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Maine Field Office – Ecological Services February 2012

Contaminants in Atlantic Sturgeon and Shortnose Sturgeon Recovered from the Penobscot and Kennebec Rivers, Maine

Fish and Wildlife Service

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Executive Summary

In the Gulf of Maine, the shortnose sturgeon (*Acipenser brevirostrum*) is a federally-listed endangered species and the Atlantic sturgeon (*Acipenser oxyrinchus*) is a recently listed threatened species. Between June and August 2006, six sturgeon were collected from the Penobscot River in Maine - two Atlantic sturgeon and three shortnose sturgeon died during scientific sampling activities and one shortnose sturgeon was killed by a seal. In July 2009, three shortnose sturgeon were recovered on the Kennebec River in Georgetown after a red tide event. A month later two more shortnose sturgeon were recovered further north in the Kennebec River near Phippsburg; apparent victims of seal predation. Shortnose and Atlantic sturgeon move seasonally between these two large Maine rivers and along the Maine coast to smaller rivers. Consequently, these fish may be exposed to contaminants from many sources. Very little contaminant information is available for both species of sturgeon in Maine.

Tissues from these 11 fish were submitted for contaminant analyses. Skinless, boneless fillets were analyzed from all eleven fish. Five liver and three gonad samples of fish recovered in the Penobscot River in 2006 were also analyzed. All sturgeon tissue samples were analyzed for 21 organochlorine compounds including polychlorinated biphenyl (PCB) and dichloro-diphenyl-trichloroethane (DDT), and 19 trace metals including mercury (Hg). Fillet samples of shortnose sturgeon recovered in the Kennebec in 2009 were also analyzed for polybrominated diphenyl ethers (PBDEs).

- Total PCB in sturgeon fillets ranged from below the detection limit (< 5.00 parts-per-billion, ppb) to 1,900.00 ppb wet weight. Five shortnose sturgeon had PCB fillet concentrations that would exceed suggested criteria for protecting fish-eating wildlife (120 ppb) and aquatic life (400 ppb).

- Total PBDE in five shortnose sturgeon fillets ranged from 4.4 ppb to 39.1 ppb. Congener BDE #47 was the greatest contributor to Total PBDE. The PBDE concentration range in Kennebec sturgeon was similar to a study that measured PBDE levels in wild-caught fish sold in fish markets and large-chain supermarkets (0.04 to 38 ppb).

- DDT metabolites and isomers were detected in all sturgeon samples, but at low levels compared to toxicity threshold levels and consumption action levels.

- Other organochlorine compounds in fillet samples were below detection limits or detected at low concentrations (~ 5 ppb).

- Mercury in fillets of shortnose sturgeon from the Penobscot and Kennebec (mean 0.49 parts-per-million, ppm; range: 0.19 to 1.00 ppm wet weight) were elevated compared to freshwater regional and national fish tissue bio-monitoring programs. Mercury levels in both Atlantic sturgeon fillets were 0.18 ppm. A suggested tissue threshold-effect concentration for mercury in whole-body fish is 0.20 ppm and the Maine Fish Tissue Action Level for consumption is also 0.20 ppm. Both Atlantic sturgeon and one shortnose sturgeon fillets were essentially at the mercury tissue threshold effect concentration and state Action Level. Eight shortnose sturgeon fillets exceeded the whole-body effect threshold concentration and Maine Action Level.

- Concentrations of 18 other trace metals in sturgeon tissue samples appeared consistent with levels reported in other sturgeon studies. The only exception was selenium in one fillet sample (2.40 ppm, wet weight) from a shortnose sturgeon recovered from the Kennebec River, which exceeded a suggested tissue effect threshold (2.00 ppm).

Keywords: Atlantic sturgeon, shortnose sturgeon, PCB, DDE, PBDE, mercury, Maine

TABLE OF CONTENTS

Page

Figure

List of Tables

Acronyms and Abbreviations

Al	aluminum
As	arsenic
B	boron
Ba	barium
BDE	brominated diphenyl ether
BDL	below detection limit
Be	beryllium
BHC	benzene hexachloride
Cd	cadmium
CGC	capillary gas chromatography
Cr	chromium
Cu	copper
DDD	dichloro-diphenyl-dichloroethane
DDE	dichloro-diphenyl-dicloroethylene
DDT	dichloro-diphenyl-tricloroethane
DEQ	Division of Environmental Quality (USFWS)
EPA	Environmental Protection Agency
ESA	Endangered Species Act
FDA	Food and Drug Administration
Fe	iron
FTAL	Fish Tissue Action Level (Maine)
g	gram
GERG	Geochemical and Environmental Research Group
GPL	GPL Laboratories LLC
HCB	hexachlorobenzene
Hg	mercury
LET	Laboratory and Environmental Testing, Inc.
MA	Massachusetts
µg/g	micrograms per gram (or parts-per-million)
ME	Maine
MECDC	Maine Center for Disease Control and Prevention
MEFO	Maine Field Office (USFWS)
Mg	magnesium
mm	millimeter
Mn	manganese
Mo	molybdenum
n/a	not analyzed
NC	not calculated
ng/g	nanograms per gram (or parts-per-billion)
NMFS	National Marine Fisheries Service

NOAA	National Oceanic and Atmospheric Administration
Ni	nickel
NY	New York
PA	Pennsylvania
PBDE	polybrominated diphenyl ether
Pb	lead
PCB	polychlorinated biphenyl
ppb	parts-per-billion (or nanograms per gram, ng/g)
ppm	parts-per-million (or micrograms per gram, µg/g)
pg/g	picogram per gram (or parts-per-trillion)
QA/QC	quality assurance / quality control
Se	selenium
Σ	upper-case Greek letter sigma; summation operator/notation
Sr	strontium
USFWS	U.S. Fish and Wildlife Service
V	vanadium
WGS	World Geodetic System
ww	wet weight
Zn	zinc

PREFACE

This report provides documentation of environmental contaminants in tissues of Atlantic sturgeon (*Acipenser oxyrinchus*) and shortnose sturgeon (*Acipenser brevirostrum*) collected from the Penobscot and Kennebec Rivers in Maine. Analytical work was completed under U.S. Fish and Wildlife Service (USFWS) Analytical Control Facility Catalog 5100032 (Purchase Orders 94420-08-Y901 organics and 94420-08-Y902 inorganics) and Catalog 5100042 (Purchase Orders 94420-09-Y022 organics and 94420-09-Y023 inorganics).

Atlantic sturgeon analyses were conducted under Interagency Agreement EM133-F06-IA-0185 (Reference/Requisition Number NFFM 5100-6-00657). Shortnose sturgeon analyses were conducted under Interagency Agreement Number EM133-F06-IA-0180 (Reference/Requisition Number NFFM 51006-00616). Pursuant to the Endangered Species Act of 1973 (ESA; 16 U.S.C. 1531 et seq.), all activities for this study were conducted by authorized personnel listed under National Marine Fisheries Service (NMFS) Endangered Species Act Permit Number 1614.

Questions, comments, and suggestions related to this report are encouraged. Written inquiries should refer to Report Number FY09-MEFO-3-EC and be directed to:

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This report complies with the peer review and certification provisions of the Information Quality Act (Public Law 106-554, Section 515).

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Biological Laboratory, University of Maryland Center for Environmental Science, Solomons, MD. Peer review of the draft report was provided by Barry Mower Ph.D., Maine Department of Environmental Protection, and James Meador Ph.D., NOAA Fisheries. Final editorial review was provided by F. Timothy Prior, USFWS retired.

1. Background

In the Gulf of Maine, the shortnose sturgeon (*Acipensor brevirostrum*) is a federally-listed endangered species and the Atlantic sturgeon (*Acipensor oxyrinchus oxyrinchus*) is a recently listed threatened species (Federal Register: February 6, 2012). Between June and August 2006, six sturgeon were collected from the Penobscot River in Maine. Two Atlantic sturgeon and three shortnose sturgeon died during scientific sampling activities and one shortnose sturgeon was killed by a seal. In July 2009, three shortnose sturgeon were recovered on the Kennebec River in Georgetown after a red tide event. A month later, two more shortnose sturgeon were recovered further north in the Kennebec River near Phippsburg, the apparent victims of seal predation.

Due to their protected status and low numbers, lethal collections of sturgeon for scientific purposes are not possible. The use of tissues from fish carcasses, however, is permitted by researchers under an Endangered Species Act Section 10 Permit issued by the National Marine Fisheries Service. Since little contaminant information is available for both species of sturgeon in the Gulf of Maine portion of their range, tissues from these 11 fish were submitted for contaminant analyses.

Potential contaminant sources and threats in Maine rivers, estuaries, and coastal waters include hazardous waste sites, junkyards, pulp and paper mills, shipyards, cement manufacturers, gravel operations, road runoff, fuel and chemical spills, municipal wastewater treatment plants, and materials associated with private residences and commercial entities. Atmospheric deposition also introduces contaminants into Maine's watersheds.

Elevated body burdens of contaminants in sturgeon species have been related to adverse biological effects (Webb *et al*. 2006). Organic contaminants may present a threat to reproduction and development in fish (Monosson 1999/2000), while exposure to trace elements affects predator avoidance, behavior and development (Berntssen *et al*. 2003, Webber and Haines 2003). Atlantic sturgeon and shortnose sturgeon foraging in Maine rivers and along the coast accumulate contaminants through the ingestion of prey and sediment, and through direct absorption of some water-dissolved contaminants across gill membranes.

2. Objectives

Determine trace metal and organic contaminant residue burdens in tissue samples of Atlantic sturgeon and shortnose sturgeon recovered from the Penobscot River and Kennebec River.

Compare contaminant concentrations in tissue samples against concentrations reported in other sturgeon studies and to suggested threshold-effect levels for other fish species.

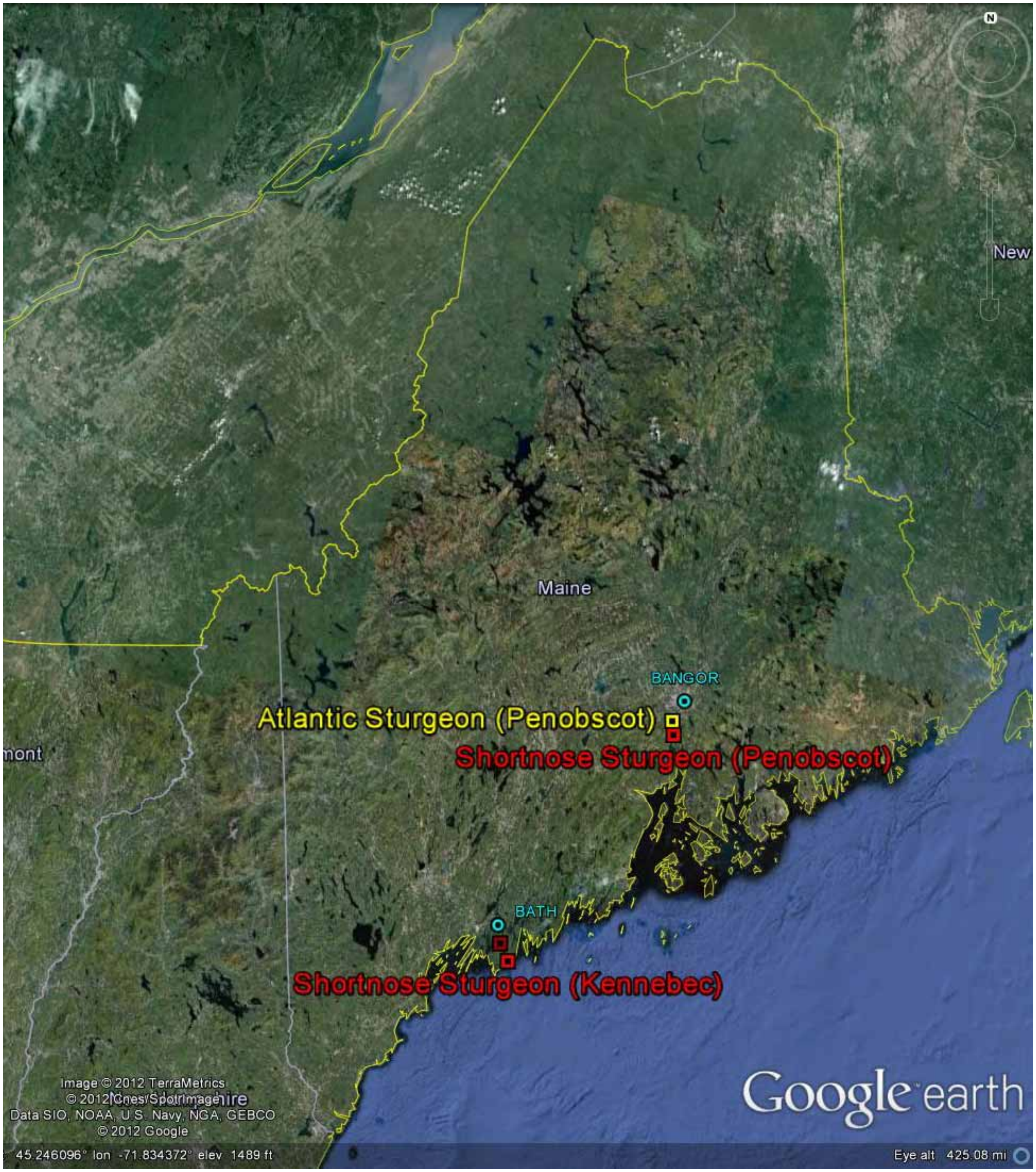
3. Collection Locations

Two Atlantic sturgeon were recovered from the Penobscot River in Orrington in 2006. Four shortnose sturgeon were collected from the Penobscot River near Hampden and Winterport in 2006 and five shortnose sturgeon were collected from the Kennebec River in Georgetown and Phippsburg in 2009. Table 1 provides recovery location coordinates based on WGS 84 map datum. Figure 1 depicts general collection locations in the two rivers.

