Status, trends and management of sturgeon and paddlefish fisheries

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Abstract

The 27 extant species of sturgeons and paddlefishes (Order Acipenseriformes) represent a unique and relict lineage of fishes. Producers of coveted black caviar, sturgeons are one of the most valuable wildlife commodities on earth. The group is among the most endangered fishes with all species listed under Convention on International Trade in Endangered Species (CITES) Appendix I (two species) or II (25 species), only two species considered Lower Risk by IUCN, four of the nine US taxa and one Caspian species protected under the Endangered Species Act, and local extinctions recorded for 19 of 27 species. Despite their well-publicized imperilled status, commercial pressure on 15 species persists. Here, after reviewing the biological characteristics of sturgeons and paddlefishes and their commercial use, an overview of global fisheries is presented. The synopsis demonstrates that, with few exceptions, sturgeon and paddlefish are imperilled across the globe and long-term survival in the wild is in jeopardy. All major sturgeon fisheries have surpassed peak productivity levels, with 70% of major fisheries posting recent harvests <15% of historic peak catches and 35% of the fisheries examined crashing within 7–20 years of inception. Even in Caspian Sea fisheries, the most important globally, present catches are below 10% of historic peak landings. Improved domestic and international fisheries management and attention to habitat and species restoration is now needed. Although captive rearing offers promise for caviar alternatives and endangered species restoration, it must advance cautiously to avoid environmental harm. To ensure a continued supply of caviar and the survival of these unique fishes we offer recommendations for priority conservation action for the future.

Keywords Acipenseriformes, aquaculture, caviar, conservation, Convention on International Trade in Endangered Species

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Introduction

Twenty-seven extant species of sturgeons and paddlefishes (Order Acipenseriformes) inhabit the rivers, estuaries, near-shore oceanic environments and inland seas of the northern hemisphere (Table 1; Fig. 1; Birstein 1993; Grande and Bemis 1996; Bemis *et al.* 1997; Bemis and Kynard 1997). A unique and relict lineage important in the evolutionary history of fishes, many sturgeons and paddlefishes now face extinction because of overfishing, pollution and habitat degradation (Birstein 1993). Producers of black caviar, the unfertilized eggs of true sturgeon, and commercial roe, the unfertilized eggs of paddlefish, the group has experienced decades of intense exploitation fuelled by a lucrative international caviar market. Their fisheries have undergone boom and bust cycles, with overexploitation resulting in harvest and population declines. Few viable sturgeon fisheries now remain.

Recent published works offer summaries of Acipenseriformes aquaculture, biology, conservation, evolution and genetics (Birstein 1993; Dettlaff *et al.* 1993; Bemis *et al.* 1997; Bemis and Kynard 1997; Birstein *et al.* 1997a,c; Findeis 1997; Choudhury and Dick 1998; Billard and Lecointre 2001; Chebanov and Billard 2001; Fontana *et al.* 2001; Mims 2001; Van Winkle *et al.* 2002). After briefly reviewing these topics, we review the status and management of 14 commercially important species, focusing on species for which improvements in fisheries management are most critical to restoration and recovery. Species threatened exclusively by habitat degradation, too endangered to support commercial fishing or fully protected from exploitation are only briefly mentioned.

Overview of Acipenseriformes

Part of the Gnathostomata or jawed fishes, sturgeons and paddlefishes represent an ancient Actinopterygian lineage. Dating from the Lower Jurassic (200 Myr BP), these 'living fossils' retain primitive characters including a heterocercal caudal fin and ganoid scales (Gardiner 1984). Characters such as a cartilaginous endoskeleton and hyostylic jaw suspension led to early classification as sharks (Bemis *et al.* 1997). Since their genesis in the Tethys Sea, Acipenseriformes lineages diverged in Europe and Asia and later radiated in North America (Bemis and Kynard 1997; Birstein *et al.* 1997b). All extant and fossil sturgeons and paddlefishes are from the temperate northern hemisphere with a distribution closely tied to the former Laurasian landmasses (Eurasia, North America) (Grande and Bemis 1996; Bemis *et al.* 1997). Some of the largest rivers and inland waterbodies are important sturgeon and paddlefish habitats (Table 1; Fig. 1).

