Acipenseriformes. AULA-Verlag Wiesban.
- Sokolov, L. I. & E. A. Tsrpkin. 1971. Sterlyad' *Acipenser ruthenus* L. v srednem i pozdnem golotsene. *Byulleten' MOIP, otdel biologicheskii* 76: 137-145. Cited In: Holcik, J. (ed.) 1989. The freshwater fishes of Europe. Vol. 1, part II. General introduction to fishes Acipenseriformes. AULA-Verlag Wiesban.

- Stewart, H. 1977. Indian Fishing, Early Methods on the Northwest Coast. The University of Washington Press. 181 pp.
- Taub, S. H. Fishery management plan for Atlantic sturgeon, *Acipenser oxyrinchus*. Fish and Wildlife Service U. S. Department of the Interior, Washington D. C. 20240
- Vecsei, P. 1999. Illustrating sturgeon species: the art of science in highlighting morphological features. *Journal of Applied Ichthyology* 15: 7-8.
- Vladykov, V. D. 1931. Poissons de la Russie Sous-Carpathique (Tchecoslovaquie). *Mem. Soc. Zool. France* 29: 217-374. Cited in: Holcik, J. (ed.) 1989. The freshwater fishes of Europe. Vol. 1, part II. General introduction to fishes Acipenseriformes. AULA-Verlag Wiesban.
- Wei, Q., F. Ke, J. Zhang, P. Zhuang, J. Luo, R. Zhou & W. Yang. 1996. Biology, fisheries and conservation of sturgeons and paddlefish in China, *Environmental Biology of Fishes*. 48: 265-278.
- Wells, A. L. 1956. The observer's book of freshwater fishes of the British Isles. Frederick Warne & Co. Ltd., London. 153 pp.
- Wu, J. & M. S. Wu. 1990. Status and utilization of fisheries in Jingsha River. pp. 53-61. In: W. L. Huang (ed) Utilization and conservation of potamodromous fisheries in Sichuan Province. Sichuan Scientific & Technical Publishing House, Chengdu.
- Yegorov, A. G. 1961. Baikal sturgeon, *Acipenser baerii stenorrhynchus natio baicalensis* A. Nikolsky (taxonomy, biology, fishery, and reproduction of reserves), Ulan-Ude (USSR). 121 pp. Cited in: Holcik, J. (ed.) 1989. The

freshwater fishes of Europe. Vol. 1, part II. General introduction to fishes  
Acipenseriformes. AULA-Verlag Wiesban.

Zholdasova, I. 1997. Sturgeons and the Aral Sea ecological catastrophe.  
Environmental Biology of Fishes 48: 373-380.

## Appendices

**Table A - 1.** Sex of adult North American sturgeons as determined by external morphology and internal gonadal examination: white *Acipenser transmontanus*, Atlantic *A. oxyrinchus*, and shortnose *A. brevirostrum* sturgeons; green *A. medirostris*, not included (see text for details).

Species	Total length cm	Examined - Dead/Alive	Sex - external	Sex - gonadal
<i>A. brevirostrum</i>	88	A	F	F
	80	A	M	M
	98	A	F	F
	102	A	M	M
	106	A	F	F
<i>np</i>	96	A	F	M
<i>np</i>	90	A	M	F
<i>A. oxyrinchus</i>	192	A	M	M
	192	A	F	F
	180	A	M	M
	225	A	F	F
	167	A	M	M
<i>np</i>	152	A	M	M
<i>np</i>	192	A	F	F
<i>np</i>	163	A	M	M

**Table A - 1. Continued**

<i>A. oxyrinchus</i>	194	A	F	F
<i>np</i>	167	A	F	F
<i>np</i>	180	A	F	F
<i>np</i>	177	A	?	F
<i>np</i>	166	A	M	M
<i>np</i>	138	A	?	M
<i>np</i>	150	A	?	M
<i>np</i>	169	D	M	F
<i>np</i>	185	D	M	F
<i>np</i>	223	A	F	F
<i>np</i>	211	A	F	F
<i>A. transmontanus</i>	152	A	F	F
	144	A	M	M
	151	A	M	M
<i>np</i>	312	A	F	NC
	160	D	F	F
	163	D	M	M
<i>np</i>	165	A	F	F
<i>np</i>	163	D	F	M
<i>np</i>	158	D	M	F
<i>np</i>	155	D	M	F

**np** = Fish not photographed prior to dissection, **?** = unable to determine sex from external examination

**Table A - 2.** Score sheet used by subjects to test inter - observer reliability of sex determination technique.

Slide	Female	Male	Confidence
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			

**Table A - 3.** Summary of biological information on sturgeon species. Canadian species are indicated by asterisks (\*).

