SPECIAL PROJECT REPORT FY09-MEFO-4-EC
Maine Field Office – Ecological Services December 2010

Environmental Contaminants in Tissues from an Atlantic Sturgeon (*Acipenser oxyrinchus*) Recovered in Wellfleet, Massachusetts

Fish and Wildlife Service

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Executive Summary

On February 2, 2007, a family walking along a Cape Cod beach in Wellfleet, Massachusetts, came upon a large dead sturgeon in the sand. The 5 foot, 45 pound sturgeon was later identified as a male Atlantic sturgeon (*Acipenser oxyrinchus*) with an estimated age of 17 years. Atlantic sturgeon are long-lived, late maturing, estuarine-dependent, anadromous, benthic feeding fish that inhabit the Atlantic coast from the Canadian Maritimes to Florida. Since very little information is available regarding contaminant burdens in Atlantic sturgeon from the New England area, the National Marine Fisheries Service (NMFS) funded an Interagency Agreement with the U.S. Fish and Wildlife Service (USFWS) so contaminant concentrations in muscle, liver, and gonad samples from the sturgeon carcass could be determined. Single samples of each tissue type were analyzed for dioxins, furans, polychlorinated biphenyl (PCBs), polychlorinated diphenyl ethers (PBDEs), other organic compounds (e.g., DDT, chlordanes), trace metals (e.g., arsenic, mercury, lead), and lipid content.

Dioxin toxic equivalent (TCDD-TEQs) values, which are an expression of combined concentrations of dioxins, furans, and dioxin-like PCB congeners, were determined in each tissue sample. TCDD-TEQs levels in tissue samples from the Wellfleet Atlantic sturgeon (max. 24.2 parts-per-trillion, ppt wet weight in gonad) were below suggested toxicity threshold levels. Over 95% of the TCDD-TEQ in muscle, liver, and gonad tissue was comprised of dioxins and furans. Dioxin-like PCB congeners contributed less than 5% to the TCDD-TEQ.

Total PCB in sturgeon tissue samples ranged from 124 parts-per-billion (ppb, wet weight) in muscle tissue to 1,890 ppb in gonad tissue. These Total PCB tissue concentrations exceed suggested toxicity threshold levels for fish. Dominant PCB congeners in all three tissue samples were PCB# 153 and PCB# 138.

Total PBDE ranged from 8.8 ppb in muscle to 148.0 ppb in gonads. A suggested toxicity threshold level for PBDE in fish has not been established, but the PBDE levels detected in the Wellfleet Atlantic sturgeon muscle tissue were similar to concentrations in fish from other regions of the U.S. The dominant PBDE congener in all three tissue samples was BDE# 47.

Among the other organic compounds included in the analytical suite, concentrations were generally low compared to suggested threshold effect levels or other sturgeon studies. Among organic compounds, the breakdown metabolites of the insecticide DDT (dichloro-diphenyl-tricloroethane) were found at higher concentrations than other organic compounds such as chlordanes (max. 37.3 ppb) and benzene hexachloride (max. 7.8 ppb). Total DDT (the sum of six metabolites) was found at a concentration of 120.6 ppb in gonad tissue with lower levels found in muscle (8.3 ppb) and liver tissue (76.6 ppb). DDT concentrations in tissue samples from the Wellfleet Atlantic sturgeon were below suggested toxicity threshold levels.

Mercury, chromium, copper, selenium, and zinc were found in some sturgeon tissue samples at elevated concentrations compared to threshold levels or other sturgeon studies. Mercury in muscle tissue (0.15 parts-per-million, ppm wet weight) and liver tissue (0.44 ppm) approached or exceeded the suggested whole-body toxicity threshold level of 0.20 ppm. Chromium tissue concentrations (max. 2.20 ppm) in the Wellfleet Atlantic sturgeon were higher than levels reported in other sturgeon studies. Copper in the sturgeon's liver tissue (6.90 ppm) exceeded a suggested threshold concentration of 3.30 ppm. Selenium in muscle (2.90 ppm) and liver (7.00 ppm) tissue samples from the sturgeon exceeded suggested threshold concentrations of 2.00 ppm and 3.00 ppm, respectively. Zinc levels in the sturgeon were low compared to suggested toxicity threshold concentrations and similar to levels reported in other sturgeon studies.

With the recently proposed listing of the Atlantic sturgeon under the Endangered Species Act, additional data are needed to thoroughly assess contaminant burdens in sturgeon. It is recommended that tissues and eggs from Atlantic sturgeon carcasses opportunistically encountered or mortalities from scientific studies be analyzed for contaminant residues.

PREFACE

This report provides documentation of environmental contaminants in tissues from a dead Atlantic sturgeon recovered on a beach in Wellfleet, Massachusetts, in 2007. Analytical work was completed under U.S. Fish and Wildlife Service (USFWS) Analytical Control Facility Catalog 5100025 - Purchase Orders 94420-06-Y585 (Organics) and 94420-07-Y839 (Trace Elements). The Interagency Agreement Number for the project was EM133F-06-IA-0185.

Questions, comments, and suggestions related to this report are encouraged. Written inquiries should refer to Report Number FY09-MEFO-4-EC and be directed to:

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 Copies of this report may be downloaded from the Maine Field Office Environmental Contaminants web site at http://www.fws.gov/northeast/mainecontaminants.

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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Acronyms and Abbreviations

Al	aluminum
As	arsenic
AWH	Alpha Woods Hole Labs
B	boron
Ba	barium
Be	beryllium
BC	British Columbia
BHC	benzenehexachloride
Cd	cadmium
CGC	capillary gas chromatography
Cr	chromium
Cu	copper
DDD	dichloro-diphenyl-dicloroethane
DDE	dichloro-diphenyl-dicloroethylene
DDT	dichloro-diphenyl-tricloroethane
DEQ	Division of Environmental Quality (USFWS)
Fe	iron
GERG	Geochemical and Environmental Research Group
Hg	mercury
MADMF	Massachusetts Division of Marine Fisheries
µg/g	micrograms per gram (or parts-per-million)
MA	Massachusetts
ME	Maine
MEFO	Maine Field Office (USFWS)
Mg	magnesium
Mn	manganese
NMFS	National Marine Fisheries Service
ng/g	nanograms per gram (or parts-per-billion)
Ni	nickel
PA	Pennsylvania
Pb	lead
PCB	polychlorinated biphenyl
ppb	parts-per-billion
ppm	parts-per-million
ppt	parts-per-trillion
pg/g	picogram per gram (or parts-per-trillion)
QA/QC	quality assurance / quality control
Se	selenium
Sr	strontium
TCDD	2,3,7,8-tetradibenzo-*p*-dioxin
TCDD-TEQ	dioxin toxic equivalent
TCDF	2,3,7,8-tetradibenzofuran
TEF	toxic equivalency factor
USFWS	U.S. Fish and Wildlife Service
ww	wet weight
Zn	zinc

1. Background

On February 2, 2007, a family walking the beach towards Great Island in Wellfleet, Massachusetts, came upon a large sturgeon carcass in the sand. The fish was intact and appeared freshly dead. The family reported the carcass location to the Woods Hole Oceanographic Institution who in turn notified the National Marine Fisheries Service (NMFS). The Massachusetts Division of Marine Fisheries (MADMF) was also notified and that agency took custody of the carcass, identified the fish as an Atlantic sturgeon (*Acipenser oxyrinchus*), and stored it in a freezer in Gloucester, Massachusetts. Since very little information is available regarding contaminant burdens in Atlantic sturgeon from the New England area, the NMFS funded an Interagency Agreement with the U.S. Fish and Wildlife Service (USFWS) so contaminant concentrations in tissues from the sturgeon carcass could be determined. Muscle, liver, and gonad tissue samples were extracted from the sturgeon and submitted to USFWS contract laboratories for a comprehensive analysis of environmental contaminants.

2. Purpose of Investigation

Determine contaminant concentrations in muscle, liver, and gonad tissue from an Atlantic sturgeon.

3. Recovery Area

The Atlantic sturgeon was discovered on February 2, 2007, on the Great Island Trail along a narrow ribbon of sand called "The Gut" north of Great Island in Wellfleet, Massachusetts (Figure 1). The Town of Wellfleet is located on Cape Cod in Barnstable County. Coordinates of the carcass location were North 41^{o} 55' 41.4" / West -070^{o} 04' 17.5", Map Datum WGS 84.

4. Methods

4.1 Carcass Processing. The frozen Atlantic sturgeon carcass was removed from the MADMF freezer on March 14, 2007 and allowed to thaw overnight. The animal was processed on March 15, 2007 by USFWS, NMFS, and MADMF personnel. NMFS, the lead federal agency for Atlantic sturgeon management in the United States, assigned a Unique Identifier Code to the fish: Ao-02-02-07. The carcass was examined for external tags and scanned for passive integrated transponder tags and coded wire tags; none were found. Prior to the collection of fish metrics (Table 1), the carcass was rinsed with tap water to remove sand and debris. Total weight was measured with a hanging scale with a 0.5 kilogram degree of accuracy. Total length and fork length were determined to the nearest millimeter (mm) with a tape measure. Mouth width and inter-orbital width to the nearest 0.1 mm were measured with dial calipers. All processing saws, knives, scissors, forceps, tables, and pans were decontaminated by a wash with Alconox, a biodegradable soap, and tap water followed by a rinse with de-ionized water. Processing personnel wore powder-free nitrile gloves.

4.2 Tissue Sample Collection. A hacksaw was used to cut through the skin and around the scutes of the sturgeon for muscle tissue extraction. Once a flap of skin could be separated from the muscle, decontaminated fillet knives were used to cut a skinless, boneless fillet sample. The fillet was taken from the left side of the fish above the lateral line and below the dorsal area. The fillet cuts were made interior from the hacksaw cut areas to minimize possible contamination from exterior skin surfaces. Fillet samples were weighed to the nearest gram on an electronic scale and placed in labeled chemical-clean jars. After collecting muscle tissue samples, the fish was placed on its dorsal side. A decontaminated stainless steel scissor was placed in the anal vent and the body cavity was cut open to expose internal organs. Liver and gonads were separated from connective tissue and weighed to the nearest gram. Portions of the liver and gonad were placed in labeled chemical-clean jars. All samples were placed in an ice-packed cooler, transported to the USFWS Maine Field Office, and frozen within five hours of collection.