Table 1. Atlantic and shortnose sturgeon collected from the Penobscot and Kennebec Rivers, Maine.

Species	NMFS Unique ID No.	USFWS ID No.	Recovery Location	Recovery Date	Coordinates		Notes
					Latitude	Longitude	
Atlantic sturgeon	none	AST-1	Penobscot River, Orrington	8/18/2006	44° 43' 18"	068° 49' 52"	Killed in gill net
Atlantic sturgeon	none	AST-2	Penobscot River, Orrington	8/18/2006	44° 43' 18"	068° 49' 52"	Killed in gill net
Shortnose sturgeon	none	SNS-1	Penobscot River, Hampden	8/24/2006	44° 41' 23"	068° 49' 33"	Killed by seal, partially eaten
Shortnose sturgeon	none	SNS-2	Penobscot River, Winterport	6/20/2006	44° 39' 59"	068° 49' 29"	Killed in gill net
Shortnose sturgeon	none	SNS-3	Penobscot River, Winterport	6/17/2006	44° 39' 59"	068° 49' 29"	Killed in gill net
Shortnose sturgeon	none	SNS-4	Penobscot River, Winterport	6/28/2006	44° 39' 59"	068° 49' 29"	Killed in gill net
Shortnose sturgeon	Abro 7011 2009	KENN-01	Kennebec River, Georgetown	7/10/2009	43° 45' 57"	069° 45' 35"	Tested positive for saxitoxin
Shortnose sturgeon	Abro 7012 2009	KENN-02	Kennebec River, Georgetown	7/10/2009	43° 45' 57"	069° 45' 35"	Tested positive for saxitoxin
Shortnose sturgeon	Abro 7013 2009	KENN-03	Kennebec River, Georgetown	7/10/2009	43° 45' 57"	069° 45' 35"	Tested positive for saxitoxin
Shortnose sturgeon	Abro 8002 2009	KENN-04	Kennebec River; Phippsburg	8/25/2009	43° 50' 16"	069° 48' 11"	Seal predation
Shortnose sturgeon	Abro 8003 2009	KENN-05	Kennebec River, Phippsburg	8/25/2009	43° 50' 16"	069° 48' 11"	Seal predation

Figure 1. Sturgeon collection locations



4. Methods

4.1 Endangered Species Act. Pursuant to the Endangered Species Act of 1973 (ESA; 16 U.S.C. 1531 *et seq*.), all activities for this study were conducted by authorized personnel and laboratories listed under NMFS Endangered Species Act Permit Number 1614.

4.2 Fish Processing. Sturgeon recovered in June and August 2006 from the Penobscot were frozen after collection and thawed for processing on 20 May 2008. Three shortnose sturgeon recovered on 10 July 2009 from the Kennebec were frozen after collection and thawed for processing on 24 August 2009. Two shortnose sturgeon recovered from the Kennebec on 25 August 2009 were refrigerated and processed on 27 August 2009.

Recorded fish metrics included total length (millimeter, mm), fork length (mm), inter-orbital width (mm), mouth width (mm), total weight (gram, g) and sample weight (g) (Table 2). Total and fork length were measured with a tape measure or fish measuring board. Inter-orbital and mouth width were measured with dial calipers. Weights were measured with an electronic scale.

Decontaminated stainless steel saws, knives, scalpels, and scissors were used to remove tissue. Fillet samples were wrapped in aluminum foil (dull side towards the sample), placed in labeled, plastic zip-loc bags and frozen. Gonad and liver tissue were placed in labeled, chemical-clean jars and frozen. Frozen samples were then shipped to analytical laboratories.

Pectoral fins were removed with a stainless steel hacksaw. Fins were placed in labeled, plastic zip-loc bags, frozen, and shipped to the Chesapeake Biological Laboratory of the University of Maryland for aging using generally accepted methods for sturgeon (Currier 1951, Brennan and Cailliet 1989, Stevenson and Secor 1999). Briefly, pectoral fin spines were sectioned using a Buehler Isomet saw with a paired diamond blade to an approximate 3 millimeter thickness, sanded to approximately a 1 millimeter thickness, and polished with 0.3 micron alumina slurry. Sections were examined under both reflected and transmitted light conditions. Each section was read twice. If there were different age estimates between readings, the section was examined a third time to derive a final age estimate.

4.3 Contaminant Analyses. Nineteen sturgeon tissue samples were submitted for analytical quantification of organochlorine compounds, trace metals, percent moisture, and percent lipids (Table 3). Shortnose sturgeon fillets from the Kennebec River in 2009 were also analyzed for polybrominated diphenyl ether (PBDE).

Organochlorine analyses of the fish collected in 2006 were conducted by GPL Laboratories LLC in Frederick, Maryland. Organochlorine and PBDE analyses of the fish collected in 2009 were conducted by the Geochemical and Environmental Research Group (GERG) in College Station, Texas. Quantification of residues was determined by megabore column electron gas chromatography.

Organochlorine compounds included the analytical scan included Total PCB; four benzene hexachloride (BHC, also known as hexachlorocyclohexanes) isomers – *alpha* BHC, *beta* BHC, *gamma* BCH, and *delta* BHC; seven chlordane compounds including *alpha* chlordane, *gamma* chlordane, *cis*-nonachlor, *trans*-nonachlor, oxychlordane, heptachlor, and heptachlor epoxide; dichloro-diphenyl-trichloroethane (DDT) metabolites and isomers including *o,p*'-DDD, *o,p*'-DDE, *o,p*'-DDT, *p,p*'-DDD, *p,p*'-DDE, and *p,p*'-DDT; aldrin, endrin, dieldrin, endosulfan II, hexachlorobenzene (HCB), mirex, pentachloro-anisole, and toxaphene. In the organics scans, GERG achieved lower wet weight detection limits for the 2009 Kennebec River samples (< 1.00 ng/g for Total PCB, < 0.05 ng/g for other organochlorines) than GPL Laboratories for the 2006 Penobscot River samples (< 5.00 ng/g for Total PCB, < 1.00 ng/g for other organochlorines).

Trace metal analyses for samples collected in 2006 and 2009 were conducted by Laboratory and Environmental Testing, Inc. (LET) of Columbia, Missouri. Inductively coupled plasma atomic emission spectrometry was used to determine concentrations of aluminum (Al), boron (B), barium (Ba), beryllium (Be), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), strontium (Sr), vanadium (V), and zinc (Zn). Mercury (Hg) concentrations were determined by cold vapor atomic absorption. Graphite furnace atomic absorption was used to measure arsenic (As) and selenium (Se). Wet weight detection limits in µg/g were 0.02 – 0.06 for Be, Cd, and Hg; 0.05 – 0.13 for Ba, Pb, Se, and Sr; 0.1 for As; 0.1 – 0.3 for Cu, Cr, Mn, Ni, V, and Zn; and 0.5 – 1.3 for Al, B, Fe, Mg, and Mo. Detection limits were lowest for fillet tissue and highest for gonad tissue.

The USFWS Analytical Control Facility Catalogs for this study were 5100032 (Purchase Order 94420-08-Y901 GPL Laboratories organics, Purchase Order 94420-08-Y902 LET inorganics) and 5100042 (Purchase Order 94420-09-Y022 GERG organics, Purchase Order 94420-09-Y023 LET inorganics).

4.4 Quality Assurance/Quality Control (QA/QC). Standard procedures of the USFWS Analytical Control Facility were used by the analytical laboratories for quality assurance and quality control (USFWS 2007). QA/QC procedures include duplicates, procedural blanks, spikes, and certified reference material. QA/QC results of the three laboratories were deemed acceptable by the USFWS Analytical Control Facility.

4.5 Data presentations. Contaminant concentrations in sturgeon tissues are presented in ng/g (parts-per-billion) for organochlorine compounds and PBDE, and in µg/g (parts-per-million) for trace metals. All concentrations are expressed on a wet weight basis. A second set of tables for trace metal results on a dry weight basis are also provided, since some investigators prefer metals data expressed on a dry weight basis. The range of contaminant concentrations for organochlorine compounds or trace metals are presented, and, when possible with a sufficient number of detections, the arithmetic mean.

5. Results

Fish metric data are listed in Table 2. Percent moisture and percent lipid values for individual samples are provided in Table 3. Table 4 (Fillets) and Table 5 (Livers and Gonads) list the organochlorine compounds in the analytical scan and results or detection limits on a wet weight basis. Table 6 lists Total PBDE and BDE congener detection limits and results in Kennebec River shortnose sturgeon fillets on a wet weight basis. Table 7a (Fillets) and Table 7b (Livers and Gonads) list trace metals in the analytical scan and results or detection limits on a wet weight basis. Table 8a (Fillets) and Table 8b (Livers and Gonads) list trace metals in the analytical scan and results or detection limits on a dry weight basis. Contaminant concentrations in the text below are presented on a wet weight basis.

5.1 Sample Metrics. Two Atlantic sturgeon recovered from the Penobscot River in 2006 were both male. Based on length, weight, and estimated age (12 and 13 years), these two fish would be considered sexually immature. The nine shortnose sturgeon collected from the Penobscot and Kennebec Rivers had estimated ages ranging from five to 19 years. Aging of sturgeon from pectoral fin spines can be imprecise (Whiteman *et al*. 2004) and age estimates may vary ± 5 years (Stevenson and Secor 1999).

Table 2. Sex, metrics, and estimated age of sturgeon from the Penobscot and Kennebec Rivers, Maine

USFWS ID No.	Collection River	NMFS Unique ID No.	Sex	Total Length (mm)	Fork Length (mm)	Inter-orbital Distance (mm)	Inside Mouth Width (mm)	Total Weight (g)	Estimated Age (years)
AST-1	Penobscot	none	M	1120	950	74.2	36.8	6500	13
AST-2	Penobscot	none	M	1010	856	64.7	34.1	4500	12
SNS-1	Penobscot	none	M	899	800	60.0	n/a	4250	14
SNS-2	Penobscot	none	M	950	830	64.0	39.0	5500	14
SNS-3	Penobscot	none	F	1024	882	59.0	45.2	5500	19
SNS-4	Penobscot	none	F	1038	900	68.0	41.2	6250	15
KENN-01	Kennebec	Abro 7011 2009	M	655	605	46.9	28.2	1052	5
KENN-02	Kennebec	Abro 7012 2009	M	747	638	46.2	n/a	1470	10
KENN-03	Kennebec	Abro 7013 2009	M	675	567	42.8	31.4	1193	6
KENN-04	Kennebec	Abro 8002 2009	F	935	780	58.5	n/a	2835	9
KENN-05	Kennebec	Abro 8003 2009	F	895	785	59.3	n/a	2790	10

n/a = not available

Table 3. Atlantic and shortnose sturgeon sample types, weight, percent moisture, and percent lipids