The Order Acipenseriformes is divided into two families, Acipenseridae (sturgeon) and Polyodontidae (paddlefish) (Table 1; Berg 1940; Grande and Bemis 1996; Bemis *et al.* 1997). The 25 extant species of sturgeon have spindle-shaped bodies covered by five rows of bony scutes and snouts with sensory barbells. The two extant species of paddlefish lack scales and scutes and have a large extended rostrum. Some taxonomic designations based upon morphology have been challenged by molecular studies and the true number of species and subspecies remains contentious (Grande and Bemis 1996; Mayden and Kuhajda 1996; Bemis *et al.* 1997; Birstein and Bemis 1997; Birstein *et al.* 1997b, 2002; Findeis 1997; Birstein and DeSalle

Table 1 Species of Acipenseriformes, current geographical range and conservation status. General references include Birstein 1993; Bemis and Kynard 1997; Birstein *et al.* 1997a; CITES 2000; Billard and Lecointre 2001; Williamson 2003.

Binomials	Common name	Geographical range	Status[2]	Range contractions
A. baerii (Brandt, 1869)[3]	Siberian sturgeon	Siberian rivers	VU (IUCN); App. II[1]	Some Yenisey and Lena river reaches
A. baerii baerii	Siberian sturgeon	Ob R. basin	EN (IUCN)	
A. baerii baicalensis	Baikal sturgeon	Lake Baikal, Siberia	VU (IUCN)	
A. baerii stenorrhynchus	Lena River sturgeon	Eastern Siberian rivers	EN (IUCN)	
A. brevirostrum (Lesueur, 1818)[4]	Shortnose sturgeon	North America, eastern coast	VU (IUCN); App. I; E (US ESA); SC (COSEWIC); EN (CT, FL, GA, MD, MA, NH, NJ, NY, NC, PA, SC, VA)	
A. dabryanus (Duméril, 1869)[5]	Yangtze/Dabry's sturgeon	Yangtze River system	CR (IUCN); App. II	Lower Yangtze River
A. fulvescens (Rafinesque, 1817)[6]	Lake sturgeon	Great Lakes, lakes of south Canada; Hudson-James Bay, Mississippi River drainage	VU (IUCN); App. II; SC (GA, NC), EN (IL, IN, IA, MO, OH, PA, TN, VT), TH (MI, NE, NY)	EX (AL, AR, MS, WV), Mississippi Delta; Lakes Winnipeg, Ontario and Erie
A. gueldenstaedtii (Brandt, 1833)	Russian sturgeon	Ponto-Caspian region	EN (IUCN[1]); App. II[1]	Upper Danube, Volga, Kuban rivers
A. g. gueldenstaedtii		Caspian Sea		
A. g. colchicus		Black Sea		
A. g. colchicus		Azov Sea		
A. medirostris (Ayres, 1854)[7]	Green sturgeon	North America, Pacific coast	VU (IUCN); App. II; SC (COSEWIC); SC (California)	Southern population segment: Upper Columbia
A. mikadoi (Hilgendorf, 1892)[8]	Sakhalin sturgeon	Pacific Ocean, Amur R. to N. Japan, Bering Sea, Tumnin R.	EN (IUCN); App. II	Korea
A. naccarii (Bonaparte, 1836)[9]	Adriatic sturgeon	Adriatic Sea, Po R.	VU (IUCN); App. II	Range contraction likely
A. nudiventris (Lovetsky, 1828)[10]	Ship sturgeon	Caspian, Black and Aral seas and rivers	EN (IUCN; Black, Caspian), CR (IUCN; Danube River), App. II	EX (Aral Sea, upper Danube R.)
A. oxyrinchus[11] (Mitchill, 1814)	Atlantic sturgeon	Gulf of Mexico and northern S. America	LR (IUCN); App. II[1]	
A. oxyrinchus desotoi	Gulf sturgeon	N. America, east coast, Florida to Labrador	VU (IUCN); T (US ESA); TH (AL, LA); SC (FL, GA); EN (MS)	
A. oxyrinchus oxyrinchus	Atlantic sturgeon		LR (IUCN); TH (CT, PA); EN (DE, MA); SC (FL, NC, VA);	
A. persicus (Borodin, 1897)	Persian sturgeon	Ponto-Caspian	EN (IUCN); App. II[1]	
A. persicus persicus		Caspian Sea	VU (IUCN)	
A. persicus colchicus		Black Sea and rivers	EN (IUCN)	
A. ruthenus (Linnaeus, 1758)	Sterlet	Caspian and Black seas and watershed; Siberian rivers	VU (IUCN); App. II	