Figure 1. Sturgeon carcass recovery location, Wellfleet, MA

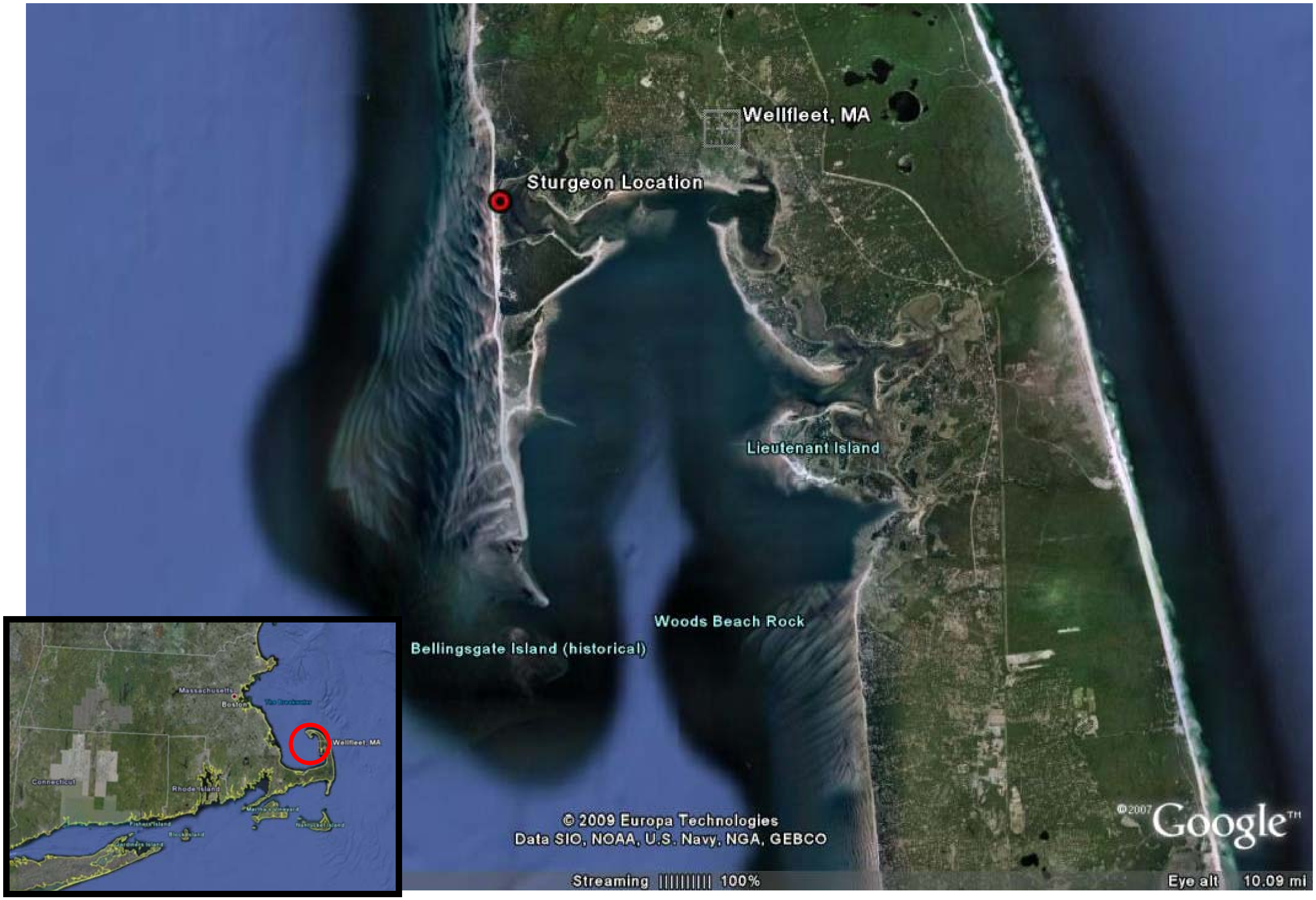

Table 1. Fish information and metrics

Species: Atlantic Sturgeon	*Acipenser oxyrinchus*
NMFS Unique Identifier	Ao 2 - 2 - 07
Total Length	163 cm [a]
Fork Length	140 cm [a]
Mouth Width	52 mm
Inter-orbital Width	119 mm
Total Weight	20.5 kg
Liver Weight	801 g
Gonad Weight	211 g
Stomach Weight	211 g
Muscle Sample Weight [b]	174.0 g
% Lipid in Muscle Sample	2.04%
Liver Sample Weight	150.0 g
% Lipid in Liver Sample	19.30%
Gonad Sample Weight	103.0 g
% Lipid in Gonad Sample	34.90%
Sex	Male
Age [c]	17 years

[a] Converted from original measurement in inches

[b] skinless and boneless

[c] estimate from pectoral fin spine

4.3 Pectoral Fin Spine. Pectoral fins were cut from the carcass with the hacksaw. Pectoral fin spines were shipped to the Chesapeake Biological Laboratory of the University of Maryland for aging by Ryan Woodland 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 (mm) thickness, sanded to approximately a 1 mm 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.

4.4 Analyses. Sturgeon tissue samples were analyzed for organic compounds by the Geochemical and Environmental Research Group (GERG) in College Station, Texas, and for trace elements by the Alpha Woods Hole Laboratory in Raynham, Massachusetts. Percent lipid was also measured in each tissue sample by GERG. Analytical work was completed under USFWS Analytical Control Facility Catalog 5100025 - Purchase Orders 94420-06-Y585 (organics) and 94420-07-Y839 (trace elements).

4.4.1 Polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans (PCDD/Fs) – The analytical scan for PCDD/Fs included seven dioxin and 10 furan congeners (Table 2). PCDD/F concentrations were determined by high resolution gas chromatography/high resolution mass spectrometry. Method detection limits for 2,3,7,8-TCDD and 2,3,7,8-TCDF were approximately 1 pg/g wet weight. Method detection limits for other PCDD/Fs were approximately 5 pg/g wet weight.

4.4.2 Polychlorinated Biphenyl (PCB) congeners – The analytical scan included 96 PCB congeners with an additional 24 congeners co-eluting with other congeners (Table 3). PCB congener concentrations were determined by capillary gas chromatography with electron capture detector. Sample detection limits for PCB congeners ranged from 27.4 pg/g to 40.2 pg/g (Table 3). Total PCB was determined by the sum of congeners.

4.4.3 Polybrominated diphenyl ethers (PBDE) – The analytical scan included 39 PBDE congeners and one co-eluting congener (Table 4). PBDE quantitative analyses were performed by capillary gas chromatography with a mass spectrometer detector in the selective ion monitoring mode for PBDEs. Sample detection limits ranged from 0.34 ng/g to 1.26 ng/g for 38 congeners, and from 54.8 ng/g to 80.3 ng/g for BDE# 209 (Table 4). Total PBDE was determined by the sum of congeners

4.4.4 Other organic compounds – Other compounds in the organic analytical scan were the metabolites and isomers of dichloro-diphenyl-tricloroethane or DDT (including *o*,*p*’-DDD, *o*,*p*’-DDE, *o*,*p*’-DDT, *p*,*p*’-DDD, *p*,*p*’-DDE, *p*,*p*’-DDT; Total DDT is the sum of all metabolites); seven chlordane compounds (*alpha* chlordane, *gamma* chlordane, *cis*-nonachlor, *trans*-nonachlor, oxychlordane, heptachlor, heptachlor epoxide; Total Chlordane is the sum of all chlordane compounds); four isomers of benzene hexachloride (BHC, also known as hexachlorocyclohexanes; the α BHC, β BHC, γ BHC, and δ BHC isomers were summed to derive Total BHC); along with aldrin, endrin, dieldrin, hexachlorobenzene (HCB), endosulfan II, mirex, pentachloro-anisole, and toxaphene. Residues of these organic compounds were quantified by capillary gas chromatography with flame ionization, electron capture, or mass spectrometer detectors. Sample detection limits ranged from 0.14 ng/g to 4.02 ng/g.

4.4.5 Trace elements - Elements included in the analytical scan were aluminum, arsenic, boron, barium, beryllium, cadmium, chromium, copper, iron, mercury, magnesium, manganese, molybdenum, nickel, lead, selenium, strontium, vanadium, and zinc. Most elements were quantified using inductively coupled plasma mass spectrometry. Arsenic, lead, and selenium were measured through graphite furnace atomic absorption. Mercury levels were determined with cold vapor atomic absorption. Method detection limits – in µg/g wet weight - were 0.02 for mercury, cadmium, and beryllium; 0.05 for arsenic, barium, lead, selenium, and strontium; 0.07 for copper; 0.10 for chromium, manganese, nickel, vanadium, and zinc; and 0.50 for aluminum, boron, iron, magnesium, and molybdenum.

Table 2. Polychlorinated dibenzo-*p* -dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) in the analytical scan

Polychlorinated dibenzo-*p*- dioxins (PCDD)

2,3,7,8-tetrachlorodibenzo-*p* -dioxin (TCDD)
1,2,3,7,8-pentachlorodibenzo-*p* -dioxin (PeCDD)
1,2,3,4,7,8-hexachlorodibenzo-*p* -dioxin (HxCDD)
1,2,3,6,7,8-hexachlorodibenzo-*p* -dioxin (HxCDD)
1,2,3,7,8,9-hexachlorodibenzo-*p* -dioxin (HxCDD)
1,2,3,4,6,7,8-heptachlorodibenzo-*p* -dioxin (HpCDD)
octochlorodibenzo-*p* -dioxin (OCDD)

Polychlorinated dibenzofurans (PCDF)

2,3,7,8-tetrachlorodibenzofuran (TCDF)
1,2,3,7,8-pentachlorodibenzofuran (PeCDF)
2,3,4,7,8-pentachlorodibenzofuran (PeCDF)
1,2,3,4,7,8-hexachlorodibenzofuran (HxCDF)
1,2,3,6,7,8-hexachlorodibenzofuran (HxCDF)
1,2,3,7,8,9-hexachlorodibenzofuran (HxCDF)
2,3,4,6,7,8-hexachlorodibenzofuran (HxCDF)
1,2,3,4,6,7,8-heptachlorodibenzofuran (HpCDF)
1,2,3,4,7,8,9-heptachlorodibenzofuran (HpCDF)
octochlorodibenzofuran (OCDF)

Table 3. PCB congeners in the analytical scan

PCB# 1		PCB# 107	
PCB# 7/9		PCB# 110	
PCB# 8/5		PCB# 114	mono-ortho
PCB# 15		PCB# 118	mono-ortho
PCB# 16/32		PCB# 119	
PCB# 18/17		PCB# 126	non-ortho
PCB# 22/51		PCB# 128	
PCB# 24/27		PCB# 129	
PCB# 25		PCB# 130	
PCB# 26		PCB# 135	
PCB# 28		PCB# 136	
PCB# 29		PCB# 138/160	
PCB# 30		PCB# 141/179	
PCB# 31		PCB# 146	
PCB# 33/20		PCB# 149/123	mono-ortho
PCB# 39		PCB# 151	
PCB# 40		PCB# 153/132	
PCB# 41/64		PCB# 156	mono-ortho
PCB# 42/59/37		PCB# 157/173/201	mono-ortho
PCB# 44		PCB# 158	
PCB# 45		PCB# 166	
PCB# 46		PCB# 167	mono-ortho
PCB# 47/75		PCB# 169	non-ortho
PCB# 48		PCB# 170/190	
PCB# 49		PCB# 171/202	
PCB# 52		PCB# 172	
PCB# 53		PCB# 174	
PCB# 60/56		PCB# 175	
PCB# 63		PCB# 176/137	
PCB# 66		PCB# 177	
PCB# 67		PCB# 178	
PCB# 69		PCB# 180	
PCB# 70		PCB# 183	
PCB# 72		PCB# 185	
PCB# 74/61		PCB# 187	
PCB# 77	non-ortho	PCB# 189	mono-ortho
PCB# 81	non-ortho	PCB# 191	
PCB# 82		PCB# 193	
PCB# 83		PCB# 194	
PCB# 84		PCB# 195/208	
PCB# 85		PCB# 196	
PCB# 87/115		PCB# 197	
PCB# 92		PCB# 199	
PCB# 95/80		PCB# 200	
PCB# 97		PCB# 205	
PCB# 99		PCB# 206	
PCB# 101/90		PCB# 207	
PCB# 105	mono-ortho	PCB# 209	

Non-ortho and mono-ortho PCB congeners with TEFs noted.
Congeners with more than one number indicate co-elutes.

Table 4. PBDE congeners in the analytical scan

BDE# 1
BDE# 2
BDE# 3
BDE# 7
BDE# 8/11 (co-elute)
BDE# 10
BDE# 12
BDE# 13
BDE# 15
BDE# 17
BDE# 25
BDE# 28
BDE# 30
BDE# 32
BDE# 33
BDE# 35
BDE# 37
BDE# 47
BDE# 49
BDE# 66
BDE# 71
BDE# 75
BDE# 77
BDE# 85
BDE# 99
BDE# 100
BDE# 116
BDE# 118
BDE# 119
BDE# 126
BDE# 138
BDE# 153
BDE# 154
BDE# 155
BDE# 166
BDE# 181
BDE# 183
BDE# 190
BDE# 209

4.5 Quality Assurance / Quality Control (QA/QC). Quality assurance and quality control (QA/QC) procedures at both analytical laboratories included procedural blanks, duplicates, spike recoveries, and certified reference material. The USFWS Analytical Control Facility reviewed QA/QC results and accepted the organic and trace element analytical data packages.