Species	Sample No.	Sample Type	Sample Weight (g)	Sample Moisture Content (%)	Sample Lipid Content (%)
Atlantic sturgeon	AST-1-F	Skinless, boneless fillet	327.1	77.0	0.52
	AST-1-L	Liver	121.8	79.4	2.90
Atlantic sturgeon	AST-2-F	Skinless, boneless fillet	266.5	75.6	2.60
	AST-2-L	Liver	103.0	79.0	4.40
Shortnose sturgeon	SNS-1-F	Skinless, boneless fillet	165.5	77.2	4.10
Shortnose sturgeon	SNS-2-F	Skinless, boneless fillet	270.4	75.3	2.30
	SNS-2-L	Liver	152.5	62.4	25.00
	SNS-2-G	Gonad	194.2	24.5	29.00
Shortnose sturgeon	SNS-3-F	Skinless, boneless fillet	286.5	70.5	7.20
	SNS-3-L	Liver	181.2	59.4	20.00
	SNS-3-G	Gonad	130.1	29.0	17.00
Shortnose sturgeon	SNS-4-F	Skinless, boneless fillet	302.4	75.2	2.40
	SNS-4-L	Liver	169.7	68.6	15.00
	SNS-4-G	Gonad	146.8	58.1	20.00
Shortnose sturgeon	KENN-01F	Skinless, boneless fillet	122.4	73.1	5.43
Shortnose sturgeon	KENN-02F	Skinless, boneless fillet	127.0	75.0	2.83
Shortnose sturgeon	KENN-03F	Skinless, boneless fillet	86.2	74.7	3.16
Shortnose sturgeon	KENN-04F	Skinless, boneless fillet	185.9	81.5	1.44
Shortnose sturgeon	KENN-05F	Skinless, boneless fillet	163.3	82.5	0.59

5.2 Organochlorine and organobromine compounds. Results of sturgeon organochlorine compound analyses are summarized in Table 4 (Fillets) and Table 5 (Livers and Gonad). Total PBDE and BDE congener results in fillets of shortnose sturgeon recovered from the Kennebec River in 2009 are listed in Table 6

5.2.1 Total Polychlorinated Biphenyl (PCB) – Total PCB was below the detection limit (< 5.00 ng/g) in all 2006 Penobscot River Atlantic and shortnose sturgeon fillet, liver, and gonad tissue samples. In contrast, all five fillet samples from shortnose sturgeon collected from the Kennebec River in 2009 had detectable levels of Total PCB (mean 864.6 ng/g, range 243.0 – 1900.0 ng/g).

5.2.2 Benzene Hexachlorides (BHC) – Total BHC (ΣBHC) was determined by summing the four isomers – *alpha* BHC, *beta* BHC, *gamma* BHC, and *delta* BHC. All sturgeon fillets from the Penobscot in 2006 were below detection for BHC. Four of five shortnose sturgeon fillets from the Kennebec in 2009 had ΣBCH ranging from 0.1 to 0.4 ng/g. BHC was below detection in all liver and gonad samples.

5.2.3 Chlordane Compounds – Total chlordane (ΣChlordane) was determined by summing five chlordane compounds: *alpha* chlordane, *gamma* chlordane, *cis*-nonachlor, *trans*-nonachlor, and oxychlordane. Heptachlor and heptachlor epoxide are separately presented.

In 2006, ΣChlordane was below detection limits in two fillets of Atlantic sturgeon and detected in one (27.6 ng/g) of four fillet samples of shortnose sturgeon collected in the Penobscot River. In 2009, all shortnose sturgeon fillets contained ΣChlordane (range: 0.7 – 10.6 ng/g). Heptachlor was below detection limits (< 0.05 ng/g) in all 2009 shortnose sturgeon fillet samples; the compound was not included in the analytical suite in 2006. Heptachlor epoxide was below detection limits in all 2006 samples (< 1.0 ng/g). Four of five shortnose sturgeon fillets from the Kennebec had heptachlor epoxide levels of 0.1 ng/g and one was below the detection limit (< 0.05 ng/g).

ΣChlordane was detected in one Atlantic sturgeon liver (1.4 ng/g) and two shortnose sturgeon livers (max. 9.1 ng/g) and found in two shortnose sturgeon gonad samples (max. 20.7 ng/g) from the Penobscot. Heptachlor was not measured in liver or gonad samples. Heptachlor epoxide was below the detection limit (< 1.0 ng/g) in all liver and gonad samples.

5.2.4 Dichloro-diphenyl-trichloroethane (DDT) – Total DDT (ΣDDT) was determined by summing concentrations of *o,p*'-DDD, *o,p*'-DDE, *o,p*'-DDT, *p,p*'-DDD, *p,p*'-DDE and *p,p*'-DDT. Mean ΣDDT was 6.0 ng/g in Atlantic sturgeon fillets. ΣDDT ranged widely in nine shortnose sturgeon fillets (5.5 to 55.1 ng/g). *p,p*'DDE was a greater component of ΣDDT in the 2009 fillet samples (53 – 78%) than the 2006 fillet samples (27 – 45%). Higher levels of DDT were detected in liver tissue (Atlantic mean 12.4 ng/g, shortnose mean 20.3 mg/g) and gonad tissue (shortnose mean 104 ng/g) than fillets.

5.2.5 Other Organochlorine Compounds – Aldrin was not measured in 2006 and below detection (< 0.05 ng/g) in all 2009 samples. Endrin was below detection limits in all fillet samples (< 0.05 – 1.0 ng/g) and liver and gonad samples (< 1.0 ng/g). Dieldrin was below detection limit in all 2006 fillet samples, and found in four of five 2009 shortnose sturgeon fillet sample (0.4 – 0.7 ng/g). One shortnose sturgeon gonad sample had a detectable level of dieldrin (3.1 ng/g), all other gonad and liver samples were below the detection limit (< 1.0 ng/g). Endosulfan II was not measured in 2006 in fillet, gonad, and liver samples; and was the below detection limit (< 0.05 ng/g) in all 2009 shortnose fillet samples. Hexachlorobenzene (HCB) was not detected in the two Atlantic sturgeon fillet samples (< 1.0 ng/g) and detected in seven of nine shortnose sturgeon fillet samples (range: 0.1 – 3.8 ng/g). HCB was detected in all sturgeon liver (range: 1.0 – 6.8 ng/g) and gonad samples (5.6 – 25.0 ng/g). Mirex was not detected in Atlantic sturgeon fillet samples (< 1.0 ng/g), but was found in seven of nine shortnose sturgeon fillet samples (range: 0.1 – 12.0 ng/g). Both Atlantic sturgeon livers (mean 4.2 ng/g), two of three shortnose sturgeon livers (5.6 and 7.2 ng/g), and all three shortnose sturgeon gonad samples (mean 38.0 ng/g) contained mirex. Pentachloro-anisole was not measured in 2006 samples, but was detected in all the 2009 shortnose sturgeon fillet samples (mean 0.4 ng/g, range: 0.1 – 0.8 ng/g). Toxaphene was below detection limits (< 1.0 ng/g) in all samples.

5.2.6 Polybrominated Diphenyl Ether (PBDE) – PBDE was only measured in shortnose sturgeon samples collected from the Kennebec River in 2009. Total PBDE in five shortnose sturgeon fillet samples ranged from 4.4 ng/g to 39.1 ng/g with a mean of 26.5 ± 14.6 ng/g. Among 39 BDE congeners in the analytical scan, BDE# 28, 47, 49, 66, 99, 100, 153, 154, and 155 were found above detection limits (Table 6). Congener BDE #47 was consistently the greatest contributor to Total PBDE.

Table 4. Organochlorine compounds in **FILLETS** of sturgeon recovered from the Penobscot and Kennebec Rivers, ng/g wet weight

	Penobscot - Atlantic Sturgeon **FILLET**			Penobscot - Shortnose Sturgeon **FILLET**					Kennebec - Shortnose Sturgeon **FILLET**					
Sample No.	AST-1-F	AST-2-F	Mean	SNS-1-F	SNS-2-F	SNS-3-F	SNS-4-F	Mean	KENN-01F	KENN-02F	KENN-03F	KENN-04F	KENN-05F	Mean
PCB-TOTAL	< 5.00	< 5.00	BDL	< 5.00	< 5.00	< 5.00	< 5.00	BDL	995.0	931.0	254.0	1900.0	243.0	864.6
PBDE-TOTAL	n/a	n/a		n/a	n/a	n/a	n/a		4.4	39.8	29.0	39.1	20.0	26.5
ΣBHC	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.4	0.2	0.1	0.3	BDL	NC
ΣChlordane	BDL	BDL	BDL	27.6	BDL	BDL	BDL	NC	9.5	7.0	4.7	10.6	0.7	6.5
heptachlor	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	< 0.0499	< 0.0500	< 0.0497	< 0.0493	< 0.0458	BDL
heptachlor epoxide	< 1.00	< 1.00	BDL	< 1.00	< 1.00	< 1.00	< 1.00	BDL	0.1	0.1	0.1	0.1	< 0.0458	NC
p,p'-DDE	1.8	2.4	2.1	19.0	3.6	10.0	4.4	9.3	31.5	11.2	7.2	42.8	4.0	19.3
ΣDDT	4.0	8.0	6.0	53.6	10.6	36.6	15.7	29.1	46.2	19.0	13.6	55.1	5.5	27.9
aldrin	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	< 0.0499	< 0.0500	< 0.0497	< 0.0493	< 0.0458	BDL
endrin	< 1.00	< 1.00	BDL	< 1.00	< 1.00	< 1.00	< 1.00	BDL	< 0.0499	< 0.0500	< 0.0497	< 0.0493	< 0.0458	BDL
dieldrin	< 1.00	< 1.00	BDL	< 1.00	< 1.00	< 1.00	< 1.00	BDL	0.4	0.6	0.5	0.7	< 0.0458	NC
endosulfan II	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	< 0.0499	< 0.0500	< 0.0497	< 0.0493	< 0.0458	BDL
HCB	< 1.00	< 1.00	BDL	< 1.00	1.4	3.8	1.9	NC	0.4	0.3	0.3	0.1	< 0.0458	NC
mirex	< 1.00	< 1.00	BDL	< 1.00	5.5	12.0	< 1.00	NC	0.9	0.3	0.1	0.7	0.1	0.4
pentachloro-anisole	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.8	0.6	0.4	0.2	0.1	0.4
toxaphene	< 1.00	< 1.00	BDL	< 1.00	< 1.00	< 1.00	< 1.00	BDL	< 0.998	< 1.00	< 0.994	< 0.985	< 0.915	BDL

ng/g = parts-per-billion. Expressed as wet weight. n/a = not analyzed.
ΣBHC is the sum of alpha, beta, gamma and delta BHC.
ΣChlordane is the sum of alpha chlordane, gamma chlordane, cis-nonachlor, trans-nonachlor, and oxychlordane.
ΣDDT is the sum of o,p-DDD, o,p'-DDE, o,p'-DDT, p,p'-DDD, p,p'-DDE, and p,p'-DDT.
Values in red preceded by < symbol indicate non-detect and the detection limit
BDL = below detection limit, NC = not calculated

Table 5. Organochlorine compounds in LIVER and GONAD of sturgeon recovered from the Penobscot River, ng/g wet weight

	Penobscot - Atlantic Sturgeon **LIVER**			Penobscot - Shortnose Sturgeon **LIVER**				Penobscot - Shortnose Sturgeon **GONAD**			
Sample No.	AST-1-L	AST-2-L	Mean	SNS-2-L	SNS-3-L	SNS-4-L	Mean	SNS-2-G	SNS-3-G	SNS-4-G	Mean
PCB-TOTAL	< 5.00	< 5.00	BDL	< 5.00	< 5.00	< 5.00	BDL	< 5.00	< 5.00	< 5.00	BDL
PBDE-TOTAL	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
ΣBHC	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
ΣChlordane	BDL	1.4	NC	BDL	1.9	9.1	NC	20.7	BDL	11.2	NC
heptachlor	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
heptachlor epoxide	< 1.00	< 1.00	BDL	< 1.00	< 1.00	< 1.00	BDL	< 1.00	< 1.00	< 1.00	BDL
p,p'-DDE	4.4	4.3	4.4	< 1.00	7.0	7.0	NC	51.0	63.0	18.0	44.0
ΣDDT	10	14.9	12.45	21	20.8	19.1	20.3	113	157	42	104
aldrin	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
endrin	< 1.00	< 1.00	BDL	< 1.00	< 1.00	< 1.00	BDL	< 1.00	< 1.00	< 1.00	BDL
dieldrin	< 1.00	< 1.00	BDL	< 1.00	< 1.00	< 1.00	BDL	< 1.00	< 1.00	3.1	NC
endosulfan II	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
HCB	1.0	4.2	2.6	6.4	6.8	3.7	5.6	16.0	25.0	5.6	15.5
mirex	2.7	5.6	4.2	< 1.00	5.6	7.2	NC	73.0	25.0	16.0	38.0
pentachloro-anisole	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
toxaphene	< 1.00	< 1.00	BDL	< 1.00	< 1.00	< 1.00	BDL	< 1.00	< 1.00	< 1.00	BDL

ng/g = parts-per-billion. Expressed as wet weight. n/a = not analyzed.
ΣBHC is the sum of alpha, beta, gamma and delta BHC.
ΣChlordane is the sum of alpha chlordane, gamma chlordane, cis-nonachlor, trans-nonachlor, and oxychlordane.
ΣDDT is the sum of o,p-DDD, o,p'-DDE, o,p'-DDT, p,p'-DDD, p,p'-DDE, and p,p'-DDT.
Values in red preceded by < symbol indicate non-detect and the detection limit
BDL = below detection limit, NC = not calculated
Livers and gonads from Kennebec River sturgeon were not analyzed.