Scientific name	Common name	Age at maturity (years)	Size at maturity (total length - cm)
<i>Acipenser nudiventris</i>	Ship sturgeon	<b>M:</b> 6-13 <b>F:</b> 12-22	<b>M:</b> 90 <b>F:</b> 140
<i>Acipenser stellatus</i>	Stellate sturgeon	<b>M:</b> 4-13 <b>F:</b> 6-17	<b>M:</b> 105 <b>F:</b> 115
<i>Acipenser gueldenstaedtii</i>	Russian sturgeon	<b>M:</b> 11-13 <b>F:</b> 12-16	<b>M:</b> 90 <b>F:</b> 115
<i>Acipenser persicus</i>	Persian sturgeon	<b>M:</b> 8-15 <b>F:</b> 12-18	<b>M:</b> 110 <b>F:</b> 130
<i>Acipenser ruthenus</i>	Sterlet	<b>M:</b> 3-8 <b>F:</b> 4-14	<b>M:</b> 30 <b>F:</b> 35
<i>Acipenser sturio</i>	Common sturgeon	<b>M:</b> 7-13 <b>F:</b> 8-16	<b>M:</b> 120 <b>F:</b> 175
<i>Acipenser brevirostrum</i> *	Shortnose sturgeon	<b>M:</b> 6-14 <b>F:</b> 8-17	<b>M:</b> 50 <b>F:</b> 60
<i>Acipenser oxyrinchus</i> *	Atlantic sturgeon	<b>M:</b> 20-24 <b>F:</b> 24-28	<b>M:</b> 150 <b>F:</b> 175

<i>Acipenser medirostris</i> *	Green sturgeon	M: 10-12 F: 12-15	M: 95 F: 120
<i>Acipenser fulvescens</i> *	Lake sturgeon	M: 12-20 F: 18-33	M: 90 F: 100
<i>Huso huso</i>	Beluga	M: 10-14 F: 13-19	M: 155 F: 170
<i>Huso dauricus</i>	Kaluga	M: 14-21 F: 17-23	M: 165 F: 175
<i>P. kaufmanni</i>	Large Amu-Dar shovelnose	M: 5-7 F: 6-8	M: 25 F: 30
<i>P. hermanni</i>	Small Amu-Dar shovelnose	M: 5-7 F: 6-8	M: 20 F: 22
<i>S. albus</i>	Pallid sturgeon	M: 8-15 F: 10-17	M: 80 F: 95
<i>P. platorhynchus</i>	Shovelnose sturgeon	M: 7-9 F: 8-10	M: 45 F: 50
<i>P. suttkusi</i>	Alabama sturgeon	Unknown	Unknown
<i>A. transmontanus</i> *	White sturgeon	M: 10-15 F: 15-32	M: 120 F: 145

<i>A. sinensis</i>	Chinese sturgeon	<b>M:</b> 8-25 <b>F:</b> 14-26	<b>M:</b> 180 <b>F:</b> 220
<i>A. dabryanus</i>	Dabry's sturgeon	<b>M:</b> 4-7 <b>F:</b> 6-8	<b>M:</b> 75 <b>F:</b> 90
<i>A. baerii</i>	Siberian sturgeon	<b>M:</b> 17-24 <b>F:</b> 19-30	<b>M:</b> 90 <b>F:</b> 100
<i>A. schrenkii</i>	Amur sturgeon	<b>M:</b> 8-12 <b>F:</b> 8-14	<b>M:</b> 90-100 <b>F:</b> 95-140