4.6 Data Presentations. Concentrations in this report are presented in pg/g (parts-per-trillion) for dioxins, furans, and PCB congeners, in ng/g (parts-per-billion) for PBDE and other organochlorine compounds, and in µg/g (parts-per-million) for trace metals. All contaminant concentrations in the text and tables are expressed on a wet weight basis. On occasion, other investigations may express trace metals data on a dry weight basis. A second trace metal data table (Table 9b) expressed on a dry weight basis is included in the report.

Dioxins, furans, and planar PCB concentrations were adjusted with toxic equivalency factors (TEFs) suggested by Van den Berg *et al*. (1998) for fish. The TCDD-TEQ is the sum of TEF-adjusted dioxin, furan, and dioxin-like PCB congener concentrations expressed in pg/g on a wet weight basis. Data from other studies, used to place the Wellfleet Atlantic sturgeon concentrations into context, were transformed for data consistency (i.e., TCDD-TEQs were recalculated with the TEFs of Van den Berg *et al*. (1998) and organochlorines were converted to ng/g).

5. Results

5.1 Fish Metrics and Age. The Atlantic sturgeon from Wellfleet had a total length of 163 centimeters, fork length of 140 centimeters, mouth width of 52 millimeters, inter-orbital width of 119 millimeters, total body weight of 20.5 kilograms, liver weight of 801 grams, gonad weight of 211 grams, and stomach weight of 211 grams (Table 1).

General observations during processing of the partially-thawed carcass were recorded. The fish's liver was a pale olive or yellow color. The gall bladder and testes were unremarkable in appearance. The exterior of the stomach had what appeared to be wart-like growths. The stomach appeared empty except for a greenish, bile-like fluid. The intestine appeared unremarkable and also contained a greenish, bile-like fluid. No obvious external or internal parasites were observed. The left eye of the animal was missing; likely due to scavenging of the beached carcass. Skin tissue along the left side of the organ cavity appeared slightly hemorrhagic, but that may likely be due to the carcass' position after death (i.e., blood settled on the animal's left side). Since the carcass had been thoroughly frozen, no tissue samples were collected for histological examinations. The liver-somatic index (LSI) and the gonadosomatic index (GSI) were 3.36 and 0.84, respectively (Busacker *et al.* 1990, Strange 1996).

Based on readings of pectoral spine sections, the age estimate of the Atlantic sturgeon was 17 years. A digital image of the spine cross-section is shown in Figure 2. Aging of sturgeon from pectoral fins can be imprecise (Whiteman *et al*. 2004) and age estimates may vary ± 5 years (Stevenson and Secor 1999), so this particular sturgeon could possibly be 12 or 22 years. Based on the length and weight of the fish, however, the lower end of this range is most plausible (Mohler J.W. 2008. USFWS – Northeast Fishery Center. Personal communication).

Figure 2. Cross-section of pectoral spine from Atlantic sturgeon recovered in Wellfleet, MA. Photo by Ryan Woodland, University of Maryland.

Age estimate:

17 Years

5.2 Organochlorine Analytical Results. Organic analytical results are presented in Table 5 (PCDDs, PCDFs, dioxin-like PCBs, and TCDD-TEQs), Table 6 (PCB congeners), Table 7 (PBDE congeners), and Table 8 (Other Organics). Lipid content in tissue samples was 2.04% in muscle, 19.3% in liver, and 34.9% in gonad. Since organic compounds are lipophilic, several compounds were found in higher concentrations in liver and gonad than muscle tissue.

5.2.1 Polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans (PCDD/Fs) - Only two of seven PCDD congeners were detected in the three tissue types – 1,2,3,6,7,8-heptaCDD and OctaCDD (Table 5). Among the three tissue types, the liver had the highest concentrations of PCDDs. PCDFs were detected more frequently in sturgeon tissue than PCDDs. 2,3,7,8-TCDF was only detected in gonad tissue (11.7 pg/g). Other PCDF congeners detected in sturgeon tissue included 1,2,3,7,8-PentaCDF, 2,3,4,7,8-PentaCDF (in muscle tissue only, 30.8 pg/g), 1,2,3,4,7,8-HexaCDF (highest in gonad, 95.2 pg/g), 1,2,3,6,7,8-HexaCDF, 2,3,4,6,7,8-HexaCDF, 1,2,3,4,6,7,8-HeptaCDF (highest in gonad at 205 pg/g and nearly 4 times higher than the other two tissue types), 1,2,3,4,7,8,9-HeptaCDF, and OctaCDF.

5.2.2 Polychlorinated Biphenyls (PCBs) - All three tissue samples were analyzed for individual PCB congeners. Of the four dioxin-like *non-ortho* PCB congeners, only PCB #77 and PCB #169 were detected and only in muscle tissue (Table 5). Of eight *mono-ortho* PCB congeners, only PCB #114 was not detected in sturgeon tissue (Table 5). Among the three tissue types, gonad tissue had the highest concentrations of *mono-ortho* PCB congeners. Dominant PCB congeners in all tissue samples were PCB# 153 (co-eluting with PCB# 132) and PCB# 138 (co-eluting with PCB# 160). Total PCB in tissue samples from the Wellfleet Atlantic sturgeon ranged from 124 ng/g in muscle tissue to 1,890 ng/g in gonad tissue (Table 8).

5.2.3 Polybrominated Diphenyl Ethers (PBDEs) - Total PBDE, the sum of 39 congeners, was 8.8 ng/g in muscle tissue, 75.7 ng/g in liver tissue, and 148.0 ng/g in gonad tissue (Table 7). Of 39 congeners in the PBDE scan, eight were detected in sturgeon tissue. Among PBDE congeners, BDE #47, BDE #99 and BDE #100 are the three most commonly detected in the environment (Rice *et al*. 2002) and all three of these congeners were detected in Wellfleet Atlantic sturgeon tissues. BDE #44 accounted for over 60% of the total PBDE in the three tissue samples from the Wellfleet Atlantic sturgeon. Other PBDE congeners detected in the Wellfleet Atlantic sturgeon included BDE #49, #154, #155, and #166. Among the three tissue types, gonad had the highest PBDE concentrations and the most congener detections.

5.2.4 Other Organochlorine Compounds - Dichloro-diphenyl-tricloroethane (DDT) metabolites were detected in all three tissue samples. Total DDT, the sum of six metabolites, was highest in the gonad (120.65 ng/g) followed by liver (76.61 ng/g) and muscle tissue (8.33 ng/g). Among the three isomers of the three DDT metabolites, the *p,p*' isomer of DDE occurred at the highest concentrations in all tissue samples. Total chlordane, the sum of seven chlordane compounds, was highest in gonad tissue at 37.29 ng/g, followed by liver with 26.31 ng/g, and muscle with 2.31 ng/g. Among the seven compounds, the highest detection was 14.70 ng/g in gonad tissue. All other chlordane compounds were detected at less than 10 ng/g in other tissues. Benzene hexachloride (BHC) was also included in the analytical scan. Total BHC, the sum of four isomers (α BHC, β BHC, γ BHC, δ BHC), was highest in gonad tissue (7.8 ng/g) and similar in muscle and liver tissue (0.38 ng/g, 0.34 ng/g). All BHC isomers were detected in gonad tissue. Muscle and liver tissue only had single detections of a BHC isomer. Maximum concentrations of other organochlorine compounds were: aldrin at 1.62 ng/g in liver, endrin at 3.21 ng/g in gonad, dieldrin at 3.60 ng/g in gonad, HCB at 3.39 ng/g in gonad, mirex at 1.63 ng/g in liver, and pentachloro-anisole at 1.29 ng/g in gonad. Endosulfan II and toxaphene were below detection limits in all samples.

Table 5. PCDDs, PCDFs, dioxin-like PCBs, and TCDD-TEQs in Atlantic sturgeon tissues, pg/g wet weight

	TEF	Muscle		Liver		Gonad	
		pg/g ww	TEF Adjusted pg/g ww	pg/g ww	TEF Adjusted pg/g ww	pg/g ww	TEF Adjusted pg/g ww
Dioxins & Furans							
2,3,7,8-TCDD	1	< 1.00	BDL	< 1.00	BDL	< 0.990	BDL
1,2,3,7,8-PeCDD	1	< 4.99	BDL	< 4.98	BDL	< 4.95	BDL
1,2,3,4,7,8-HxCDD	0.5	< 4.99	BDL	< 4.98	BDL	< 4.95	BDL
1,2,3,6,7,8-HxCDD	0.01	< 4.99	BDL	< 4.98	BDL	< 4.95	BDL
1,2,3,7,8,9-HxCDD	0.01	< 4.99	BDL	< 4.98	BDL	< 4.95	BDL
1,2,3,4,6,7,8-HpCDD	0.001	23	0.023	30.8	0.0308	30.5	0.0305
OCDD	0.0001	43.5	0.00435	75	0.0075	68.4	0.00684
2,3,7,8-TCDF	0.05	< 1.00	BDL	< 1.00	BDL	11.7	0.585
1,2,3,7,8-PeCDF	0.05	17.3	0.865	61.5	3.075	153	7.65
2,3,4,7,8-PeCDF	0.5	30.8	15.4	< 4.98	BDL	< 4.95	BDL
1,2,3,4,7,8-HxCDF	0.1	36.6	3.66	53	5.3	95.2	9.52
1,2,3,6,7,8-HxCDF	0.1	14.1	1.41	18.1	1.81	16.6	1.66
1,2,3,7,8,9-HxCDF	0.1	< 4.99	BDL	< 4.98	BDL	< 4.95	BDL
2,3,4,6,7,8-HxCDF	0.1	18.6	1.86	21.2	2.12	19	1.9
1,2,3,4,6,7,8-HpCDF	0.01	55.5	0.555	36.5	0.365	205	2.05
1,2,3,4,7,8,9-HpCDF	0.01	5.6	0.056	< 4.98	BDL	6.5	0.065
OCDF	0.0001	19.9	0.00199	28.8	0.00288	22.8	0.00228
TEQ PCDD/Fs			23.8		12.7		23.5
PCB Congeners							
PCB #77	0.0001	50	0.005	< 39.8	BDL	< 40.2	BDL
PCB #81	0.0005	< 27.4	BDL	< 39.8	BDL	< 40.2	BDL
PCB #126	0.005	< 27.4	BDL	< 39.8	BDL	< 40.2	BDL
PCB #169	0.00005	40	0.002	< 39.8	BDL	< 40.2	BDL
PCB #105	0.000005	1320	0.0066	11300	0.0565	20900	0.1045
PCB #114	0.000005	< 27.4	BDL	< 39.8	BDL	< 40.2	BDL
PCB #118	0.000005	3580	0.0179	19300	0.0965	40500	0.2025
PCB #123 (co-elute)	0.000005	4330	0.02165	21500	0.1075	52500	0.2625
PCB #156	0.000005	610	0.00305	8700	0.0435	13700	0.0685
PCB #157 (co-elute)	0.000005	924	0.00462	4460	0.0223	8210	0.04105
PCB #167	0.000005	855	0.004275	5710	0.02855	3220	0.0161
PCB #189	0.000005	1030	0.00515	1750	0.00875	3110	0.01555
TEQ Total (PCDD/Fs + planar PCBs)			23.9		13.1		24.2

pg/g = parts-per-trillion. Toxic equivalency factors (TEFs) for fish from Van den berg*et al* . 1998. Values in red preceded by < symbol indicate non-detects and detection limits. BDL = Below Detection Limit

Table 6. PCB congeners in Atlantic sturgeon tissues, pg/g wet weight.