Table 6. Total PBDE and BDE congeners in shortnose surgeon from the Kennebec River, ng/g wet weight

Sample No. Sample Type	KENN-01F Fillet	KENN-02F Fillet	KENN-03F Fillet	KENN-04F Fillet	KENN-05F Fillet
PBDE-TOTAL	4.40	38.90	29.00	39.10	20.00
BDE# 1	< 0.125	< 0.125	< 0.124	< 0.123	< 0.114
BDE# 2	< 0.125	< 0.125	< 0.124	< 0.123	< 0.114
BDE# 3	< 0.125	< 0.125	< 0.124	< 0.123	< 0.114
BDE# 7	< 0.125	< 0.125	< 0.124	< 0.123	< 0.114
BDE# 8/11	< 0.125	< 0.125	< 0.124	< 0.123	< 0.114
BDE# 10	< 0.125	< 0.125	< 0.124	< 0.123	< 0.114
BDE# 12	< 0.125	< 0.125	< 0.124	< 0.123	< 0.114
BDE# 13	< 0.125	< 0.125	< 0.124	< 0.123	< 0.114
BDE# 15	< 0.125	< 0.125	< 0.124	< 0.123	< 0.114
BDE# 17	< 0.125	< 0.125	< 0.124	< 0.123	< 0.114
BDE# 25	< 0.125	< 0.125	< 0.124	< 0.123	< 0.114
BDE# 28	0.27	3.46	0.99	2.02	0.84
BDE# 30	< 0.125	< 0.125	< 0.124	< 0.123	< 0.114
BDE# 32	< 0.125	< 0.125	< 0.124	< 0.123	< 0.114
BDE# 33	< 0.125	< 0.125	< 0.124	< 0.123	< 0.114
BDE# 35	< 0.125	< 0.125	< 0.124	< 0.123	< 0.114
BDE# 37	< 0.125	< 0.125	< 0.124	< 0.123	< 0.114
BDE# 47	1.30	23.00	19.20	14.60	6.10
BDE# 49	0.15	1.04	0.68	1.50	1.38
BDE# 66	< 0.125	0.39	0.45	0.18	0.15
BDE# 71	< 0.125	< 0.125	< 0.124	< 0.123	< 0.114
BDE# 75	< 0.125	< 0.125	< 0.124	< 0.123	< 0.114
BDE# 77	< 0.125	< 0.125	< 0.124	< 0.123	< 0.114
BDE# 85	< 0.187	< 0.188	< 0.186	< 0.185	< 0.172
BDE# 99	0.33	0.41	0.80	0.20	0.20
BDE# 100	0.91	7.14	4.12	11.5	5.59
BDE# 116	< 0.187	< 0.188	< 0.186	< 0.185	< 0.172
BDE# 118	< 0.187	< 0.188	< 0.186	< 0.185	< 0.172
BDE# 119	< 0.187	< 0.188	< 0.186	< 0.185	< 0.172
BDE# 126	< 0.187	< 0.188	< 0.186	< 0.185	< 0.172
BDE# 138	< 0.250	< 0.250	< 0.249	< 0.246	< 0.229
BDE# 153	< 0.250	0.40	0.77	0.35	0.24
BDE# 154	1.09	2.48	1.56	7.15	3.85
BDE# 155	0.27	0.44	0.25	1.38	1.55
BDE# 166	< 0.250	< 0.250	< 0.249	< 0.246	< 0.229
BDE# 181	< 0.312	< 0.312	< 0.311	< 0.308	< 0.286
BDE# 183	< 0.312	< 0.312	< 0.311	< 0.308	< 0.286
BDE# 190	< 0.312	< 0.312	< 0.311	< 0.308	< 0.286
BDE# 209	< 20.0	< 20.0	< 19.9	< 19.7	< 18.3

ng/g = parts-per-billion
Values in red preceded by < symbol indicate non-detects and detection limit
Sturgeon samples from the Penobscot River were not analyzed for PBDEs

5.3 Trace metals. Trace metal results are listed in Table 7a (Fillet) and Table 7b (Liver and Gonad) on a wet weight basis and in Tables 8a (Fillet) and Table 8b (Liver and Gonad) on a dry weight basis. Results on a wet weight basis are summarized below.

5.3.1 Aluminum (Al) – Fillet samples were wrapped in aluminum foil, so residue results should be viewed with caution. Liver and gonad samples were placed in chemical-clean jars. Aluminum was below detection in all but one sturgeon fillet sample from the 2006 collection, and when detected, was found at the detection limit of 0.50 µg/g. Aluminum ranged from 0.80 to 9.50 µg/g in shortnose sturgeon fillets collected in 2009. In liver samples, Al ranged from 2.0 to 11.0 µg/g. Aluminum was below detection in two gonad samples and at 6.6 µg/g in the third sample.

5.3.2 Arsenic (As) – Arsenic was detected in all samples. The highest As concentrations were detected in a 2006 Atlantic sturgeon fillet sample at 4.30 µg/g and a 2009 Kennebec River shortnose sturgeon fillet sample at 3.10 µg/g. Shortnose sturgeon gonads (mean 0.30 µg/g, range: 0.20 – 0.35 µg/g) appeared to have lower As levels than livers (mean 0.41 µg/g, range: 0.28 – 0.56 µg/g). One Atlantic sturgeon liver had an As concentration (1.30 µg/g) twice as high as the other Atlantic (0.44 µg/g) and the three shortnose sturgeon livers (mean 0.41 µg/g).

5.3.3 Boron (B) – Boron was below detection limits (< 0.50 µg/g) in all but one fillet samples. One 2009 shortnose sturgeon fillet from the Kennebec had a B level at the detection limit. Similarly, B was below detection in all but one liver sample. One shortnose sturgeon recovered from the Penobscot River in 2006 had a liver B concentration of 0.90 µg/g. Boron was below detection (< 2.00 µg/g) in the three shortnose sturgeon gonad samples.

5.3.4 Barium (Ba) – Barium was sporadically detected in sturgeon fillet samples. One 2006 Atlantic sturgeon fillet sample had a Ba concentration of 0.05 µg/g and three of the 2009 Kennebec River shortnose sturgeon fillet samples had concentrations ranging from 0.06 µg/g to 0.10 µg/g. Barium was detected in all liver and gonad samples. The mean Ba concentration was 0.58 µg/g in two Atlantic sturgeon livers, 0.64 µg/g in three shortnose sturgeon livers, and 0.23 µg/g in three shortnose sturgeon gonads.

5.3.5 Beryllium (Be) – Beryllium was below detection limits (< 0.02 µg/g fillets, < 0.04 µg/g livers, < 0.08 µg/g gonads) in all samples from the 2006 collections. Four of five fillets from shortnose sturgeon recovered from the Kennebec in 2009 had Be concentrations ranging from 0.03 µg/g to 0.04 µg/g which was slightly above the detection limit (< 0.02 µg/g).

5.3.6 Cadmium (Cd) – Cadmium was below detection limits in all fillet (< 0.10 µg/g) and gonad samples (< 0.08 µg/g). Both Atlantic sturgeon livers (mean 0.23 µg/g) and two of three shortnose sturgeon livers samples (0.04 µg/g, 0.08 µg/g) had detectable levels of Cd.

5.3.7 Chromium (Cr) – Chromium was below detection limits in fillet (< 0.10 µg/g), liver (< 0.20 µg/g), and gonad (< 0.40 µg/g) samples.

5.3.8 Copper (Cu) – Copper was detected in all samples. The highest Cu concentrations were detected in liver samples (range: 1.50 – 4.40 µg/g). Two Atlantic sturgeon fillet samples had identical Cu concentrations, 0.20 µg/g. Copper in shortnose sturgeon fillet samples from 2006 and 2009 ranged from 0.24 to 0.61 µg/g. The three shortnose gonad samples had a mean Cu concentration of 0.59 µg/g.

5.3.9 Iron (Fe) – Iron was detected in all samples. Concentrations of Fe in sturgeon fillet samples varied widely between the 2006 and 2009 samples with the highest concentration detected in a shortnose sturgeon recovered from the Kennebec River in 2009 (40.0 µg/g). Five-fold higher Fe concentrations occurred in shortnose liver samples (mean 241.0 µg/g) compared to their gonad samples (mean 43.0 µg/g).

5.3.10 Mercury (Hg) – Mercury content in two Atlantic sturgeon fillets was identical at 0.18 µg/g. Mercury in nine shortnose sturgeon fillet samples ranged widely from 0.19 µg/g to 1.00 µg/g. Among samples types, gonad samples had the lowest Hg levels with two of the three shortnose sturgeon samples below the sample detection limit and one at the detection limit (0.07 µg/g). Liver samples from two Atlantic sturgeon (0.44 µg/g, 0.78 µg/g) and three shortnose sturgeon (range: 0.18 – 0.81 µg/g) also had varying levels of Hg.

5.3.11 Magnesium (Mg) – Magnesium was detected in all sturgeon tissue samples. Fillet samples (range: 195 – 325 µg/g) contained more than two-fold Mg than liver (range: 91 – 107 µg/g) and gonad (range: 29 – 100 µg/g) samples.

5.3.12 Manganese (Mn) – Manganese was detected in all sturgeon fillet samples (range: 0.10 – 0.58 µg/g) and liver samples (range: 0.54 – 1.00 µg/g). Two of the three shortnose sturgeon gonad contained detectable levels of Mn (0.40 µg/g, 0.70 µg/g).

5.3.13 Molybdenum (Mo) – Molybdenum was below detection limits in fillet (< 0.50 µg/g), liver (< 0.80 µg/g), and gonad (< 2.00 µg/g) samples.

5.3.14 Nickel (Ni) – Nickel was below detection limits in all sturgeon fillet samples. All shortnose sturgeon liver (< 0.02 µg/g) and gonad (< 0.40 µg/g) samples were below nickel detection limits. Nickel was detected in both Atlantic sturgeon liver samples (0.20 µg/g, 0.42 µg/g).

5.3.15 Lead (Pb) – Except for one shortnose sturgeon fillet sample with a Pb concentration at the detection limit (0.05 µg/g), all other sturgeon fillet samples were below detection limits. Lead was below sample detection limits (< 0.06 µg/g) in all three shortnose sturgeon gonad samples. Lead was detected in all sturgeon liver samples. Higher Pb levels were detected in the two Atlantic sturgeon liver samples (0.39 µg/g, 1.70 µg/g) than the three shortnose sturgeon samples (0.09 µg/g, 0.10 µg/g, 0.10 µg/g).

5.3.16 Selenium (Se) – Selenium was detected in all sturgeon tissue samples (range: 0.32 – 2.40 µg/g). The maximum Se fillet concentration was found in a shortnose sturgeon collected from the Kennebec River in 2009. Average concentrations of Se in Atlantic and shortnose sturgeon liver samples were similar (1.80 µg/g). The mean Se concentration in three shortnose gonad samples was 0.57 µg/g.

5.3.17 Strontium (Sr) – Strontium was detected in all sturgeon fillet (range: 0.10 – 1.30 µg/g) and liver (range: 0.20 – 0.58 µg/g) samples. Strontium concentrations appeared twice as high in Atlantic sturgeon than shortnose sturgeon livers. One of the three shortnose sturgeon gonad samples had a Sr level at the detection limit (0.20 µg/g). The other two gonad samples were below Sr detection limits (< 0.20 µg/g, < 0.10 µg/g).

5.3.18 Vanadium (V) – Vanadium was below the detection limit (< 0.10 µg/g) in all fillet samples. All liver samples analyzed from sturgeon recovered from the Penobscot River in 2006 contained detectable amounts of V. The average V concentration in two Atlantic sturgeon livers was 0.63 µg/g and the average was 0.47 µg/g in three shortnose sturgeon livers. Vanadium was below the detection limit (< 0.40 µg/g) in three shortnose sturgeon gonad samples.