Table 1 Continued.

Binomials	Common name	Geographical range	Status[1]	Range contractions
A. schrenckii (Brandt, 1869)[12]	Amur River sturgeon	Amur R. system	EN (IUCN); App. II	
A. sinensis (Gray, 1835)[13]	Chinese sturgeon	Yangtze R. system	EN (IUCN); App. II	Upper Yangtze
A. stellatus (Pallas, 1771)	Stellate sturgeon	Ponto-Caspian	EN (IUCN); App. II[1]	Upper Danube, Volga, Kuban rivers
A. s. stellatus		Caspian Sea	VU (IUCN)	
A. s. ponticus		Black Sea	EN (IUCN)	
A. s. donensis		Sea of Azov	EN (IUCN)	
A. sturio (Linnaeus, 1758)[14]	Atlantic (Baltic) sturgeon	Baltic, Eastern N. Atlantic, Mediterranean, Black Sea	CR (IUCN); App. I	Throughout Europe
A. transmontanus (Richardson, 1836)[15]	White sturgeon	North America, west coast, Gulf of Alaska to Baja	LR (IUCN); EN (IUCN; Kootenai R. population); E (US ESA, Kootenai R. population); E (COSEWIC); IM (British Columbia)	
Huso dauricus (Georgi, 1775)	Kaluga sturgeon	Amur R. system	EN (IUCN); App. II	
H. huso (Linnaeus, 1758)		Ponto-Caspian	EN (IUCN); T (US ESA); App. II[1]	Upper Danube, Dnieper, Volga, Kuban rivers; EX EX (IUCN)
H. h. caspicus		Caspian Sea	EN (IUCN)	
H. h. ponticus		Black Sea	EN (IUCN)	
H. h. maeoticus		Sea of Azov Adriatic Sea	CR (IUCN)	
Pseudoscaphirhynchus fedtschenkoi (Kessler, 1872)[16]	Syr-Dar shovelnose sturgeon	Syr-Darya R. (Kazakhstan, Central Asia)	CR (IUCN); App. II	Possibly extinct
P. hermanni (Kessler, 1877)[17]	Small Amu Dar shovelnose sturgeon	Amu-Darya R. (Uzbekistan, Central Asia)	CR (IUCN); App. II	
P. kaufmanni (Kessler ex. (Bogdanov), 1874)[18]	Large Amu-Dar shovelnose sturgeon	Amu-Darya R. (Turkmenistan, Uzbekistan and Tajikistan, Central Asia)	EN (IUCN); App. II	Upper Amu Darya R.
Scaphirhynchus albus (Forbes and Richardson, 1905)[19]	Pallid sturgeon	Missouri–Mississippi R. basins	EN (IUCN); App. II E (USA ESA); EN (US[1])	
S. platorynchus (Rafinesque, 1820)[20]	Shovelnose sturgeon	Missouri–Mississippi R. basins	VU (IUCN); App. II; EN (OH); TH (TX)	EX (Al? NM, NC, PA, WV?; Rio Grande (TX))
S. suttkusi (Williams and Clemmer, 1991)[21]	Alabama sturgeon	Missouri- Mississippi R. basins	CR (IUCN); App. II; E (USA ESA); PR (AL); EN (MS)	85% of former range

Table 1 Continued.