	Muscle	Liver	Gonad
PCB - Total	123374	892543	1891441
PCB# 1	< 27.4	1800	< 40.2
PCB# 7/9	< 27.4	702	< 40.2
PCB# 8/5	2120	5790	19300
PCB# 15	813	2940	2810
PCB# 16/32	138	183	1470
PCB# 18/17	667	2040	5870
PCB# 22/51	553	< 39.8	2160
PCB# 24/27	< 27.4	< 39.8	65300
PCB# 25	113	1810	< 40.2
PCB# 26	< 27.4	< 39.8	< 40.2
PCB# 28	743	7740	7800
PCB# 29	< 27.4	< 39.8	40500
PCB# 30	< 27.4	< 39.8	< 40.2
PCB# 31	29	535	< 40.2
PCB# 33/20	< 27.4	740	< 40.2
PCB# 39	< 27.4	< 39.8	< 40.2
PCB# 40	< 27.4	< 39.8	< 40.2
PCB# 41/64	1500	3950	1760
PCB# 42/59/37	831	< 39.8	2270
PCB# 44	780	172	532
PCB# 45	< 27.4	< 39.8	1120
PCB# 46	< 27.4	5200	< 40.2
PCB# 47/75	892	15800	18800
PCB# 48	< 27.4	< 39.8	< 40.2
PCB# 49	390	6930	5840
PCB# 52	281	7450	8920
PCB# 53	1150	3940	8370
PCB# 60/56	424	6470	9790
PCB# 63	< 27.4	< 39.8	676
PCB# 66	395	1160	2730
PCB# 67	< 27.4	< 39.8	2500
PCB# 69	< 27.4	< 39.8	< 40.2
PCB# 70	858	1340	8160
PCB# 72	< 27.4	3510	4920
PCB# 74/61	1070	14700	22200
PCB# 77	50	< 39.8	< 40.2
PCB# 81	< 27.4	< 39.8	< 40.2
PCB# 82	< 27.4	< 39.8	< 40.2
PCB# 83	206	1730	4410
PCB# 84	< 27.4	1350	1390
PCB# 85	1000	6680	9690
PCB# 87/115	1200	3440	7720
PCB# 92	1450	10200	2860
PCB# 95/80	1670	5470	17800
PCB# 97	724	5370	11100
PCB# 99	3580	41600	166000
PCB# 101/90	323	13900	30800
PCB# 105	1320	11300	20900
PCB# 107	528	1350	7380
PCB# 110	3770	12900	39200
PCB# 114	< 27.4	< 39.8	< 40.2
PCB# 118	3580	19300	40500
PCB# 119	< 27.4	505	551
PCB# 126	< 27.4	< 39.8	< 40.2
PCB# 128	2360	21100	35200
PCB# 129	< 27.4	707	2040
PCB# 130	565	290	4870
PCB# 135	978	4020	10900
PCB# 136	< 27.4	97	1130
PCB# 138/160	14500	131000	252000
PCB# 141/179	1420	6680	15800
PCB# 146	4400	23300	46000
PCB# 149/123	4330	21500	52500
PCB# 151	348	< 39.8	9770

pg/g = parts-per-trillion. Values in red preceded by < symbol indicate non-detects and detection limits.
Non-ortho and mono-ortho PCB congeners with TEFs highlighted.

(continued)

Table 6. PCB congeners in Atlantic sturgeon tissues, pg/g wet weight (continued).

	Muscle	Liver	Gonad
PCB# 153/132	15300	172000	286000
PCB# 156	610	8700	13700
PCB# 157/173/201	924	4460	8210
PCB# 158	920	5640	16000
PCB# 166	< 27.4	< 39.8	< 40.2
PCB# 167	855	5710	3220
PCB# 169	40	< 39.8	< 40.2
PCB# 170/190	2820	13100	29300
PCB# 171/202	1460	10500	18200
PCB# 172	524	4800	7130
PCB# 174	887	4890	9840
PCB# 175	156	1140	4290
PCB# 176/137	1320	2710	13400
PCB# 177	1820	15300	25900
PCB# 178	1970	8040	16200
PCB# 180	8090	63600	124000
PCB# 183	2420	22100	34100
PCB# 185	122	1890	1570
PCB# 187	6480	37100	126000
PCB# 189	1030	1750	3110
PCB# 191	< 27.4	679	652
PCB# 193	551	5460	7100
PCB# 194	1580	9630	16600
PCB# 195/208	1620	2410	12500
PCB# 196	1870	12500	22100
PCB# 197	< 27.4	1260	234
PCB# 199	2300	12300	25300
PCB# 200	174	240	496
PCB# 205	572	< 39.8	1680
PCB# 206	2030	13500	14200
PCB# 207	< 27.4	243	1800
PCB# 209	2880	12200	14300

pg/g = parts-per-trillion. Values in red preceded by < symbol indicate non-detects and detection limits.
Non-ortho and mono-ortho PCB congeners with TEFs highlighted.

Table 7. PBDE congeners in Atlantic sturgeon tissues, ng/g wet weight

	Muscle	Liver	Gonad
BDE-TOTAL	8.8	75.7	148.0
BDE# 1	< 0.342	< 0.498	< 0.502
BDE# 2	< 0.342	< 0.498	< 0.502
BDE# 3	< 0.342	< 0.498	< 0.502
BDE# 7	< 0.342	< 0.498	< 0.502
BDE# 8/11 (co-elute)	< 0.342	< 0.498	< 0.502
BDE# 10	< 0.342	< 0.498	< 0.502
BDE# 12	< 0.342	< 0.498	< 0.502
BDE# 13	< 0.342	< 0.498	< 0.502
BDE# 15	< 0.342	< 0.498	< 0.502
BDE# 17	< 0.342	< 0.498	< 0.502
BDE# 25	< 0.342	< 0.498	< 0.502
BDE# 28	< 0.342	< 0.498	< 0.502
BDE# 30	< 0.342	< 0.498	< 0.502
BDE# 32	< 0.342	< 0.498	< 0.502
BDE# 33	< 0.342	< 0.498	< 0.502
BDE# 35	< 0.342	< 0.498	< 0.502
BDE# 37	< 0.342	< 0.498	< 0.502
BDE# 47	5.22	48.30	93.30
BDE# 49	< 0.342	2.15	4.33
BDE# 66	< 0.342	< 0.498	0.85
BDE# 71	< 0.342	< 0.498	< 0.502
BDE# 75	< 0.342	< 0.498	< 0.502
BDE# 77	< 0.342	< 0.498	< 0.502
BDE# 85	< 0.514	< 0.747	< 0.753
BDE# 99	0.60	3.47	7.54
BDE# 100	1.53	13.40	26.60
BDE# 116	< 0.514	< 0.747	< 0.753
BDE# 118	< 0.514	< 0.747	< 0.753
BDE# 119	< 0.514	< 0.747	< 0.753
BDE# 126	< 0.514	< 0.747	< 0.753
BDE# 138	< 0.685	< 0.996	< 1.00
BDE# 153	< 0.685	2.41	4.42
BDE# 154	< 0.685	4.21	7.92
BDE# 155	< 0.685	1.60	2.76
BDE# 166	< 0.685	< 0.996	< 1.00
BDE# 181	< 0.856	< 1.25	< 1.26
BDE# 183	< 0.856	< 1.25	< 1.26
BDE# 190	< 0.856	< 1.25	< 1.26
BDE# 209	< 54.8	< 79.7	< 80.3

ng/g = parts-per-billion
Values in red preceded by < symbol indicated non-detect and detection limit.

Table 8. Organic compounds in Atlantic sturgeon tissues, ng/g wet weight.

	Muscle	Liver	Gonad
PCB and PBDE			
PCB - Total	124.0	894.0	1890.0
PBDE - Total	8.8	75.7	148.0
Benzene Hexachloride (also known as Hexachlorocyclohexanes, HCH)			
alpha BHC	< 0.137	< 0.199	0.315
beta BHC	0.383	< 0.199	1.520
gamma BHC	< 0.137	0.340	1.030
delta BHC	< 0.137	< 0.199	4.980
Total BHC	0.383	0.340	7.845
Chlordane Compounds			
alpha chlordane	0.310	3.110	7.780
gamma chlordane	0.159	2.330	3.820
cis-nonachlor	0.384	8.470	6.770
trans-nonachlor	0.776	8.170	14.700
oxychlordane	0.474	2.590	3.320
heptachlor epoxide	0.211	0.893	0.903
heptachlor	< 0.137	0.752	< 0.201
Total Chlordane	2.314	26.315	37.293
DDT Metabolites			
o,p'-DDD	3.460	8.960	18.700
o,p'-DDE	< 0.137	0.241	< 0.201
o,p'-DDT	0.386	5.220	4.310
p,p'-DDD	1.770	19.100	22.000
p,p'-DDE	2.370	39.800	69.500
p,p'-DDT	0.348	3.290	6.140
Total DDT	8.334	76.611	120.650
Other Organochlorine Compounds			
aldrin	0.262	1.620	1.060
endrin	< 0.137	0.490	3.210
dieldrin	0.450	1.700	3.600
endosulfan II	< 0.137	< 0.199	< 0.201
HCB	< 0.137	1.270	3.390
mirex	0.472	1.630	< 0.201
pentachloro-anisole	0.357	0.514	1.290
toxaphene	< 2.74	< 3.98	< 4.02

ng/g = parts-per-billion
Values in red preceded by < symbol indicate non-detects and detection limits
Non-detects not included in sums for Total BHC, Total Chlordane and Total DDT

5.3 Trace Metal Analytical Results. Trace metal results for the Wellfleet Atlantic sturgeon are presented in Table 9a (wet weight concentrations) and Table 9b (dry weight concentrations). Concentrations below are discussed on a wet weight basis.

Aluminum was below detection limits in all three tissue samples. Arsenic was detected in all tissue types with the highest concentration occurring in muscle tissue (4.90 µg/g). Concentrations of arsenic in liver and gonad tissue were 3.80 µg/g and 2.50 µg/g, respectively. Boron was below the detection limit in gonad tissue (< 0.83 µg/g), detected at 0.87 µg/g in muscle tissue, and found at 1.40 µg/g in liver tissue. Barium was detected in liver tissue (0.65 µg/g), but below detection limits in muscle (< 0.048 µg/g) and gonad tissue (< 0.083 µg/g). Beryllium was below detection limits in all three samples. Cadmium was only detected in liver tissue at a concentration of 0.31 µg/g. Chromium was highest in gonad tissue (2.20 µg/g) followed by liver (1.20 µg/g) and muscle tissue (0.56 µg/g). Copper concentrations in muscle and gonad tissue were similar (0.29 µg/g and 0.24 µg/g, respectively), but liver tissue contained a Cu concentration of 6.90 µg/g. Iron was below detection limits in muscle (< 9.50 µg/g) and gonad (< 17.0 µg/g) tissue, and detected at 170 µg/g in liver tissue.

Mercury was highest in liver tissue (0.44 µg/g) and below the detection limit (< 0.02 µg/g) in gonad tissue. Muscle tissue contained 0.15 µg/g of Hg. Magnesium was highest in muscle tissue (400 µg/g), at 330 µg/g in liver tissue, and at 70 µg/g in gonad tissue. Manganese was detected in muscle (0.19 µg/g) and liver (1.10 µg/g), but was below the detection limit in gonad (< 0.170 µg/g). Molybdenum was below detection limits in muscle (< 0.048 µg/g) and gonad (< 0.083 µg/g) tissue, and found at 0.12 µg/g in liver tissue. Nickel was also below detection limits in muscle (< 0.048 µg/g) and gonad (< 0.083 µg/g) tissue, and found at 0.23 µg/g in liver tissue. Among the three tissue types, lead (Pb) was only detected in liver tissue (0.64 µg/g). Selenium was detected in all tissue types. Highest Se levels were found in liver (7.00 µg/g) followed by muscle (2.90 µg/g) and gonad (1.10 µg/g). Strontium was detected in all tissue with 0.83 µg/g in muscle, 2.10 µg/g in liver, and 0.48 µg/g in gonad. Vanadium was only detected in liver tissue (1.00 µg/g). Zinc was lowest in gonad tissue (4.5 µg/g) and highest in liver tissue (27.0 µg/g). The muscle Zn level was 5.6 µg/g.