5.3.19 Zinc (Zn) – Zinc was detected in all sturgeon fillet samples with a narrow range between 3.3 µg/g and 4.6 µg/g. Similarly, the Zn range in liver samples from Atlantic and shortnose sturgeon was also narrow (20.0 – 22.9 µg/g). Zinc in three shortnose sturgeon gonad samples ranged from 14.0 µg/g to 31.3 µg/g.

Table 7a. Trace metals in FILLETS of sturgeon recovered from the Penobscot and Kennebec Rivers, µg/g wet weight.

WET WEIGHT

Sample No.	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
FILLET - Atlantic Sturgeon, Penobscot River 2006																			
AST-1-F	< 0.50	4.30	< 0.50	< 0.05	< 0.02	< 0.02	< 0.10	0.20	3.7	0.18	255	0.20	< 0.50	< 0.10	< 0.05	1.20	0.10	< 0.10	3.3
AST-2-F	< 0.50	1.20	< 0.50	0.05	< 0.02	< 0.02	< 0.10	0.20	1.9	0.18	239	0.10	< 0.50	< 0.10	< 0.05	0.84	0.17	< 0.10	4.2
Mean	BDL	2.75	BDL	NC	BDL	BDL	BDL	0.20	2.8	0.18	247	0.15	BDL	BDL	BDL	1.02	0.14	BDL	3.8
FILLET - Shortnose Sturgeon, Penobscot River 2006																			
SNS-1-F	< 0.50	1.20	< 0.50	< 0.50	< 0.02	< 0.02	< 0.10	0.61	3.7	0.92	228	0.20	< 0.50	< 0.10	0.05	0.66	0.10	< 0.10	4.1
SNS-2-F	< 0.50	0.99	< 0.50	< 0.50	< 0.02	< 0.02	< 0.10	0.32	1.8	0.19	258	0.20	< 0.50	< 0.10	< 0.05	0.71	0.10	< 0.10	3.7
SNS-3-F	< 0.60	0.99	< 0.60	< 0.06	< 0.03	< 0.03	< 0.10	0.45	2.9	0.24	262	0.20	< 0.60	< 0.10	< 0.06	0.64	0.20	< 0.10	4.6
SNS-4-F	0.50	0.79	< 0.50	< 0.50	< 0.02	< 0.02	< 0.10	0.39	2.3	0.32	278	0.31	< 0.50	< 0.10	< 0.05	0.70	0.22	< 0.10	4.1
Mean	NC	0.99	BDL	BDL	BDL	BDL	BDL	0.44	2.7	0.42	257	0.23	BDL	BDL	NC	0.68	0.16	BDL	4.1
FILLET - Shortnose Sturgeon, Kennebec River 2009																			
KENN-01F	9.50	3.10	< 0.50	0.06	0.04	< 0.03	< 0.10	0.49	22.0	0.50	325	0.46	< 0.50	< 0.10	< 0.05	2.40	1.30	< 0.10	4.5
KENN-02F	7.00	1.80	0.50	0.09	< 0.02	< 0.02	< 0.10	0.28	40.0	0.35	302	0.58	< 0.50	< 0.10	< 0.05	0.89	0.72	< 0.10	3.7
KENN-03F	5.30	2.10	< 0.50	0.10	0.03	< 0.03	< 0.10	0.26	7.6	0.30	308	0.51	< 0.50	< 0.10	< 0.05	0.58	1.20	< 0.10	3.8
KENN-04F	0.60	0.73	< 0.40	< 0.04	0.03	< 0.02	< 0.09	0.37	6.1	0.60	198	0.38	< 0.40	< 0.09	< 0.04	0.32	0.31	< 0.09	4.3
KENN-05F	0.80	1.10	< 0.40	< 0.04	0.03	< 0.02	< 0.09	0.24	17.0	1.00	195	0.32	< 0.40	< 0.09	< 0.04	0.57	0.33	< 0.09	3.9
Mean	4.64	1.77	NC	NC	NC	BDL	BDL	0.33	18.5	0.55	266	0.45	BDL	BDL	BDL	0.95	0.77	BDL	4.0

Skinless, boneless fillets

µg/g = parts-per-million. Expressed as wet weight.

Values in red preceded by < symbol indicate non-detect and the detection limit

BDL = below detection limit, NC = not calculated

Table 7b. Trace metals in LIVER and GONAD of sturgeon recovered from the Penobscot River, µg/g wet weight

WET WEIGHT

Sample No.	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
LIVER - Atlantic Sturgeon, Penobscot River																			
AST-1-L	11.0	1.30	< 0.40	0.77	< 0.02	0.18	< 0.10	4.40	226.0	0.78	107	0.55	< 0.40	0.42	1.70	2.10	0.51	0.88	22.9
AST-2-L	6.1	0.44	< 0.40	0.38	< 0.02	0.27	< 0.10	2.80	181.0	0.44	107	0.54	< 0.40	0.20	0.39	1.50	0.58	0.37	20.1
Mean	8.6	0.87	BDL	0.58	BDL	0.23	BDL	3.60	203.5	0.61	107	0.55	BDL	0.31	1.05	1.80	0.55	0.63	21.5
LIVER - Shortnose Sturgeon, Penobscot River																			
SNS-2-L	2.0	0.40	< 0.80	0.67	< 0.04	< 0.04	< 0.20	2.60	260.0	0.18	94	1.00	< 0.80	< 0.20	0.10	1.90	0.20	0.40	21.0
SNS-3-L	5.7	0.56	0.90	0.79	< 0.04	0.08	< 0.20	2.20	171.0	0.81	91	0.60	< 0.80	< 0.20	0.10	2.00	0.34	0.40	22.2
SNS-4-L	3.1	0.28	< 0.60	0.46	< 0.03	0.04	< 0.20	1.50	292.0	0.24	95	0.67	< 0.60	< 0.20	0.09	1.50	0.22	0.60	20.0
Mean	3.6	0.41	NC	0.64	BDL	0.06	BDL	2.10	241.0	0.41	93	0.76	BDL	BDL	0.10	1.80	0.25	0.47	21.1
GONAD - Shortnose Sturgeon, Penobscot River																			
SNS-2-G	< 2.00	0.20	< 2.00	0.20	< 0.08	< 0.08	< 0.40	0.65	47.0	< 0.08	29	0.70	< 2.00	< 0.40	< 0.20	0.40	< 0.20	< 0.40	14.0
SNS-3-G	< 1.00	0.35	< 1.00	0.20	< 0.07	< 0.07	< 0.40	0.50	29.0	< 0.07	41	< 0.40	< 1.00	< 0.40	< 0.10	0.56	< 0.10	< 0.40	19.0
SNS-4-G	6.6	0.35	< 0.80	0.30	< 0.04	< 0.04	< 0.20	0.61	53.0	0.07	100	0.40	< 0.80	< 0.20	< 0.08	0.74	0.20	< 0.20	31.3
Mean	NC	0.30	BDL	0.23	BDL	BDL	BDL	0.59	43.0	NC	57	NC	BDL	BDL	BDL	0.57	NC	BDL	21.4

µg/g = parts-per-million. Expressed as wet

Values in red preceded by < symbol indicate non-detect and the detection limit

BDL = below detection limit, NC = not calculated

Table 8a. Trace metals in FILLETS of sturgeon recovered from the Penobscot and Kennebec Rivers, µg/g dry weight.

DRY WEIGHT

Sample No.	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
FILLET - Atlantic Sturgeon, Penobscot River 2006																			
AST-1-F	< 2.00	19.0	< 2.00	< 0.200	< 0.100	< 0.100	< 0.500	0.7	16	0.77	1110	0.9	< 2.00	< 0.500	< 0.200	5.1	0.61	< 0.500	15
AST-2-F	< 2.00	4.9	< 2.00	0.20	< 0.100	< 0.100	< 0.500	0.7	8	0.74	983	0.5	< 2.00	< 0.500	< 0.200	3.5	0.68	< 0.500	17
Mean	BDL	12.0	BDL	NC	BDL	BDL	BDL	0.7	12	0.76	1047	0.7	BDL	BDL	BDL	4.3	0.65	BDL	16
FILLET - Shortnose Sturgeon, Penobscot River 2006																			
SNS-1-F	< 2.00	5.2	< 2.00	< 0.200	< 0.100	< 0.100	< 0.500	2.7	16	4.00	999	1.0	< 2.00	< 0.500	0.20	2.9	0.50	< 0.500	18
SNS-2-F	< 2.00	4.0	< 2.00	< 0.200	< 0.100	< 0.100	< 0.500	1.3	7	0.75	1050	1.0	< 2.00	< 0.500	< 0.200	2.9	0.50	< 0.500	15
SNS-3-F	< 2.00	3.3	< 2.00	< 0.200	< 0.100	< 0.100	< 0.500	1.5	10	0.82	890	0.7	< 2.00	< 0.500	< 0.200	2.2	0.60	< 0.500	16
SNS-4-F	2.0	3.2	< 2.00	< 0.200	< 0.100	< 0.100	< 0.500	1.6	9	1.30	1120	1.0	< 2.00	< 0.500	< 0.200	2.8	0.88	< 0.500	17
Mean	NC	3.9	BDL	BDL	BDL	BDL	BDL	1.8	11	1.72	1015	0.9	BDL	BDL	NC	2.7	0.62	BDL	17
FILLET - Shortnose Sturgeon, Kennebec River 2009																			
KENN-01F	35.0	11.0	< 2.00	0.20	0.10	< 0.100	< 0.500	1.8	80	1.90	1210	1.7	< 2.00	< 0.500	< 0.200	8.9	4.90	< 0.500	17
KENN-02F	28.0	7.1	2.0	0.40	< 0.100	< 0.100	< 0.500	1.1	160	1.40	1210	2.3	< 2.00	< 0.500	< 0.200	3.6	2.90	< 0.500	15
KENN-03F	21.0	8.4	< 2.00	0.50	0.10	< 0.100	< 0.500	1.0	30	1.20	1220	2.0	< 2.00	< 0.500	< 0.200	2.3	4.70	< 0.500	15
KENN-04F	3.0	3.9	< 2.00	< 0.200	0.20	< 0.100	< 0.500	2.0	33	3.20	1070	2.0	< 2.00	< 0.500	< 0.200	1.7	1.70	< 0.500	23
KENN-05F	5.0	6.4	< 2.00	< 0.200	0.20	< 0.100	< 0.500	1.4	95	5.80	1110	1.8	< 2.00	< 0.500	< 0.200	3.2	1.90	< 0.500	22
Mean	18.4	7.4	NC	NC	NC	BDL	BDL	1.5	80	2.70	1164	2.0	BDL	BDL	BDL	3.9	3.22	BDL	18

Skinless, boneless fillets
µg/g = parts-per-million. Expressed as dry weight.
Values in red preceded by < symbol indicate non-detect and the detection limit
BDL = below detection limit, NC = not calculated

Table 8b. Trace metals in LIVER and GONAD of sturgeon recovered from the Penobscot River, µg/g dry weight.