**Table A - 4. RL&L catch summary of white sturgeon, *Acipenser transmontanus*, from Priest Rapids, Columbia River.**

River Mile <sup>a</sup>	Reservoir	Capture Date	Sex	Maturity <sup>b</sup>	Fork Length (cm)	Weight (kg)	Recaptured	Sonic Tag <sup>c</sup>	Sonic Tag # (Code)	PIT Tag #	Comments
422.0R	Wanapum	05/06/00	Male	2	188.0	69.5	No	Pinger	8069(10)	4110542969	Blood sample taken; gonad sample not available
423.1R	Wanapum	05/07/00	Female	11	152.5	40.9	No	Pinger	8061(2)	4110555711	No blood or gonad sample taken
426.0L	Wanapum	05/06/00	Male	3	194.5	69.1	No	Pinger	8072(13)	4110421B27	Gonad sample taken only
426.0L	Wanapum	05/06/00	Female	15	206.5	91.8	No	CHAT	8077(47)	411032637F	Eggs fully detached, filling 3/4 of ventral cavity; egg sample taken; eggs 3.0 mm diameter; no blood or gonad sample taken
426.0L	Wanapum	05/07/00	Male	3	183.0	59.8	No	None	None	41104F495B	Gonad sample taken only
426.0L	Wanapum	05/07/00	Male	4	199.5	77.7	No	CHAT	8078(63)	41105C7446	Testes filling over 3/4 of ventral cavity; lobing apparent in anterior 3/4 of testes (no black speckling); no gonad or blood sample taken
427.0L	Wanapum	05/06/00	Female	13	213.0	80.5	No	Pinger	8070(11)	411063223C	Blood and gonad sample taken
427.0L	Wanapum	05/06/00	Male	2	169.5	49.2	No	Pinger	8060(1)	41105B560E	Gonad sample taken only
427.0L	Wanapum	05/07/00	Male	4	180.0	63.0	No	None	None	4110530A02	No blood or gonad sample taken
427.0L	Wanapum	05/07/00	Male	3	193.0	61.6	No	None	None	411065755D	Blood and gonad sample taken
428.0L	Wanapum	05/09/00	Female	14	175.0	45.0	No	Pinger	8068(9)	4110554907	Gonad sample taken only
428.0L	Wanapum	05/09/00	Male	4	180.0	58.4	No	None	None	411057291A	No blood or gonad sample taken
428.0L	Wanapum	05/09/00	Female	13	227.0	117.7	No	Pinger	8071(12)	41104B673C	Gonad sample taken only
429.0R	Wanapum	05/08/00	Male	4	179.0	46.4	No	Pinger	8074(15)	411055676C	Blood and gonad sample taken
438.0L	Wanapum	05/11/00	Female	11	166.5	47.3	No	Pinger	8062(3)	41104F245E	No blood or gonad sample taken
438.9L	Wanapum	05/10/00	Female	13	220.0	97.3	No	Pinger	8067(8)	41105B634A	Blood and gonad sample taken
445.0R	Wanapum	05/13/00	Female	12	172.5	54.2	No	Pinger	8063(4)	41104262C2E	Gonad sample taken only
449.0R	Wanapum	05/15/00	Female	11	184.5	55.2	No	Pinger	8065(6)	41426A3730	Blood and gonad sample taken
450.0L	Wanapum	05/15/00	Male	3	152.5	29.5	No	None	None	41104E5812	No blood or gonad sample taken
450.8R	Wanapum	05/15/00	Female	14	180.0	65.7	No	CHAT	8075(15)	41104446714	Body cavity full of eggs, 2.9 mm in diameter; eggs fully pigmented; very fleshy fish; blood and gonad sample taken
452.0R	Wanapum	05/14/00	Male	4	196.0	71.3	No	Pinger	8066(7)	4110501C21	Blood and gonad sample taken

<sup>a</sup> R = Right bank as viewed facing downstream; L = Left bank as viewed facing downstream

<sup>b</sup> Maturity stages adapted from Conte et al. (1988). See Table 2 for code descriptions.

<sup>c</sup> Pinger = Simple sonic tag; CHAT = Communicating History Acoustic Transponder; None = No sonic tag applied

**Table A - 5. Sex maturity codes for white sturgeon sampled by RL&L.**

Sex	Code	Development State Description
Male	1	Non-reproductive, testes appear as thin strips with no pigmentation
	2	Maturing; small testes; some folding may be apparent; translucent, smoky pigmentation Early reproductive; large testes, folds beginning to form lobes; some pigmentation still present; testes more white than cream coloured
	3	
	4	Late reproductive; testes large, often filling posterior of body cavity; white with little or no pigmentation
	5	Ripe; milt flowing; large white lobular testes; no pigmentation
	6	Spent; testes pinkish-white, flaccid, and strongly lobed
	10	General unknown maturity
Female	11	Non-reproductive; ovaries small, folded with no visible oocytes; tissue colour white to yellowish Pre-vitellogenic, moderate size ovary with small eggs present (0.2 to 0.5 mm diameter); may have "salt and pepper" appearance
	12	
	13	Early vitellogenic; large ovary varying in colour from white to yellowish-cream to light grey; eggs 0.6 to 2.1 mm in diameter Late vitellogenic; ovaries large with pigmented oocytes still attached to ovarian tissue; eggs 2.2 to 2.9 mm in diameter; sometimes with salt and pepper appearance
	14	
	15	Ripe; eggs fully pigmented and easily detached from ovarian tissue; eggs 3.0 to 3.4 mm in diameter
	16	Spent; ovaries are flaccid with some residual fully developed eggs Pre-vitellogenic with atretic oocytes; small eggs (< 0.5 mm diameter) present; dark pigmented tissue present that may be reabsorbed eggs
	17	
	20	General unknown maturity
Unknown	97	Adult based on size, no surgical examination
	98	Juvenile/Sub-adult based on size, no surgical examination
	99	Gonad undifferentiated or not visible during surgical examination