METALS - WET WEIGHT

Table 9a. Trace metals in Atlantic sturgeon tissue samples, µg/g wet weight.

	Muscle	Liver	Gonad
Aluminum (Al)	< 9.50	< 12.0	< 17.0
Arsenic (As)	4.90	3.80	2.50
Boron (B)	0.87	1.40	< 0.830
Barium (Ba)	< 0.048	0.65	< 0.083
Beryllium (Be)	< 0.048	< 0.062	< 0.083
Cadmium (Cd)	< 0.019	0.31	< 0.033
Chromium (Cr)	0.56	1.20	2.20
Copper (Cu)	0.29	6.90	0.24
Iron (Fe)	< 9.50	170	< 17.0
Mercury (Hg)	0.15	0.44	< 0.021
Magnesium (Mg)	400	330	70
Manganese (Mn)	0.19	1.10	< 0.170
Molybdenum (Mo)	< 0.048	0.12	< 0.083
Nickel (Ni)	< 0.048	0.23	< 0.083
Lead (Pb)	< 0.019	0.64	< 0.033
Selenium (Se)	2.90	7.00	1.10
Strontium (Sr)	0.83	2.10	0.48
Vanadium (V)	< 0.480	1.00	< 0.830
Zinc (Zn)	5.6	27.0	4.5

µg/g = parts-per-million
Values in red preceded by < symbol indicate non-detects and detection limits
Muscle sample was skinless and boneless

Table 9b. Trace metals in Atlantic sturgeon tissue samples, µg/g dry weight.

	Muscle	Liver	Gonad
Aluminum (Al)	< 31.6	< 24.3	< 34.2
Arsenic (As)	16.3	7.69	5.03
Boron (B)	2.89	2.83	< 1.67
Barium (Ba)	< 0.159	1.32	< 0.167
Beryllium (Be)	< 0.159	< 0.126	< 0.167
Cadmium (Cd)	< 0.0631	0.63	< 0.0664
Chromium (Cr)	1.86	2.43	4.43
Copper (Cu)	0.96	14.00	0.48
Iron (Fe)	< 31.6	344	< 34.2
Mercury (Hg)	0.498	0.891	< 0.0423
Magnesium (Mg)	1330	668	141
Manganese (Mn)	0.63	2.23	< 0.342
Molybdenum (Mo)	< 0.159	0.243	< 0.167
Nickel (Ni)	< 0.159	0.466	< 0.167
Lead (Pb)	< 0.0631	1.30	< 0.0664
Selenium (Se)	9.63	14.20	2.21
Strontium (Sr)	2.76	4.25	0.97
Vanadium (V)	< 1.59	2.02	< 1.67
Zinc (Zn)	18.6	54.7	9.1

µg/g = parts-per-million
Values in red preceded by < symbol indicate non-detects and detection limits
Muscle sample was skinless and boneless

6. Discussion

6.1 Atlantic Sturgeon. Atlantic sturgeon are currently present in over 35 rivers along the Atlantic coast of the United States from the St. Croix River in Maine to the St. Johns River in Florida (Atlantic Sturgeon Status Review Team 2007). The Wellfleet Atlantic sturgeon was recovered in an area that is considered part of the Gulf of Maine Distinct Population Segment where the species is being proposed for listing as a threatened species under the Endangered Species Act (Federal Register. October 6, 2010).

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. Based on genetic analyses conducted by the U.S. Geological Survey (USGS), the Atlantic sturgeon recovered in Wellfleet was assigned a river-of-origin. The highest likelihood of assignment was to the Kennebec River baseline data. The fish assigned to three possible river/populations in the following order: Kennebec River (Maine), St. John River (New Brunswick), and Hudson River (New York) - a distant third. USGS determined with a near certainty that the Atlantic sturgeon recovered in Wellfleet is of Gulf of Maine origin (T. King. USGS – Leetown Science Center. 2010. Personal communication.). As noted above, the Gulf of Maine is a Distinct Population Segment (DPS) in the proposed listing of the Atlantic sturgeon under the Endangered Species Act.

According to NMFS personnel, the Atlantic sturgeon recovered in Wellfleet was a mature male likely to spawn the next breeding season. No cause of death could be determined from observation of the carcass. Over its estimated 17-year life span, this particular fish could have ranged widely and accumulated contaminants from prey inhabiting a variety of polluted areas along the Atlantic coast (e.g., New Bedford Harbor, Boston Harbor, Portsmouth Harbor, etc.).

Due to the size of the Wellfleet Atlantic sturgeon, whole-body contaminant analyses would have been impractical. Tissues used in this contaminant screening were muscle, liver, and testes (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).

Little information was found in the scientific literature that reported contaminant concentrations in tissues of Atlantic sturgeon from the Gulf of Maine portion of its range. To place the Wellfleet Atlantic sturgeon concentrations in context, contaminant levels reported in Atlantic sturgeon studies from other regions (St. Johns estuary in New Brunswick, Dadswell 1975; the Hudson River in New York, Sloan *et al*. 2005; the Penobscot River in Maine, USFWS unpublished data) or studies reporting tissue residue values in other sturgeon species (e.g., Gulf sturgeon *Acipenser oxyrhynchus desotoi*, shortnose sturgeon *Acipenser brevirostrum*, white sturgeon *Acipenser transmontanus*, pallid sturgeon *Scaphirhynchus alba*) are summarized below. Since contaminant burdens may vary depending on fish size, diet, and age (Wiener *et al*. 2003), an appendix table (Table A-1) lists the lengths and weights of sturgeon in these other studies. Data from these other studies are useful for qualitatively assessing contaminant burdens. Caution should be used in using these comparative data. Some studies are rather dated, while others involve collections in heavily contaminated areas (e.g., PCBs in the Hudson River). Their inclusion is only meant to place the contaminant burdens in the Wellfleet Atlantic sturgeon in context with other sturgeon investigations; i.e., are the contaminant levels in the Wellfleet Atlantic sturgeon higher or lower than concentrations reported elsewhere.

When available, fish tissue threshold effect values suggested by a variety of investigators are also used to evaluate contaminant concentrations in the Wellfleet Atlantic sturgeon. These tissue threshold effect values are not specific to any particular species, and it is not known if the Atlantic sturgeon is more or less sensitive to any particular contaminant. Moreover, these suggested tissue threshold levels often are related to whole-body residue burdens. It is not known if toxic concentrations in specific fish tissues such as muscle, liver, or gonad may be higher or lower than these whole-body threshold levels. In addition, U.S. Food and Drug Administration action levels (FDA 2000) and U.S. Environmental Protection Agency fish consumption limits (EPA 2000) are also provided to further place the Wellfleet Atlantic sturgeon tissue levels in context.

6.2 Organochlorine Compounds. Organochlorine compounds are lipophilic and accordingly contaminant concentrations in the Wellfleet Atlantic sturgeon were typically highest in the tissue type with the greatest lipid content (gonad lipid was 34.90%, followed by liver at 19.30%, and muscle at 2.04%). The only exception was TCDD-TEQ in muscle tissue.

6.2.1 Dioxin Toxic Equivalents (TCDD-TEQ) – Among polychlorinated dibenzo-*p*-dioxin (PCDD), polychlorinated dibenzofurans (PCDF), and dioxin-like polychlorinated biphenyls (PCB) congeners, the congener 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (referred to as TCDD) is widely considered among the most toxic. The toxic equivalency factor (TEF) concept is used to assess cumulative risk from PCDDs, PCDFs and PCB relative to TCDD (Van den Berg *et al*. 1998). PCDD, PCDF, and dioxin-like PCB congener concentrations in tissue samples from the Wellfleet Atlantic sturgeon were adjusted with TEFs and summed to determine a dioxin toxic equivalent (TCDD-TEQ) value (Table 5).

PCDDs occur naturally (e.g., originating from forest fires and volcanic activity) and are also introduced to the environment from human sources (e.g., incinerator and combustion emissions, pulp and paper bleaching processes, herbicides, and wastewater treatment systems) (ATSDR 1998). PCDFs, which commonly co-occur with PCDDs, are a contaminant family similar in structure and toxicological properties as dioxins (Colburn *et al*. 1997). Dioxin-like PCB congeners are structurally similar to dioxin, but are less toxic to fish than most PCDD and PCDF congeners.

Early life stages of fish exposed to dioxin can exhibit hemorrhage, yolk-sac edema, and craniofacial abnormalities. The TCDD-TEQ in Wellfleet Atlantic sturgeon tissues was comprised primarily of PCDDs and PCDFs. Dioxin-like PCBs contributed only 1% of the TCDD-TEQ in muscle sample and only 3% in liver and gonad (Table 5).

TCDD-TEQ Data Comparisons. Relatively little information was found in the literature regarding sturgeon TCDD-TEQs concentrations in sturgeon (Table 10). TCDD-TEQs levels reported in other sturgeon studies in Maine, Pennsylvania, and British Columbia were re-calculated for Table 10 using the TEFs from Van den Berg *et al*. (1998).

Table 10. Dioxin toxic equivalents (TCDD-TEQ) in sturgeon tissues, pg/g wet weight

Species	Year	n	Location	Muscle	Liver	Gonad	Data Source
Atlantic Sturgeon	2007	1	Wellfleet, MA	23.9	13.1	24.2	This Report
Shortnose Sturgeon	2003	1	Kennebec River, ME	1.1	5.3	10.4	ERC 2003[ab]
Shortnose Sturgeon	2001	1	Delaware River, PA	0.4	7.1	18.0	ERC 2002[ab]
Shortnose Sturgeon	2001	1	Delaware River, PA	1.8	11.3	43.8	ERC 2002[ab]
White Sturgeon	1991 - 1992	4	Fraser River, BC	12.9 – 52.7	14.8 – 23.5		MacDonald *et al*. 1997[a]

[a] TEQ recalculated using TEFs from Van den Berg *et al*. 1998, [b] Does not include dioxin-like PCBs, PCDD/Fs only; PCB congeners not analyzed.

TCDD-TEQ Hazard Assessment – Too little information is available to fully assess TCDD-TEQ concentrations in samples from the Wellfleet Atlantic sturgeon. Compared to limited exposure data from a white sturgeon study (MacDonald *et al*. 1997), the TCDD-TEQ concentrations for the Atlantic sturgeon from Wellfleet do not appear dissimilar to that study. More tissue residue data would be required to determine if TCDD-TEQ levels in the

Wellfleet Atlantic sturgeon would be considered elevated or consistent with background ranges.

Hinck *et al*. (2009) reported a TCDD-TEQ toxicity threshold range of 4.4 to 30 pg/g for whole-body freshwater fish. Muscle and organ tissue samples from the Wellfleet Atlantic sturgeon fall within that threshold toxicity range (as mentioned earlier, a whole-body analysis of a large sturgeon would be impractical). The sensitivity of sturgeon to TCDD is not well known. In a shovelnose sturgeon *Scaphirhynchus platorrynchus* study, the no-observed-adverse-effects-level (NOAEL) and low-observed-adverse-effect-level (LOAEL) for eggs were 2,100 pg/g and 12,900 pg/g, respectively (Coffey *et al*. 2009). The authors concluded that early life stage shovelnose sturgeon may be less sensitive to TCDD than others fish species. Without laboratory studies, however, it is not known if early life stages of Atlantic sturgeon would have a similar sensitivity to TCDD.

6.2.2 Total Polychlorinated Biphenyls (PCBs) – 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).

The highest Total PCB concentration in the Wellfleet Atlantic sturgeon was detected in gonad tissue (1890.0 ng/g), which also had the highest lipid content among the three tissue samples submitted for analysis.

PCB Data Comparisons. Comparative PCB data were found for sturgeon collected in Maine, New York, Pennsylvania, Florida, Oregon, California, Nebraska, and North Dakota (Table 11).