DRY WEIGHT

Sample No.	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
LIVER - Atlantic Sturgeon, Penobscot River																			
AST-1-L	55.0	6.20	< 2.00	3.70	< 0.100	0.85	< 0.500	21.0	1100	3.80	520	2.7	< 2.00	2.1	8.1	10.00	2.50	4.3	111.0
AST-2-L	29.0	2.10	< 2.00	1.80	< 0.100	1.30	< 0.500	14.0	863	2.10	511	2.6	< 2.00	1.0	1.8	7.10	2.80	1.8	95.5
Mean	42.0	4.15	BDL	2.75	BDL	1.08	BDL	17.5	982	2.95	516	2.7	BDL	1.6	5.0	8.55	2.65	3.1	103.3
LIVER - Shortnose Sturgeon, Penobscot River																			
SNS-2-L	5.0	1.10	< 2.00	1.80	< 0.100	< 0.100	< 0.500	6.9	691	0.48	249	2.8	< 2.00	< 0.500	0.3	5.00	0.60	1.0	55.8
SNS-3-L	14.0	1.40	2.0	1.90	< 0.100	0.20	< 0.500	5.3	420	2.00	223	1.0	< 2.00	< 0.500	0.3	4.90	0.82	1.0	54.6
SNS-4-L	9.8	0.91	< 2.00	1.50	< 0.100	0.10	< 0.500	4.8	932	0.77	301	2.1	< 2.00	< 0.500	0.3	4.70	0.70	1.9	63.7
Mean	9.6	1.14	NC	1.73	BDL	NC	BDL	5.7	681	1.08	258	2.0	BDL	BDL	0.3	4.87	0.71	1.3	58.0
GONAD - Shortnose Sturgeon, Penobscot River																			
SNS-2-G	< 2.00	0.30	< 2.00	0.30	< 0.100	< 0.100	< 0.500	0.9	62	< 0.100	39	0.9	< 2.00	< 0.500	< 0.200	0.50	< 0.200	< 0.500	18.0
SNS-3-G	< 2.00	0.50	< 2.00	0.30	< 0.100	< 0.100	< 0.500	0.7	41	< 0.100	57	< 0.500	< 2.00	< 0.500	< 0.200	0.79	< 0.200	< 0.500	27.0
SNS-4-G	16.0	0.83	< 2.00	0.72	< 0.100	< 0.100	< 0.500	1.5	130	0.20	239	0.8	< 2.00	< 0.500	< 0.200	1.80	0.50	< 0.500	74.7
Mean	NC	0.54	BDL	0.44	BDL	BDL	BDL	1.0	78	NC	112	NC	BDL	BDL	BDL	1.03	NC	BDL	39.9

µg/g = parts-per-million. Expressed as dry weight.
Values in red preceded by < symbol indicate non-detect and the detection limit
BDL = below detection limit, NC = not calculated

6. Discussion

6.1 Atlantic and shortnose sturgeon. The Atlantic sturgeon is a long-lived (possibly up to 60 years), late maturing fish that can attain a length of 4.3 meters (14 feet) and weight of 362.9 kilograms (800 pounds) (Mangin 1964, Scott and Crossman 1973, Atlantic Sturgeon Status Review Team 2007). Atlantic sturgeon are omnivorous benthic feeders with the larger adults having a diet of mollusks, polychaete worms, gastropods, shrimp, amphipods, isopods, and small fish, particularly sand lance (*Ammodytes*)(Scott and Crossman 1973). Large quantities of mud may be taken in during feeding (Smith 1985). Atlantic sturgeon travel widely and forage in marine and estuarine habitats at different times of the year, and move into fresh water to spawn. The two male Atlantic sturgeon recovered in the Penobscot River in 2006 were estimated to be 12 and 13 years of age (Table 2).

The shortnose sturgeon is small compared to other sturgeon species attaining lengths up to 121.9 centimeters (4 feet), a total weight of 6.8 kilograms (15 pounds) and a maximum age of possibly 30 years for males and 67 years for females (Scott and Crossman 1973, MEIFW 2003). Like the Atlantic sturgeon, the shortnose sturgeon is a benthic feeder consuming sludge-worms, chironomid larvae, small crustaceans, and plants (Scott and Crossman 1973). Shortnose sturgeon collected from the Kennebec River in 2009 (estimated age range: 5 – 10 years, three males and two females) appeared younger than fish collected from the Penobscot River in 2006 (estimated age range: 14 – 19 years, two males and two females) (Table 2).

In the recent federal listing of Atlantic sturgeon as threatened, the Gulf of Maine Distinct Population Segment includes all Atlantic sturgeons that are spawned in the watersheds from the Maine/Canadian border and extending southward to include all associated watersheds draining into the Gulf of Maine as far south as Chatham, MA (Federal Register: February 6, 2012). Recent research by the University of New England and by USGS documents seasonal movement of Atlantic sturgeon and shortnose sturgeon among the Merrimack River, Saco River, and Kennebec River (Little 2011, Kieffer 2011). The University of Maine has documented seasonal movements of Atlantic and shortnose sturgeon between the Penobscot River and Kennebec River (Fernandes *et al*. 2010, Dionne 2010) and in small coastal rivers between the Kennebec and Penobscot Rivers (Zydlewski *et al*. 2011). In this report, contaminant concentrations are presented based on where the fish were collected – the Penobscot or Kennebec. Due to the documented seasonal movements of sturgeon in Maine, however, contaminant uptake could have occurred anywhere in the two large Maine rivers or in the smaller rivers between them (i.e., St. George, Medomak or Damariscotta Rivers). Hence, contaminant levels in sturgeon tissue should not be ascribed to a particular Maine river. Moreover, none of the sturgeon analyzed for this study were examined for genetics. The river of origin for any of the sturgeon analyzed for this report is not known.

Due to the relatively large size of sturgeon, whole-body contaminant analyses would have been impractical. Tissues used in this contaminant screening were muscle fillets, liver, and gonad.

Muscle tissue is often used in residue analyses to assess human health risk since fillets are often extracted from sportfish for consumption. Axial muscle or fillet tissue is known to accumulate trace metals such as selenium, arsenic, and mercury (Schmitt and Finger 1987). The liver is an organ with a high capacity to bind, concentrate, biotransform, and excrete contaminants (Klaassen 1986). Livers have been used in fish studies to monitor trace metals (Benoit 1975, Lindsey *et al*. 1998) and are currently being used to assess emerging contaminants of concern (EPA 2009). Residues in gonad tissue can be used to assess parental transfer of contaminants to offspring (Gillespie and Baumann 1986).

Lipid content is higher in liver and gonad tissue than fillets (Table 3). Consequently, concentrations of lipophilic contaminants such as organochlorine compounds will be higher in organ tissues than fillets.

6.2 Data Comparisons. To place the Maine sturgeon contaminant concentrations in context, fillet, liver, or gonad levels were qualitatively compared to concentrations reported in other Atlantic and shortnose sturgeon investigations in Maine or elsewhere. Few Atlantic and shortnose sturgeon contaminant residue studies were found in the scientific literature for the Gulf of Maine. A couple of dozen shortnose sturgeon and Atlantic sturgeon from the St. John estuary in New Brunswick were examined for mercury between 1973 and 1975 (Dadswell 1975). One shortnose sturgeon from the Kennebec River in Maine was also analyzed for organochlorines and metals in 2003 (ERC 2003). In 2007, a large Atlantic sturgeon (Total Length 163cm, Total Weight 20.5 kilograms) from Cape Cod in Massachusetts was examined for dioxins, furans, other organochlorines, PBDE, and trace metals (Mierzykowski 2010). Based on genetic analyses, this particular Atlantic sturgeon had the highest likelihood of being of Kennebec River origin (T. King. USGS – Leetown Science Center. 2010. Personal communication). Sturgeon from two other Distinct Population Segments have also been examined for contaminants. Total PCB was measured in over a dozen Atlantic sturgeon and two shortnose sturgeon from the Hudson River in New York in 1992 and 1998 (Sloan *et al*. 2005). Two shortnose sturgeon from the Delaware River in Pennsylvania in 2001 were analyzed for organochlorine compounds and trace metals (ERC 2002). These studies allow a rough comparison of contaminant burdens in sturgeon among areas, but clearly more residue data is needed from both species throughout all the Distinct Population Segments.

If available, suggested toxicity threshold effect levels for fish were also used to evaluate tissue concentrations. Toxicity threshold effect levels for contaminants in fish and wildlife have been suggested by several investigators for different compounds and metals (e.g., Newell *et al*. 1987, Eisler and Belisle 1996, Beckvar *et al*. 2005, Hinck *et al*. 2009, Beyer and Meador 2011). These threshold levels typically represent consensus values based on toxicity investigations involving a variety of fish species. Data from national and regional bio-monitoring programs (Yeardley *et al*. 1998, Hinck *et al*. 2009, Stahl *et al*. 2009) or human-health consumption advisory action levels (FDA 2000, EPA 2000, MECDC 2001) were also used to evaluate sturgeon residue concentrations.

Data from the information sources above have a host of limitations (e.g., potential differences in species-specific sensitivities; geographic or habitat variations; sex and age differences; sample type – muscle, organ, or whole-body; etc.) and are marginally useful for qualitatively assessing contaminant burdens in fish tissue. The inclusions of these data are only meant to place the contaminant burdens in Maine sturgeon in context with other sturgeon and fish investigations (i.e., are the contaminant levels in Maine sturgeon relatively higher or lower than concentrations reported elsewhere). Lastly, both species are protected under the Endangered Species Act and it would be illegal to catch and consume a sturgeon. U.S. Food and Drug Administration (FDA 2000), Environment Protection Agency (EPA 2000), or Maine Center for Disease Control and Prevention (MECDC 2001) consumption limits or fish tissue action levels (FTALs) are only provided for information purposes.

6.3 Organochlorine and organobromine compounds. The analytical suite included 23 organochlorine compounds. Several compounds such as benzene hexachlorides (BHCs), chlordanes, cyclodiene pesticides (e.g., aldrin, endrin, dieldrin), were below detection limits or detected at low concentrations (< 5 ng/g) and will not be discussed. Two organochlorine compounds are discussed – polychlorinated biphenyl (PCB), dichloro-diphenyl-trichloroethane (DDT) - along with one organobromine compound - polybrominated diphenyl ether (PBDE).

6.3.1 Polychlorinated Biphenyl (PCB) - PCBs were used for decades as a coolant and insulating agent in electrical transformers and capacitors (Eisler and Belisle 1996). Although PCBs were banned in the United States in 1979, the compound persists in the environment as a legacy contaminant from historic discharges and improper disposal practices. Incineration of PCB-contaminated material has also spread the compound worldwide through atmospheric deposition. PCBs, particularly PCBs with dioxin-like activity, adversely affect survival, growth, reproduction, metabolism, and accumulation in wildlife (Eisler and Belisle 1996).

PCB Data Comparisons. Comparative PCB data were found for sturgeon collected in Maine, Massachusetts, New York, and Pennsylvania (Table 9).

Table 9. Total PCB in sturgeon tissues, ng/g wet weight

Species	Year	n	Location	Muscle	Liver	Gonad	Data Source
Atlantic Sturgeon	2006	2	Penobscot River, ME	< 5.0	< 5.0		This Report
Atlantic Sturgeon	2007	1	Wellfleet, MA	124.0	894.0	1890.0	Mierzykowski 2010
Atlantic Sturgeon	1993-1998	14	Hudson River, NY	2170.0			Sloan *et al*. 2005
Shortnose Sturgeon	2006	4	Penobscot River, ME	< 5.0	< 5.0[a]	< 5.0[a]	This Report
Shortnose Sturgeon	2009	5	Kennebec River, ME	864.6			This Report
Shortnose Sturgeon	2003	1	Kennebec River, ME	370.0	710.0	2500.0	ERC 2003[b]
Shortnose Sturgeon	1992	1	Hudson River, NY	28400.0			Sloan *et al*. 2005
Shortnose Sturgeon	1998	1	Hudson River, NY	8700.0			Sloan *et al*. 2005
Shortnose Sturgeon	2001	1	Delaware River, PA	< 33.0	2000.0	5700.0	ERC 2002[b]
Shortnose Sturgeon	2001	1	Delaware River, PA	< 36.0	< 73.0	< 86.0	ERC 2002[b]

[a] Three samples analyzed, [b] Reported as Aroclor 1260

Total PCB Hazard Assessment – Newell *et al*. (1987) proposed a fish flesh guideline of 120 ng/g ΣPCB to protect fish-eating wildlife. Eisler and Belisle (1996) proposed a ΣPCB criterion range for the protection of aquatic life of 300 (eggs) to 400 ng/g (whole-body). Fillets of shortnose sturgeon recovered from the Kennebec (mean 864.6 ng/g) exceeded the 120 ng/g suggested guideline. Estimated whole-body PCB concentrations of Kennebec shortnose sturgeon (mean 1988.6 ng/g, using a fillet-to-whole body conversion equation in Bevelhimer *et al*. 1997) would also exceed the whole-body proposed criteria in Eisler and Belisle (1996).

The current FDA guideline for PCBs in fish tissue is 2000 ng/g in an edible portion (FDA 2000). Fillet samples from Atlantic sturgeon and shortnose sturgeon recovered from the Penobscot in 2006 (< 5.0 ng/g) did not exceeded the FDA guideline. Mean ΣPCB in fillets of five shortnose sturgeon recovered from the Kennebec in 2009 (864 ng/g; range: 243 – 1900 ng/g) also would not exceed the FDA guideline. All shortnose sturgeon fillets from the Kennebec, however, would greatly exceed EPA cancer and non-cancer endpoints (EPA 2000), and Maine cancer (11 ng/g) and non-cancer action (43 ng/g) levels (MECDC 2001) resulting in restricted consumption limits.

6.3.2 Dichloro-diphenyl-trichloroethane (DDT) – DDT was used in northern Maine in the 1950s and 1960s for the control of spruce budworm (*Choristoneura fumiferana*). The insecticide was last used in Maine in 1967 (Dimond and Owen 1996), but the compound decays slowly due to low soil temperatures, high organic matter, and low microbial population (Owen *et al*. 1977). During the years of DDT spraying in the state, elevated concentrations of the compound were detected in fish tissue. In an early 1960s study in Maine, Warner and Fenderson (1962) reported DDT concentrations in whole-body brook trout ranging from 300 to 25,900 ng/g (assumed wet weight). The levels of DDT metabolites currently detected in sturgeon samples illustrate the persistence of this insecticide after its last use in Maine 40 years ago.

DDE Data Comparisons. Comparative p,p'-DDE data for sturgeon collected in Maine, Massachusetts, and Pennsylvania are listed in Table 10.

Table 10. *p,p'*-DDE in sturgeon tissues, ng/g wet weight

Species	Year	n	Location	Muscle	Liver	Gonad	Data Source
Atlantic Sturgeon	2006	2	Penobscot River, ME	2.1	4.4		This Report
Atlantic Sturgeon	2007	1	Wellfleet, MA	2.4	39.8	69.5	Mierzykowski 2010
Shortnose Sturgeon	2006	4	Penobscot River, ME	9.3	4.8[ab]	44.0[a]	This Report
Shortnose Sturgeon	2009	5	Kennebec River, ME	19.3			This Report
Shortnose Sturgeon	2003	1	Kennebec River, ME	< 15	<29	<140	ERC 2003
Shortnose Sturgeon	2001	2	Delaware River, PA	205	435	1800	ERC 2002

[a] Three samples analyzed. [b] DDE in one liver was below detection, ½ detection limit used in average.

DDT Hazard Assessment – For DDT, the parent compound of DDE, a protective whole-body concentration of 600 ng/g in juvenile fish and adult fish, and a 700 ng/g for early life-stage fish has been suggested (Beckvar *et al*. 2005). Since these values were primarily based on mortality studies, a lower threshold value (e.g., 480 ng/g, the 5th empirical percentile low-effect residue in Beckvar *et al*. 2005) may be more appropriate (Meador, J. NOAA. 2012. Personal communication). None of the fillet, gonad, or liver tissue samples from the sturgeon collected from the Penobscot and Kennebec Rivers approached the protective concentration levels suggested by Beckvar *et al*. (2005). Estimated Maine sturgeon whole-body p,p'-DDE (max. 98.4 ng/g) and ΣDDT (max. 126.7 ng/g) concentrations (based on a fillet-to-whole body conversion equation in Bevelhimer *et al*. 1997) would also be lower than the suggested tissue effect threshold (Beckvar *et al*. 2005).

Lethal concentrations of ΣDDT in whole-body fish range from 290 to 113,000 ng/g with a mean of 2,380 ng/g (Beckvar and Lotufo 2011). Reduced sex steroid production can occur in adult fish with *p,p*'-DDE residues of 400 to 600 ng/g (Beckvar and Lotufo 2011). Mean ΣDDT concentrations in Atlantic sturgeon (Penobscot) and shortnose sturgeon (Penobscot and Kennebec combined) fillets were 6.0 ng/g and 28.4 ng/g, respectively, so lethal and sub-lethal thresholds were not reached.

The FDA action level for DDT in fish tissue is 5,000 ng/g (FDA 2000) and shortnose sturgeon fillets from the Kennebec were well below this level. MECDC (2001) fish tissue action levels for DDT are 64 ng/g for cancer and 1,080 ng/g for non-cancer. All sturgeon fillet samples from the Kennebec River in 2009 would exceed the state's DDT cancer action level and one would exceed the non-cancer action level.

6.3.3 Polybrominated diphenyl ether (PBDE) – PBDEs are flame-retardant chemicals added to plastics, electronics, and foam products. Similar to PCBs, PBDEs exist as mixtures of similar chemicals called congeners. The three primary groups of PBDEs are penta-BDE, octa-BDE, and deca-BDE. Because they are mixed into products rather than bound to them, PBDEs can leave the products that contain them and enter the environment. PBDEs enter air, water, and soil during their manufacture and use, and through atmosphere deposition, wastewater treatment facilities, and runoff (Anderson and MacRae 2006). PBDEs do not dissolve easily in water, but adhere to particles and settle to the bottom of rivers or lakes where they can accumulate in fish.

PBDE Data Comparisons ΣPBDE in five shortnose sturgeon fillets from the Kennebec in 2009 ranged from 4.4 to 39.1 ng/g. These concentrations are similar to a study that measured PBDE levels in wild caught and farm-raised fish sold in fish markets and large-chain supermarkets (0.04 to 38 ng/g, Hayward *et al*. 2007). An Atlantic sturgeon of Kennebec River origin recovered on Cape Cod in 2007 had 8.8 ng/g of ΣPBDE in its fillet (Mierzykowski 2010). One study was found in the literature that reported PBDE concentrations in Maine fish tissue. Anderson and

MacRae (2006) measured PBDE in smallmouth bass fillets from the Penobscot River and expressed their results on a lipid weight basis. ΣPBDE in bass fillets from three locations on the river ranged from 2,800 to 17,000 ng/g lipid (Table 11). In comparison, ΣPBDE in five sturgeon fillets from the Kennebec ranged from 81 to 3,390 ng/g lipid (mean 1,696 ng/g lipid); considerably lower than the Penobscot bass.

Total PBDE Hazard Assessment - Toxicity threshold levels for ΣPBDE in fish have not been developed. Compared to the study by Hayward *et al*. (2007) that measured PBDE residue levels in wild and farm-raised fish fillets from supermarkets, ΣPBDE concentrations in sturgeon fillets from the Penobscot and Kennebec Rivers do not appear to be elevated.

Risk-based thresholds for PBDE in fish tissue have yet to be developed (Hites *et al*. 2004). Virginia has developed a trigger level of 500 ng PBDE/g for issuance of a human-health, fish-eating advisory (Flammia 2010). Fish with average PBDE concentrations ranging from 500 ng/g to 1,000 ng/g would trigger a consumption advisory of 2 fish meals/month. Virginia would recommend no consumption of fish with average PBDE concentrations exceeding 1,000 ng/g (Flammia 2010). Average PBDE concentration in shortnose sturgeon from the Kennebec River was 26.1 ng/g wet weight; well below the VA suggested consumption trigger levels. It is not known at this time if the liver or gonad tissue PBDE concentrations in the Penobscot and Kennebec sturgeon would be considered elevated or within normal ranges.

Table 11. PBDE in fillets of shortnose sturgeon from the Kennebec compared to smallmouth bass from the Penobscot River, ng/g lipid **LIPID WEIGHT**

Location	Species (number)	Year	Total PBDE	BDE-47	BDE-71	BDE-85	BDE-99	BDE-100	BDE-138	BDE-153	BDE-154
Kennebec River	SNS (5)	2009	1696	698 (415)	< DL	< DL	19 (11)	429 (417)	< DL	26 (11)	261 (292)
Penobscot River - C	SmB (5)	2002	17000	6490 (3004)	378 (169)	< 50	5630 (5700)	1790 (1199)	< DL	544 (395)	579 (381)
Penobscot River - B	SmB (5)	2002	8100	3730 (3133)	200 (136)	< 50	2210 (1286)	937 (575)	109 (115)	274 (123)	625 (290)
Penobscot River - A	SmB (3)	2002	2800	161 (103)	88 (108)	< 50	736 (273)	180 (157)	141 (66)	63 (66)	102 (75)

SNS = shortnose sturgeon, SmB = smallmouth bass

SNS fillets were skinless and boneless. SmB fillets were skinless and boneless.

Penobscot data from Anderson and MacRae (2006, see page 1156 Table 1)

< DL indicates less than detection limit

Mean concentrations with standard deviations in parentheses

Nine congeners analyzed in Anderson and MacRae (2006). Thirty-nine congeners analyzed for this study - see Table 6 for congener list.

6.4 Trace metals. Trace elements are naturally occurring and regularly found in soil, sediment, water, and biota. Some trace elements are essential nutrients for biota, but may be hazardous at highly elevated levels. Although 19 trace metals were included in the analytical scan, only five are discussed below – arsenic, copper, mercury, selenium, and zinc. Aluminum and chromium are not discussed since fillet samples were wrapped in aluminum foil. Boron, beryllium, cadmium, molybdenum, lead, and vanadium concentrations were at or below their respective detection limits. Iron, magnesium, and manganese are essential elements and practically non-toxic (Merian 1991). Ecological effect data related to barium or strontium levels in fish tissue are not available.

6.4.1 Arsenic (As) - Arsenic is a metalloid used in the production of pesticides and wood preservatives. Coal-fired power utilities and metal smelters annually release tons of arsenic into the atmosphere (Environment Canada 1993). Pressure-treated lumber has been used extensively for construction with earlier pressure-treated formulations containing chromated copper arsenate. Arsenic is a teratogen and carcinogen, which bioconcentrates in organisms, but does not biomagnify in food chains (Eisler 1994).

Arsenic Data Comparisons. Comparative As data were found for sturgeon collected in Maine, Pennsylvania, and Florida (Table 12).

Table 12. Arsenic (As) in sturgeon tissues, μg/g wet weight

Species	Year	n	Location	Muscle	Liver	Gonad	Data Source
Atlantic Sturgeon	2006	2	Penobscot River, ME	2.75	0.87		This Report
Atlantic Sturgeon	2007	1	Wellfleet, MA	4.90	3.80	2.50	Mierzykowski 2010
Shortnose Sturgeon	2006	4	Penobscot River, ME	0.99	0.41[a]	0.30[a]	This Report
Shortnose Sturgeon	2009	5	Kennebec River, ME	1.77			This Report
Shortnose Sturgeon	2001	2	Delaware River, PA	< 5.00	< 5.00	< 5.00	ERC 2002

[a] Three samples analyzed

Arsenic Hazard Assessment – One suggested As toxicity threshold level for fish is 3 μg/g (USDOI 1998a, converted to wet weight based on 75% moisture). Hinck *et al*. (2009) provided an As toxicity threshold range of 2.2 μg/g to 11.6 μg/g for whole-body freshwater fish. Shortnose sturgeon tissue samples from the Penobscot and Kennebec did not exceed suggested whole-body toxicity thresholds. Atlantic sturgeon recovered from the Penobscot had higher As tissue concentrations than shortnose sturgeon.

Arsenic concentrations in sturgeon fillet samples are reported by the analytical laboratory as total arsenic. EPA Health Endpoints and MECDC Action levels, however, are for inorganic As. Reported sturgeon fillet As concentrations were multiplied by 0.1 under the assumption that 10% of the total As in fish is inorganic As (FDA 1993, MECDC 2001). Non-cancer endpoints would not be exceeded by As levels in sturgeon fillets, but Maine and EPA endpoints would result in consumption limits.

6.4.2 Copper (Cu) - Copper is used in the preservation and coloring of foods, and in brass and Cu water pipes and domestic utensils (Gross *et al*. 2003). Copper is also a fish neurotoxin that is found in fungicides, algaecides, vehicle exhaust and brake pad wear (Sandahl *et al*. 2004). Exposure to waterborne or dissolved Cu impairs juvenile salmon sensory physiology and predator avoidance (Hecht *et al*. 2007, Sandahl *et al*. 2007). Copper is not carcinogenic, mutagenic, or teratogenic at environmentally realistic concentration (Eisler 1997).

Copper Data Comparisons. Comparative Cu data were found for sturgeon collected in Maine, Massachusetts, and Pennsylvania (Table 13).

Table 13. Copper (Cu) in sturgeon tissues, µg/g wet weight

Species	Year	n	Location	Muscle	Liver	Gonad	Data Source
Atlantic Sturgeon	2006	2	Penobscot River, ME	0.20	3.60		This Report
Atlantic Sturgeon	2007	1	Wellfleet, MA	0.29	6.90	0.24	Mierzykowski 2010
Shortnose Sturgeon	2006	4	Penobscot River, ME	0.44	2.10[a]	0.59[a]	This Report
Shortnose Sturgeon	2009	5	Kennebec River, ME	0.33			This Report
Shortnose Sturgeon	2003	1	Kennebec River, ME	< 5.00	< 5.00	14.00	ERC 2003
Shortnose Sturgeon	2001	2	Delaware River, PA	0.85	16.5	1.35	ERC 2002

[a] Three samples analyzed

Copper Hazard Assessment – One suggested toxicity threshold level for Cu in whole-body fish is 3.3 µg/g (USDOI 1998b, converted from dry weight to wet weight based on 75% moisture). Hinck *et al*. (2009) presented a suggested higher Cu toxicity threshold range for whole-body freshwater fish between 11.1 µg/g and 42.0 µg/g. The liver Cu concentration in the Penobscot River Atlantic sturgeon would exceed the lower suggested whole-body threshold concentration (USDOI 1998b), but be lower than the range suggested by Hinck *et al*. (2009).

Copper concentrations in fillet and gonad tissue from the Penobscot and Kennebec River sturgeon would be well below the USDOI (1998b) or Hinck *et al*. (2009) threshold levels.