Table 11. Total PCB in sturgeon tissues, ng/g wet weight

Species	Year	n	Location	Muscle	Liver	Gonad	Data Source
Atlantic Sturgeon	2007	1	Wellfleet, MA	124.0	894.0	1890.0	This Report
Atlantic Sturgeon	2006	2	Penobscot River, ME	< 5.0	< 5.0		USFWS unpublished data
Atlantic Sturgeon	1993-1998	14	Hudson River, NY	2170.0			Sloan *et al*. 2005
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	2006	4	Penobscot River, ME	< 5.0	< 5.0	< 5.0	USFWS unpublished data
Shortnose Sturgeon	2009	5	Kennebec River, ME	864.6			USFWS unpublished data
Shortnose Sturgeon	2003	1	Kennebec River, ME	370.0	710.0	2500.0	ERC 2003[a]
Shortnose Sturgeon	2001	1	Delaware River, PA	< 33.0	2000.0	5700.0	ERC 2002[a]
Shortnose Sturgeon	2001	1	Delaware River, PA	< 36.0	< 73.0	< 86.0	ERC 2002[a]
Gulf Sturgeon	1985 - 1991	10	Gulf Coast, FL	nd	nd – 80.0	nd – 190.0	Bateman & Brim 1994
White Sturgeon	1996	7	Columbia River, OR			50.0	Foster *et al*. 2001
White Sturgeon	1996	11	Columbia River, OR			30.0	Foster *et al*. 2001
White Sturgeon	1997	2[b]	South Bay, CA	23.0			Davis *et al*. 2002
White Sturgeon	1997	2[b]	San Pablo Bay, CA	33.0			Davis *et al*. 2002
Pallid Sturgeon	1988	1	Missouri River, NE			28520.0	Ruelle & Keenlyne 1993
Pallid Sturgeon	1983	1	Missouri River, ND	2410.0	1720.0		Ruelle & Keenlyne 1993
Pallid Sturgeon	1988	1	Missouri River, ND	25360.0	20510.0		Ruelle & Keenlyne 1993

[a] Reported as Aroclor 1260, [b] Composites of 2 to 3 fish, nd = non-detect, detection limits not reported

Total PCB Hazard Assessment – The current FDA guideline for PCBs in fish tissue is 2000 ng/g in an edible portion (FDA 2000). The muscle tissue sample from the Wellfleet Atlantic sturgeon did not exceeded the FDA guideline.

Newell *et al*. (1987) proposed a fish flesh guideline of 120 ng/g Total PCB to protect fish-eating wildlife, and all Wellfleet sturgeon tissue samples exceeded that suggested guideline. Liver and gonad samples from the Wellfleet Atlantic sturgeon also greatly exceeded the Total PCB criterion of 300 ng/g (egg derived criterion for the protection of aquatic life and 400 ng/g (whole-body derived criterion)(Eisler and Belisle 1996).

6.2.3 Polybrominated Diphenyl Ethers (PBDEs) – 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. No PBDE residue data for sturgeon were located in the literature. In a study of fish fillets obtained from fish markets and large-chain supermarkets, PBDE in wild caught fish ranged from 0.04 to 38 ng/g (Hayward *et al*. 2007). The fillet from the Wellfleet Atlantic sturgeon had a PBDE concentration of 8.8 ng/g. Liver and gonad tissue from the Wellfleet Atlantic sturgeon contained 75.7 ng/g and 148.0 ng/g of Total PBDE, respectively.

Total PBDE Hazard Assessment - Toxicity threshold levels for Total PBDE in fish have not been developed. Compared to the study by Hayward *et al*. (2007) that measured PBDE residue levels in fish fillets, the PBDE concentration in the fillet sample from the Wellfleet Atlantic sturgeon does not appear to be elevated. It is not known at this time if the liver or gonad tissue PBDE concentrations in the Wellfleet Atlantic sturgeon would be considered elevated or within normal ranges.

6.2.4 Dichloro-diphenyl-dicloroethylene (DDE) - DDT is an insecticide that was banned from use in the United States in 1972 after it was implicated in avian eggshell thinning. Although banned for decades, DDT metabolite residues persist in the environment with the *para*, *para* (*p,p'*) isomer DDE being detected most often in fish and wildlife tissues.

DDE in the Wellfleet Atlantic sturgeon was highest in gonad tissue (69.5 ng/g) followed by liver tissue (39.8 ng/g), and lowest in muscle tissue (2.37 ng/g).

DDE Data Comparisons. Comparative p,p'-DDE data for sturgeon collected in Maine, Pennsylvania, Florida, Oregon, California, Nebraska, and North Dakota are listed in Table 12.

Table 12. *p,p'*-DDE in sturgeon tissues, ng/g wet weight

Species	Year	n	Location	Muscle	Liver	Gonad	Data Source
Atlantic Sturgeon	2007	1	Wellfleet, MA	2.37	39.8	69.5	This Report
Atlantic Sturgeon	2006	2	Penobscot River, ME	2.10	4.35		USFWS unpublished data
Shortnose Sturgeon	2006	4	Penobscot River, ME	9.25	7.00	44.0	USFWS unpublished data
Shortnose Sturgeon	2009	5	Kennebec River, ME	19.34			USFWS unpublished data
Shortnose Sturgeon	2003	1	Kennebec River, ME	< 3 - 6			ERC 2003
Shortnose Sturgeon	2001	2	Delaware River, PA	8.0	44.0	100.0	ERC 2002
Gulf Sturgeon	1985 - 1991	10	Gulf Coast, FL	nd – 150	nd - 620	10 - 4020	Bateman & Brim 1994[a]
White Sturgeon	1996	7	Columbia River, OR			1450	Foster *et al*. 2001
White Sturgeon	1996	11	Columbia River, OR			4380	Foster *et al*. 2001
White Sturgeon	1997	2	South Bay, CA	9.1[b]			Davis *et al*. 2002
White Sturgeon	1997	2	San Pablo Bay, CA	23.0[b]			Davis *et al*. 2002
Pallid Sturgeon	1988	1	Missouri River, NE			3100.0	Ruelle & Keenlyne 1993
Pallid Sturgeon	1983	1	Missouri River, ND	3560.0	3780.0		Ruelle & Keenlyne 1993
Pallid Sturgeon	1988	1	Missouri River, ND	3670.0	2820.0		Ruelle & Keenlyne 1993

[a] Reported as o,p'-DDE and p,p'-DDE combined, [b] Reported at Total DDT, nd = non-detect, detection limits not reported

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). None of the three tissue samples from the Wellfleet Atlantic sturgeon approached the protective concentration levels suggested by Beckvar *et al*. (2005).

6.2.5 Total Chlordane - Chlordane is a cyclodiene insecticide that was once widely used in the United States to control termites, ants, and agricultural pests (Eisler 1990). The use of chlordane was banned in the United States in 1988, but components of the contaminant persist in the environment and in fish and wildlife tissues.

In the Wellfleet Atlantic sturgeon, total chlordane was highest in gonad tissue at 37.29 ng/g. Liver tissue had a total chlordane concentration of 26.31 ng/g and muscle tissue contained 2.31 ng/g. Among the seven chlordane compounds in the analytical scan, *trans*-nonachlor was the compound found in the highest concentrations in the three tissue types from the Wellfleet Atlantic sturgeon. Kajiwara *et al*. (2003) also found *trans*-nonachlor the most abundant chlordane compound in sturgeon from the Caspian Sea.

Chlordane Data Comparisons. Comparative Total Chlordane data were found for sturgeon collected in Maine, Pennsylvania, Florida, California, Nebraska, and North Dakota (Table 13).

Table 13. Total Chlordane in sturgeon tissues, ng/g wet weight

Species	Year	n	Location	Muscle	Liver	Gonad	Data Source
Atlantic Sturgeon	2007	1	Wellfleet, MA	2.31	26.31	37.29	This Report
Atlantic Sturgeon	2006	2	Penobscot River, ME	< 1 - 5	1.4		USFWS unpublished data
Shortnose Sturgeon	2006	4	Penobscot River, ME	27.6	5.5	15.6	USFWS unpublished data
Shortnose Sturgeon	2009	5	Kennebec River, ME	6.6			USFWS unpublished data
Shortnose Sturgeon	2003	1	Kennebec River, ME	< 3 - 6			ERC 2003
Shortnose Sturgeon	2001	1	Delaware River, PA	8.0[a]	44.0[a]	100.0[a]	ERC 2002
White Sturgeon	1997	2[b]	South Bay, CA	2.5			Davis *et al*. 2002
White Sturgeon	1997	2[b]	San Pablo Bay, CA	5.9			Davis *et al*. 2002
Pallid Sturgeon	1988	1	Missouri River, NE			5800	Ruelle & Keenlyne 1993
Pallid Sturgeon	1983	1	Missouri River, ND	230	190		Ruelle & Keenlyne 1993
Pallid Sturgeon	1988	1	Missouri River, ND	460	420		Ruelle & Keenlyne 1993

[a] Reported as alpha chlordane, [b] Composites of 2 to 3 fish

Chlordane Hazard Assessment – Eisler (1990) suggested a chlordane tissue concentration of less than 100 ng/g for the protection of natural resources and human health, but noted that “safe” residues in tissues of aquatic biota require clarification and additional research. Newell *et al*. (1987) proposed a fish flesh guideline of 500 ng/g Total Chlordane to protect fish-eating wildlife, and all Wellfleet tissue samples were well below that suggested guideline.

The current FDA regulatory guideline for chlordane in fish tissue is 300 ng/g in an edible portion and all three Wellfleet Atlantic sturgeon tissue samples would be below the FDA threshold. EPA has established monthly fish consumption limits for chlordane and no consumption limits would be placed on tissues with less than 150 ng/g (noncancer health endpoint) or 8.4 ng/g (cancer health endpoint). Under the EPA guidelines (EPA 2000), there would be no restriction on consumption of muscle tissue from the Wellfleet Atlantic sturgeon. Liver tissue from the Wellfleet Atlantic sturgeon would have consumption restrictions of 16 (noncancer health endpoint) and 8 (cancer health endpoint) fish meals/month, while gonad tissue would have consumption restrictions of 12 (noncancer health endpoint) and 4 (cancer health endpoint) fish meals/month.

6.2.7 Other Organic Compounds – Benzene hexachloride (BHC), aldrin, endrin, dieldrin, hexachlorobenzene (HCB), mirex, and pentachloro-anisole results are listed in Table 8.

6.3 Trace Metals.

Eight trace metals frequently associated with ecological harm are discussed below. The toxicological effects of residues of boron, barium, iron, magnesium, manganese, molybdenum, nickel, strontium, and vanadium in fish tissues are not well known or they are essential elements commonly detected in fish tissue, so these metals are not discussed. Aluminum and beryllium were below detection limits in all three samples, and also are not discussed. Concentrations below are expressed on a wet weight basis. Consult Table 9b for trace metal concentrations on a dry weight basis.

6.3.1 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). Arsenic is a teratogen and carcinogen. Arsenic bioconcentrates in organisms, but does not biomagnify in food chains (Eisler 1994). Arsenic concentrations in biota are usually less than 1 µg/g, with higher concentrations found in marine organisms particularly crustaceans (Eisler 1994). The non-toxic form of As, arsenobetaine, is the major form of As in marine fish muscle and organ tissue with species such as Atlantic salmon (*Salmo salar*) and Atlantic cod (*Gadus morhua*) containing 0.6 µg/g and > 5.6 µg/g, respectively (Amlund *et al*. 2006). Arsenic in the Wellfleet Atlantic sturgeon ranged from 4.90 µg/g (muscle) to 2.50 µg/g (gonad).

Arsenic Data Comparisons. Comparative As data were found for sturgeon collected in Maine, Pennsylvania, and Florida (Table 11).