6.4.3 Mercury (Hg) - Mercury is a global pollutant with biological mercury hotspots existing in the northeastern United States (Evers *et al*. 2007). Potential sources of Hg contamination include emissions from coal-fired energy facilities, incinerators, mining activities, operation of chlor-alkali plants, and disposal of mercury-contaminated products such as batteries and fluorescent lamps (Eisler 1987). Possibly the largest Hg point source in Maine is the former Holtra-Chem facility located on the east bank of the Penobscot River in Orrington. Elevated levels of Hg have been detected in fish and wildlife downriver from the former chlor-alkali facility (Bodaly *et al*. 2009).

Mercury is a mutagen, teratogen, and carcinogen which bioconcentrates in organisms and biomagnifies through food chains (Eisler 1987). The most toxic form or Hg is the organic form, methylmercury. Methylmercury may account for nearly all of the total mercury in fish tissue (Grieb *et al*. 1990) and preferentially accumulates in axial muscle tissue. Chronic exposure to elevated dietary Hg (> 10 µg/g) caused oxidative stress, brain lesions, and altered behavior in Atlantic salmon parr (Berntssen *et al*. 2003).

Mercury Data Comparisons. Mercury concentrations in sturgeon tissues have been reported for New Brunswick, Maine, Massachusetts, and Pennsylvania (Table 14).

Table 14. Mercury (Hg) in sturgeon tissues, µg/g wet weight

Species	Year	n	Location	Muscle	Liver	Gonad	Data Source
Atlantic Sturgeon	2006	2	Penobscot River, ME	0.18	0.61		This Report
Atlantic Sturgeon	2007	1	Wellfleet, MA	0.15	0.44	< 0.02	Mierzykowski 2010
Atlantic Sturgeon	1973 - 1975	30	St. John Estuary, NB	0.29		0.04	Dadswell 1975
Shortnose Sturgeon	2006	4	Penobscot River, ME	0.42	0.41[a]	0.07[a]	This Report
Shortnose Sturgeon	2009	5	Kennebec River, ME	0.55			This Report
Shortnose Sturgeon	2003	1	Kennebec River, ME	0.26	0.15	0.12	ERC 2003
Shortnose Sturgeon	1973 -1975	24	St. John Estuary, NB	1.17		0.30	Dadswell 1975
Shortnose Sturgeon	2001	2	Delaware River, PA	0.08	1.04	0.06	ERC 2002

[a] Three samples analyzed

Mercury Hazard Assessment – Axial muscle tissue with concentrations of 6 µg/g to 20 µg/g are associated with Hg toxicity in fish (Wiener *et al*. 2003). Sub-lethal effects of Hg on freshwater fish, including changes in reproductive health, have been observed in laboratory and field studies of fish with having approximately 0.50 µg Hg/g wet weight or greater in the fillet (Sandheinrich and Wiener 2011). Four of nine shortnose sturgeon fillets had Hg concentrations above this sub-lethal effect threshold.

The mean Hg concentration in fillets (0.49 µg/g) and estimated whole-body (0.26 µg/g, based on a conversion equation in Peterson *et al*. 2007) of shortnose sturgeon from the Penobscot and Kennebec were elevated compared to freshwater regional and national fish tissue bio-monitoring programs (0.17 µg/g, Yeardley *et al*. 1998; 0.13 µg/g, Hinck *et al*. 2009; both include multiple species analyzed whole-body). Stahl *et al*. (2009) examined Hg in fillets of predator fish species from 500 lakes in the lower 48 U.S. states and found a mean concentration of 0.35 µg/g. Mean Hg in Penobscot and Kennebec shortnose sturgeon was identical to the concentration found in fillets of predator fish (0.49 µg/g) and considerably higher than the mean level in whole-body omnivore fish (0.23 µg/g) from 125 Maine lakes (Mower *et al*. 1997).

Beckvar *et al*. (2005) suggested a Hg whole-body tissue threshold-effect level (t-TEL) of 0.20 µg/g would be protective of juvenile and adult fish. Estimated whole-body Hg levels in two shortnose sturgeon recovered from the Penobscot and five shortnose sturgeon recovered from the Kennebec would exceed the suggested t-TEL.

6.4.4 Selenium (Se) - Selenium is a beneficial or essential element for some biota at trace amounts to parts-per-billion concentrations, but toxic at elevated concentrations (Eisler 1985). Selenium is present in rocks and soils. However, coal and oil combustion, nonferrous metal production, iron manufacturing, municipal and sewage refuse incineration, and production of phosphate fertilizers introduce greater amounts of Se into the environment than natural sources (Ohlendorf 2003).

Selenium Data Comparisons. Comparative Se data were found for sturgeon collected in Massachusetts and Pennsylvania (Table 15).

Table 15. Selenium (Se) in sturgeon tissues, µg/g wet weight

Species	**Year**	**n**	**Location**	**Muscle**	**Liver**	**Gonad**	**Data Source**
Atlantic Sturgeon	2006	2	Penobscot River, ME	1.02	1.80		This Report
Atlantic Sturgeon	2007	1	Wellfleet, MA	2.90	7.00	1.10	Mierzykowski 2010
Shortnose Sturgeon	2006	4	Penobscot River, ME	0.68	1.80[a]	0.57[a]	This Report
Shortnose Sturgeon	2009	5	Kennebec River, ME	0.95			This Report
Shortnose Sturgeon	2001	1	Delaware River, PA	< 10.00	<10.00	< 10.00	ERC 2002
Shortnose Sturgeon	2001	1	Delaware River, PA	< 10.00	< 10.00	<10.00	ERC 2002

[a] Three samples analyzed

Selenium Hazard Assessment – Lemly (1996) suggested Se thresholds that affect health and reproduction success of freshwater and anadromous fish of 1 µg/g for whole-body, 2 µg/g for skeletal muscle or skinless fillets, 3 µg/g for liver, and 2.5 µg/g for ovaries and eggs (all converted from dry weight to wet weight based on 75% moisture). Except for one fillet sample of a shortnose sturgeon recovered from the Kennebec River (2.40 µg/g KENN-01F), tissue concentrations of sturgeon recovered from the Penobscot and Kennebec did not exceed these suggested Se thresholds.

6.4.5 Zinc (Zn) - Zinc is used in galvanized metal alloys, paints, wood preservatives, fertilizers, and rodenticides (Opresko 1992, Eisler 1993). Zinc is an essential trace nutrient that is required in relatively high concentrations and is a cofactor of enzymes regulating metabolic processes (Leland and Kuwabara 1985). Citing several sources, Murphy *et al*. (1978) reported average Zn whole fish concentrations from uncontaminated areas ranging from 12 to 43 µg/g.

Zinc Data Comparisons. Comparative Zn data were found for sturgeon collected in Maine, Massachusetts and Pennsylvania (Table 16).

Table 16. Zinc (Zn) in sturgeon tissues, µg/g wet weight

Species	**Year**	**n**	**Location**	**Muscle**	**Liver**	**Gonad**	**Data Source**
Atlantic Sturgeon	2006	2	Penobscot River, ME	3.8	21.5		This Report
Atlantic Sturgeon	2007	1	Wellfleet, MA	5.6	27.0	4.5	Mierzykowski 2010
Shortnose Sturgeon	2006	4	Penobscot River, ME	4.1	21.1[a]	21.4[a]	This Report
Shortnose Sturgeon	2009	5	Kennebec River, ME	4.0			This Report
Shortnose Sturgeon	2003	1	Kennebec River, ME	6.0	65.0	28.0	ERC 2003
Shortnose Sturgeon	2001	2	Delaware River, PA	7.3	32.0	47.5	ERC 2002

[a] Three samples analyzed

Zinc Hazard Assessment – Zinc tissue levels in the sturgeon fillets from the Penobscot and Kennebec Rivers were similar to levels reported in other sturgeon studies.

Hinck *et al*. (2009) presented a suggested Zn toxicity threshold range for whole-body freshwater fish between 40 and 60 µg/g. Tissue samples from the sturgeon collected in Maine did not approach this suggested Zn threshold range. A Zn threshold level for estuarine and marine species has not been established.

7. Summary and Management Recommendation

Summary - In the Gulf of Maine, the shortnose sturgeon (*Acipenser brevirostrum*) is a federally-listed endangered species and the Atlantic sturgeon (*Acipenser oxyrinchus*) is a recently listed threatened species. Between June and August 2006, six sturgeon were collected from the Penobscot River in Maine - two Atlantic sturgeon and three shortnose sturgeon died during scientific sampling activities and one shortnose sturgeon was killed by a seal. In July 2009, three shortnose sturgeon were recovered on the Kennebec River in Georgetown after a red tide event. A month later two more shortnose sturgeon were recovered further north in the Kennebec River near Phippsburg; apparent victims of seal predation. Shortnose and Atlantic sturgeon move seasonally between these two large Maine rivers and along the Maine coast to smaller rivers.

- Total PCB in sturgeon fillets ranged from below the detection limit (< 5.00 ng/g) to 1,900.00 ng/g. Five shortnose sturgeon had PCB fillet concentrations that would exceed suggested criteria for protecting fish-eating wildlife (120 ng/g, Newell 1987) and aquatic life (300 – 400 ng/g, Eisler and Belisle 1996).

- Total PBDE in five shortnose sturgeon fillets ranged from 4.4 ng/g to 39.1 ng/g. Congener BDE #47 was the greatest contributor to Total PBDE. The PBDE concentration range in Kennebec sturgeon was similar to a study that measured PBDE levels in wild-caught fish sold in fish markets and large-chain supermarkets (0.04 to 38 ng/g, Hayward *et al*. 2007).

- DDT metabolites and isomers were detected in all sturgeon samples, but at low concentrations compared to suggested toxicity threshold levels. DDT concentrations in sturgeon recovered from the Kennebec River in 2009, however, were sufficiently elevated to trigger state fish consumption advisories (MECDC 2001).

- Other organochlorine compounds in fillet samples were below detection limits or detected at low concentrations (~ 5 ng/g).

- Mercury in fillets of shortnose sturgeon from the Penobscot and Kennebec (mean 0.49

µg/g, range: 0.19 to 1.00 µg/g) were elevated compared to freshwater regional and national fish tissue bio-monitoring programs (0.17 µg/g, Yeardley *et al*. 1998; 0.13 µg/g, Hinck *et al*. 2009; both include multiple species analyzed whole-body; 0.35 µg/g in predator fillets, Stahl *et al*. 2009). Mean Hg in Penobscot and Kennebec shortnose sturgeon was identical to the concentration found in fillets of predator fish (0.49 µg/g) and considerably higher than the mean level in whole-body omnivore fish (0.23 µg/g) from 125 Maine lakes (Mower *et al*. 1997). Mercury levels in both Atlantic sturgeon fillets were 0.18 µg/g. A suggested tissue threshold-effect concentration for Hg in whole-body fish is 0.20 µg/g (Beckvar *et al*. 2005) and the Maine Action Level for consumption is also 0.20 µg/g (MECDC 2001). Both Atlantic sturgeon and one shortnose sturgeon fillets were essentially at the Hg tissue threshold effect concentration and state Action Level. Eight shortnose sturgeon fillets exceeded the whole-body effect threshold concentration and Action Level for Hg.

- Concentrations of 18 other trace metals in sturgeon tissue samples appeared consistent with levels reported in other sturgeon studies. The only exception was selenium in one fillet sample (2.40 µg/g) from a shortnose sturgeon recovered from the Kennebec River, which exceeded a suggested tissue effect threshold (2.00 µg/g, Lemly 1996).

<u>Management Recommendations</u> - With the recent listing of the Atlantic sturgeon as threatened in the Gulf of Maine Distinct Population Segment, additional data are needed to thoroughly assess contaminant burdens in sturgeon from this DPS.

Tissues from Atlantic and shortnose sturgeon carcasses opportunistically encountered or mortalities from scientific studies in the Gulf of Maine should be analyzed for contaminant residues. Bile samples from fresh carcasses should be examined for polycyclic aromatic hydrocarbons. Gonads from fresh carcasses should be preserved for histological examinations for evidence of intersex. Plasma samples from live animals captured for scientific studies should be analyzed for sex steroids (e.g., 17β estradiol, 11-ketotestosterone, and testosterone) and vitellogenin. These plasma analyses would provide insight into the potential for endocrine disruption.

Non-lethal tissue sampling should be considered during scientific collections of both sturgeon to document Hg exposure. Non-lethal samples combined with information collected from dead carcasses may be useful if a Natural Resource Damage Assessment is considered for the lower Penobscot River.

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