Table 14. Arsenic (As) in sturgeon tissues, µg/g wet weight

Species	Year	n	Location	Muscle	Liver	Gonad	Data Source
Atlantic Sturgeon	2007	1	Wellfleet, MA	4.90	3.80	2.50	This Report
Atlantic Sturgeon	2006	2	Penobscot River, ME	2.75	0.87		USFWS unpublished data
Shortnose Sturgeon	2006	4	Penobscot River, ME	0.99	0.41	0.30	USFWS unpublished data
Shortnose Sturgeon	2009	5	Kennebec River, ME	1.77			USFWS unpublished data
Shortnose Sturgeon	2001	2	Delaware River, PA	< 5.00	< 5.00	< 5.00	ERC 2002
Gulf Sturgeon	1985 - 1991	10	Gulf Coast, FL	9.09	7.54	8.14	Bateman & Brim 1994

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. All the tissue samples from the Wellfleet Atlantic sturgeon exceed the lower ends of the suggested whole-body toxicity thresholds.

6.3.2 Cadmium (Cd) – Cadmium is a toxic metal and a common byproduct of copper, zinc, and lead mining (Eisler 1985, Gross *et al*. 2003). The element primarily accumulates in kidney and liver. Cadmium reduces plasma sex steroids and vitellogenin, and has been associated with degenerative changes in gonads of fish (Gross *et al*. 2003).

Cadmium Data Comparisons. Comparative Cd tissue data were found for sturgeon collected in Maine, Pennsylvania, Florida, and British Columbia (Table 15).

Table 15. Cadmium (Cd) in sturgeon tissues, µg/g wet weight

Species	Year	n	Location	Muscle	Liver	Gonad	Data Source
Atlantic Sturgeon	2007	1	Wellfleet, MA	< 0.019	0.31	< 0.033	This Report
Atlantic Sturgeon	2006	2	Penobscot River, ME	< 0.02	0.23		USFWS unpublished data
Shortnose Sturgeon	2006	4	Penobscot River, ME	< 0.02	0.05	< 0.08	USFWS unpublished data
Shortnose Sturgeon	2009	5	Kennebec River, ME	< 0.02			USFWS unpublished data
Shortnose Sturgeon	2003	1	Kennebec River, ME	< 0.20	< 0.20	0.60	ERC 2003
Shortnose Sturgeon	2001	2	Delaware River, PA	< 0.50	2.55	< 0.50	ERC 2002
Gulf Sturgeon	1985–1991	10	Gulf Coast, FL	nd – 0.01	0.07 – 0.67	nd – 0.07	Bateman & Brim 1994
White Sturgeon	1991-1992	6	Upper Fraser River, BC	< 0.44[a]	0.58[b]		MacDonald *et al*. 1997

[a] Three samples analyzed, reported as white muscle. [b] Three samples analyzed.

Cadmium Hazard Assessment – Eisler (1985) suggested that residues in excess of 10 µg/g in liver may be indicative of Cd contamination. The Cd liver level of the Wellfleet Atlantic sturgeon (0.31 µg/g in liver tissue) was well below the suggested 10 µg/g threshold.

6.3.3 Chromium (Cr) – Trivalent Cr is an essential element for vertebrates. The hexavalent form of Cr, however, may cause adverse effects in the liver and kidney, and could also be a carcinogen (FDA 1993, Environment Canada and Health Canada 1994). In the laboratory, Cr is a mutagen, carcinogen, and teratogen to several organisms (Eisler 1986). In fish, Cr bioaccumulates in gills, liver, and kidneys (Holdway 1988). Chromium exposure can alter smoltification and affect growth and survival in salmon (Farag *et al*. 2006), an anadromous species like the sturgeon. Chromium is metabolically regulated and accumulates less in fish than other trace metals (Hamilton and Hoffman 2003).

Chromium Data Comparisons. Comparative Cr data were found for sturgeon collected in Maine, Pennsylvania, Florida, and British Columbia (Table 16). In several other sturgeon studies, Cr was below detection in sturgeon tissues. Chromium was detected in all three tissue types from the Wellfleet Atlantic sturgeon with the highest concentration occurring in gonad tissue (2.20 µg/g).

Table 16. Chromium (Cr) in sturgeon tissues, µg/g wet weight

Species	Year	n	Location	Muscle	Liver	Gonad	Data Source
Atlantic Sturgeon	2007	1	Wellfleet, MA	0.56	1.20	2.20	This Report
Atlantic Sturgeon	2006	2	Penobscot River, ME	< 0.10	< 0.10		USFWS unpublished data
Shortnose Sturgeon	2006	4	Penobscot River, ME	< 0.10	< 0.20	< 0.40	USFWS unpublished data
Shortnose Sturgeon	2009	5	Kennebec River, ME	< 0.10			USFWS unpublished data
Shortnose Sturgeon	2003	1	Kennebec River, ME	< 5.00	< 5.00	< 5.00	ERC 2003
Shortnose Sturgeon	2001	2	Delaware River, PA	< 0.50	< 0.50	1.20[a]	ERC 2002
White Sturgeon	1991 - 1992	6	Upper Fraser River, BC	0.12[b]	0.58[c]		MacDonald *et al*. 1997

[a] One sample. The other was < 0.50 µg/g. [b] Three samples analyzed, reported as white muscle. [c] Three samples analyzed.

Chromium Hazard Assessment – Hinck *et al*. (2009) presented a suggested Cr toxicity threshold level for whole-body freshwater fish of 1.0 µg/g. Liver and gonad tissue from the Wellfleet Atlantic sturgeon exceeded this suggested whole-body threshold concentration.

6.3.4 Copper (Cu) – Copper is used in the preservation and coloring of foods, and in brass and copper 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 sensory physiology and predator avoidance in juvenile fish (Hecht *et al*. 2007, Sandahl *et al*. 2007). Copper is not carcinogenic, mutagenic, or teratogenic at environmentally realistic concentration (Eisler 1997).

Liver tissue from the Wellfleet Atlantic sturgeon had the highest Cu concentration (6.90 µg/g). Muscle and gonad tissue had similar Cu concentrations of 0.29 µg/g and 0.24 µg/g, respectively.

Copper Data Comparisons. Comparative Cu data were found for sturgeon collected in Maine and Pennsylvania (Table 17).

Table 17. Copper (Cu) in sturgeon tissues, µg/g wet weight

Species	Year	n	Location	Muscle	Liver	Gonad	Data Source
Atlantic Sturgeon	2007	1	Wellfleet, MA	0.29	6.90	0.24	This Report
Atlantic Sturgeon	2006	2	Penobscot River, ME	0.20	3.60		USFWS unpublished data
Shortnose Sturgeon	2006	4	Penobscot River, ME	0.44	2.10	0.59	USFWS unpublished data
Shortnose Sturgeon	2009	5	Kennebec River, ME	0.33			USFWS unpublished data
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

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 concentration in the Wellfleet Atlantic sturgeon would exceed the lower suggested Cu whole-body threshold concentration, but be lower than the range suggested by Hinck *et al*. (2009). Copper concentrations in muscle and gonad tissue from the Wellfleet Atlantic sturgeon would be well below the USDOI (1998) or Hinck *et al*. (2009) threshold levels.

6.3.5 Mercury (Hg) – Mercury is a global pollutant with biological mercury hotspots existing in the northeastern United States (Evers *et al*. 2007). Sources of Hg contamination include emissions from coal-fired energy facilities, incinerators, mining activities, operation of chloralkali plants, and disposal of mercury-contaminated products such as batteries and fluorescent lamps (Eisler 1987). Mercury is a mutagen, teratogen, and carcinogen which bioconcentrates in organisms and biomagnifies through food chains (Eisler 1987). Most of the Hg in fish tissue is the organic form, MeHg or methylmercury (Wiener *et al*. 2003). Detrimental effects of Hg exposure in fish include changes in behavior, growth, reproduction, and survival (Wiener and Spry 1996).

Mercury Data Comparisons. Mercury concentrations in sturgeon tissues have been reported by a number of investigators (Table 18).

Table 18. Mercury (Hg) in sturgeon tissues, µg/g wet weight

Species	Year	n	Location	Muscle	Liver	Gonad	Data Source
Atlantic Sturgeon	2007	1	Wellfleet, MA	0.15	0.44	< 0.02	This Report
Atlantic Sturgeon	2006	2	Penobscot River, ME	0.18	0.61		USFWS unpublished data
Atlantic Sturgeon	1973 - 1975	30	St. John Estuary, NB	0.29		0.04	Dadswell 1975
Shortnose Sturgeon	1973 -1975	24	St. John Estuary, NB	1.17		0.30	Dadswell 1975
Shortnose Sturgeon	2006	4	Penobscot River, ME	0.42	0.41[a]	0.07[a]	USFWS unpublished data
Shortnose Sturgeon	2009	5	Kennebec River, ME	0.55			USFWS unpublished data
Shortnose Sturgeon	2003	1	Kennebec River, ME	0.26	0.15	0.12	ERC 2003
Shortnose Sturgeon	2001	2	Delaware River, PA	0.08	1.04	0.06	ERC 2002
Gulf Sturgeon	1985 - 1991	10	Gulf Coast, FL	0.10	0.53	0.05	Bateman & Brim 1994
White Sturgeon	1991	5	Fraser River, BC	0.65[b]	0.34[c]		MacDonald *et al*. 1997
White Sturgeon	1997	2[d]	South Bay, CA	0.30			Davis *et al*. 2002
White Sturgeon	1997	2[d]	San Pablo Bay, CA	0.26			Davis *et al*. 2002
White Sturgeon	2000 - 2001	57	Columbia River, OR	0.17	0.14	0.03	Webb *et al*. 2006
White Sturgeon	2003	1	Columbia River, OR	1.09	1.68	0.03	Webb *et al*. 2006

[a] Three samples analyzed, [b] Reported as white muscle tissue, [c] Four samples analyzed, [d] Composites of 2 to 3 fish

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). The Hg concentration in muscle tissue of the Wellfleet Atlantic sturgeon was low compared to older regional Atlantic sturgeon studies (St. John estuary, New Brunswick; Dadswell 1975) and similar to more recent collections in Maine (USFWS, unpublished data). The muscle Hg level in the Wellfleet Atlantic sturgeon is also lower than consumptive guideline concentrations (e.g., 0.20 µg/g and 0.50 µg/g). Beckvar *et al*. (2005) suggested that a Hg whole-body tissue threshold-effect level (t-TEL) of 0.20 µg/g would be protective of juvenile and adult fish.

6.3.6 Lead (Pb) – Lead is an ubiquitous environmental contaminant commonly found in fish and wildlife tissues, particularly in species with habitats proximal to roads and urban or industrial developments. Lead is bioconcentrated, but does not appear to magnify through food chains (Eisler 1988). Exposure to Pb may cause neurological effects, kidney dysfunction, and anemia in vertebrates (Leland and Kuwabara 1985). Lead is known to inhibit δ-aminolevulinic acid dehydratase (ALAD) activity, an enzyme necessary for hemoglobin synthesis, and to elevate protoporphyrin concentrations (Henny *et al.* 1991, Schmitt *et al*. 1993).

Adverse Pb effects on aquatic biota can include reduced survival, impaired reproduction, impaired function of the liver, kidney, and spleen, reduced growth, and spinal deformities (Holcombe *et al*. 1976, Eisler 1988). Lead accumulation varies among fish species, and concentrations do not appear to be related to size (Czarnezki 1985). Lead is concentrated at higher levels in calcified or hard tissue (i.e., bone, skin, scales) than in muscle and other soft tissues (Patterson and Settle 1976). Lead, at 0.64 µg/g, was only detected in the liver tissue of the Wellfleet Atlantic sturgeon.

Lead Data Comparisons. Comparative Pb data were found for sturgeon collected in Maine, Pennsylvania, and Florida (Table 19).

Table 19. Lead (Pb) in sturgeon tissues, µg/g wet weight							
Species	**Year**	**n**	**Location**	**Muscle**	**Liver**	**Gonad**	**Data Source**
Atlantic Sturgeon	2007	1	Wellfleet, MA	<0.02	0.64	< 0.03	This Report
Atlantic Sturgeon	2006	2	Penobscot River, ME	<0.05	1.05		USFWS unpublished data
Shortnose Sturgeon	2006	4	Penobscot River, ME	<0.06	0.10[a]	<0.20[a]	USFWS unpublished data
Shortnose Sturgeon	2009	5	Kennebec River, ME	<0.05			USFWS unpublished data
Shortnose Sturgeon	2001	2	Delaware River, PA	<2.00	<2.00	<2.00	ERC 2002
Gulf Sturgeon	1985 - 1991	10	Gulf Coast, FL	nd	nd–0.80	nd	Bateman & Brim 1994
[a] Three samples analyzed. nd= non-detect, detection limit not reported.							

Lead Hazard Assessment –The liver Pb tissue levels in the Wellfleet Atlantic sturgeon was within the ranges reported in other sturgeon studies. Jarvinen and Ankley (1999) suggested that the Pb effects threshold in fish is greater than 0.40 µg/g. Hinck *et al*. (2009) presented a suggested lead toxicity threshold range for whole-body freshwater fish between 0.40 and 8.8 µg/g. Tissue samples from the Wellfleet Atlantic sturgeon did not approach these suggested threshold levels for freshwater fish. A Pb threshold level for estuarine and marine species has not been established.

6.3.7 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). Elevated selenium exposure in white sturgeon caused significant increase in larval mortality and abnormality rates, including edema and spinal deformities (Linares *et al*. 2004, Linville 2006)

Selenium Data Comparisons. Comparative Se data were found for sturgeon collected in Maine and Pennsylvania (Table 20).

Table 20. Selenium (Se) in sturgeon tissues, µg/g wet weight							
Species	**Year**	**n**	**Location**	**Muscle**	**Liver**	**Gonad**	**Data Source**
Atlantic Sturgeon	2007	1	Wellfleet, MA	2.90	7.00	1.10	This Report
Atlantic Sturgeon	2006	2	Penobscot River, ME	1.02	1.80		USFWS unpublished data
Shortnose Sturgeon	2006	4	Penobscot River, ME	0.68	1.80[a]	0.57[a]	USFWS unpublished data
Shortnose Sturgeon	2009	5	Kennebec River, ME	0.95			USFWS unpublished data
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] Only 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 the gonad tissue, the tissue samples from the Wellfleet Atlantic sturgeon would exceed the suggested Se thresholds.

6.3.8 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, is a cofactor of enzymes regulating metabolic processes, and rarely toxic (Leland and Kuwabara 1985, Gross *et al*. 2003). Elevated Zn exposure, however, may cause reproductive alterations in fish including decreased circulating levels of vitellogenin, delayed spawning, decreased egg viability, impaired spermatogenesis, increased oocyte atresia, reduced egg size, and larval deformities (Gross *et al*. 2003).

Zinc Data Comparisons. Comparative Zn data were found for sturgeon collected in Maine, Pennsylvania, and British Columbia (Table 21).

Table 21. Zinc (Zn) in sturgeon tissues, µg/g wet weight

Species	Year	n	Location	Muscle	Liver	Gonad	Data Source
Atlantic Sturgeon	2007	1	Wellfleet, MA	5.6	27.0	4.5	This Report
Atlantic Sturgeon	2006	2	Penobscot River, ME	3.8	21.5		USFWS unpublished data
Shortnose Sturgeon	2006	4	Penobscot River, ME	4.1	21.1	21.4	USFWS unpublished data
Shortnose Sturgeon	2009	5	Kennebec River, ME	4.0			USFWS unpublished data
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
White Sturgeon	1991	3	Fraser River, BC	3.1[a]	35.7		MacDonald *et al*. 1997

[a] Reported as white muscle tissue

Zinc Hazard Assessment – Zinc tissue levels in the Wellfleet Atlantic sturgeon 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 Wellfleet Atlantic sturgeon 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

TCDD-TEQs levels in tissue samples from the Wellfleet Atlantic sturgeon (max. 24.2 pg/g in gonad) were below suggested toxicity threshold levels. Over 95% of the TCDD-TEQ in muscle, liver, and gonad tissue was comprised of dioxins and furans, while dioxin-like PCB congeners contributed less than 5% to the TCDD-TEQ.

Total PCB in sturgeon tissue samples ranged from 124 ng/g in muscle tissue to 1,890 ng/g in gonad tissue. These Total PCB tissue concentrations exceed suggested toxicity threshold levels for fish. Dominant PCB congeners in all three tissue samples from the Wellfleet Atlantic sturgeon were PCB# 153 and PCB# 138.

Total PBDE ranged from 8.8 ng/g in muscle to 148 ng/g in gonad. A suggested toxicity threshold level for PBDE in fish has not been established, but the PBDE levels detected in the Wellfleet Atlantic sturgeon fillet tissue were similar to concentrations in fish from other regions of the U.S. The dominant PBDE congener in all three tissue samples was BDE# 47. Insufficient information is available to assess PBDE levels in liver and gonad from the Wellfleet Atlantic sturgeon.

Among the other organic compounds included in the analytical suite, concentrations were generally low compared to suggested threshold effect levels or other sturgeon studies. Among organic compounds, the breakdown metabolites of the insecticide DDT were found at higher concentrations than other organic compounds such as chlordanes (max. 37.3 ng/g) and benzene hexachloride (max. 7.8 ng/g). Total DDT (the sum of six metabolites) was found at a concentration of 120.6 ng/g in gonad tissue with lower levels found in muscle (8.3 ng/g) and liver tissue (76.6 ng/g). DDT concentrations in tissue samples from the Wellfleet Atlantic sturgeon were below suggested toxicity threshold levels (Beckvar *et al*. 2005).

Mercury, chromium, copper, selenium, and zinc were found in tissue samples at elevated concentrations compared to threshold levels or other sturgeon studies. Mercury in muscle tissue (0.15 µg/g) and liver tissue (0.44 µg/g) approached or exceeded the suggested whole-body toxicity threshold level of 0.20 µg/g (Beckvar *et al*. 2005). Chromium tissue concentrations (max. 2.20 µg/g) in the Wellfleet Atlantic sturgeon were higher than levels reported in other sturgeon studies. Copper in the sturgeon's liver tissue (6.90 µg/g) exceeded a suggested threshold concentration of 3.30 µg/g (USDOI 1998b), but was well below a suggested higher threshold range of 11.1 µg/g to 42.0 µg/g (Hinck *et al*. 2009). Selenium in muscle (2.90 µg/g) and liver (7.00 µg/g) tissue samples from the sturgeon exceeded suggested threshold concentrations of 2.00 µg/g and 3.00 µg/g, respectively (Lemly 1996). Zinc levels in the sturgeon were low compared to suggested toxicity threshold concentrations and similar to levels reported in other sturgeon studies.

<u>Management Recommendation</u>

With the recently proposed listing of the Atlantic sturgeon as threatened in the Gulf of Maine Distinct Population Segment (DPS), additional data are needed to thoroughly assess contaminant burdens in sturgeon from this DPS.

Tissues from Atlantic sturgeon carcasses opportunistically encountered or mortalities from scientific studies 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.

Future tissue sampling should also include genetic analyses to determine river-of-origin for the Atlantic sturgeon being analyzed since the species is highly migratory and is known to visit estuaries distant from its natal system.

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Table A-1. Lengths and weights of sturgeon used for contaminant residue comparisons.

Year (s)	Location	Species	Scientific Name	n	Total Length - Millimeters Individual or Mean (Range)	Weight - Grams Individual or Mean (Range)	Reference
2007	Wellfleet, MA	Atlantic sturgeon	*Acipensor oxyrinchus*	1	1630	20500	This study
1973 - 1975	St. John Estuary, NB	Atlantic sturgeon	*Acipensor oxyrinchus*	30	n/a	n/a	Dadswell 1975
1993	Hudson River, NY	Atlantic sturgeon	*Acipensor oxyrinchus*	1	680	1362	Sloan *et al* . 2005
1994	Hudson River, NY	Atlantic sturgeon	*Acipensor oxyrinchus*	1	580	851	Sloan *et al* . 2005
1994	Hudson River, NY	Atlantic sturgeon	*Acipensor oxyrinchus*	2	800 (745 - 855)	2100 (1731 - 2469)	Sloan *et al* . 2005
1994	Hudson River, NY	Atlantic sturgeon	*Acipensor oxyrinchus*	1	890	3140	Sloan *et al* . 2005
1994	Hudson River, NY	Atlantic sturgeon	*Acipensor oxyrinchus*	1	1020	4824	Sloan *et al* . 2005
1997	Hudson River, NY	Atlantic sturgeon	*Acipensor oxyrinchus*	1	109	4	Sloan *et al* . 2005
1998	Hudson River, NY	Atlantic sturgeon	*Acipensor oxyrinchus*	1	1600	21319	Sloan *et al* . 2005
1998	Hudson River, NY	Atlantic sturgeon	*Acipensor oxyrinchus*	4	590 (199 - 743)	1251 (25 - 1820)	Sloan *et al* . 2005
1998	Hudson River, NY	Atlantic sturgeon	*Acipensor oxyrinchus*	2	1865 (1800 - 1930)	34020 (33566 - 34473)	Sloan *et al* . 2005
2006	Penobscot River, ME	Atlantic sturgeon	*Acipensor oxyrinchus*	2	1036 (980 - 1092)	5150 (4200 - 6100)	USFWS unpublished data
1985 - 1991	Gulf Coast, FL	Gulf Sturgeon	*Acipensor oxyrinchus desotoi*	10	1591 (1310 - 1920)	25090 (12400 - 49100)	Bateman and Brim 1994
1973 - 1975	St. John Estuary, NB	Shortnose Sturgeon	*Acipensor brevirostrum*	24	n/a	n/a	Dadswell 1975
1992	Hudson River, NY	Shortnose Sturgeon	*Acipensor brevirostrum*	1	614	586	Sloan *et al* . 2005
1998	Hudson River, NY	Shortnose Sturgeon	*Acipensor brevirostrum*	1	631	1660	Sloan *et al* . 2005
2001	Delaware River, PA	Shortnose Sturgeon	*Acipensor brevirostrum*	2	676 (667 - 686)	1625 (1500- 1750)	ERC 2002
2003	Kennebec River, ME	Shortnose Sturgeon	*Acipensor brevirostrum*	1	890	6500	ERC 2003
2006	Penobscot River, ME	Shortnose Sturgeon	*Acipensor brevirostrum*	4	933 (835 - 994)	4838 (2800 - 6000)	USFWS unpublished data
2009	Kennebec River, ME	Shortnose Sturgeon	*Acipensor brevirostrum*	5	781 (655 - 935)	1868 (1052 - 2835)	USFWS unpublished data
1991 - 1992	Fraser River, BC	White Sturgeon	*Acipensor transmontanus*	6	1752 (1220 - 2130)	49083 (15400 - 91000)	MacDonald *et al* . 1997
1996	Columbia River, OR [a]	White Sturgeon	*Acipensor transmontanus*	18	1253	n/a	Foster *et al* . 2001
1997	San Francisco Bay, CA [a]	White Sturgeon	*Acipensor transmontanus*	4	(1170 - 1490)	n/a	Davis *et al* . 2002
2000 - 2001	Columbia River, OR	White Sturgeon	*Acipensor transmontanus*	57	1100 - 1370 [b]	n/a	Webb *et al* . 2006
2003	Columbia River, OR	White Sturgeon	*Acipensor transmontanus*	1	2620 [c]	170450	Webb *et al* . 2006
1988	Missouri River, NE	Pallid Sturgeon	*Scaphirhynchus albus*	1	959	2239	Ruelle and Keenlyne 1993
1983 - 1988	Missouri River, ND	Pallid Sturgeon	*Scaphirhynchus albus*	2	1444 (1314 - 1575)	13555 (10000 - 17110)	Ruelle and Keenlyne 1993

n/a = not available, [a] Two locations, [b] legal-size slot limit, [c] fork length