Binomials	Common name	Geographical range	Status[1]	Range contractions
Polyodon spathula (Walbaum in Artedi, 1792)[22]	North American paddlefish	Mississippi R. system	VU (IUCN); App. II; E (COSEWIC); TH (MI, OH, TX, WI), SC (T), EN (NC, VA)	EX (Ontario, MD, NC, NY, PA)
Psephurus gladius (Martens, 1862)[23]	Chinese paddlefish	Yangtze R.	CR (IUCN); App. II;	East China Sea, Yellow River, some Yangtze River tributaries

[1]All populations included in designation.
[2]IUCN Listings: VU, vulnerable; LR, lower risk; CR, critically endangered; EX, extinct. USA Endangered Species Act Listing: E, endangered; T, threatened. *CITES Listings*: App. I, Appendix I; App. II, Appendix II. Canada Listing (COSEWIC): SC, special concern; E, Extirpated. *State and province classifications*: TH, threatened; EN, endangered; EX, extinct; IM, imperilled; SC, special concern; PR, protected non-game species. *State Abbreviations for US listings as follows*: Alabama, AL; Arkansas, AR; CT, Connecticut; DE, Delaware; FL, Florida; GA, Georgia; ID, Idaho; IL, Illinois; IN, Indiana; IA, Iowa; KS, Kansas; KY, Kentucky; LA, Louisiana; MA, Massachusetts; MD, Maryland; MI, Michigan; MN, Minnesota; MS, Mississippi; MO, Missouri; MT, Montana; NE, Nebraska; NJ, New Jersey; NM, New Mexico; NY, New York; NC, North Carolina; ND, North Dakota; OH, Ohio; OK, Oklahoma; PA, Pennsylvania; SC, South Carolina; SD, South Dakota; TN, Tennessee; TX, Texas; VT, Vermont; VA, Virginia; WI, Wisconsin; WY, Wyoming. Sources: Birstein *et al.* 1997a; Williamson 2003.
[3]Solovov and Vasila'v (1989); Ruban (1997).
[4]Kynard (1997); NMFS (1998a); Grunwald *et al.* (2002); Kynard and Horgan (2002).
[5]Wei *et al.* (1997, 2004); Zhuang *et al.* (1997).
[6]Ferguson and Duckworth (1997); Thuemler (1997); Knights *et al.* (2002).
[7]Birstein and Bemis (1997); EPIC (2001); Erickson *et al.* (2002).
[8]Artyukhin and Andronov (1990).
[9]Lelek (1987).
[10]Zholdasova (1997).
[11]Ong *et al.* (1996); Stabile *et al.* (1996); Smith and Clugston (1997); NMFS (1998b); Kynard and Horgan (2002); Waldman *et al.* (2002).
[12]Krykhtin and Svirskii (1997).
[13]Wei *et al.* (1997, 2004)
[14]Rochard *et al.* (1990); Debus (1997); Williot *et al.* (1997).
[15]Anders *et al.* (2002).
[16]Birstein (1997b).
[17]Salnikov *et al.* (1996).
[18]Salnikov *et al.* (1996); Birstein (1997b).
[19]Kallemeyn (1983); Mayden and Kuhajda (1996, 1997a); Campton *et al.* (2000); Bramblett and White (2001); Tranah *et al.* (2001).
[20]Mayden and Kuhajda (1996); Keenlyne (1997); Campton *et al.* (2000); Bramblett and White (2001); Tranah *et al.* (2001).
[21]Mayden and Kuhajda (1996, 1997b); Campton *et al.* (2000); Tranah *et al.* (2001).
[22]Graham (1997); Jennings and Zigler (2000); Mims (2001).
[23]Mims *et al.* (1993); Wei *et al.* (1997, 2004).

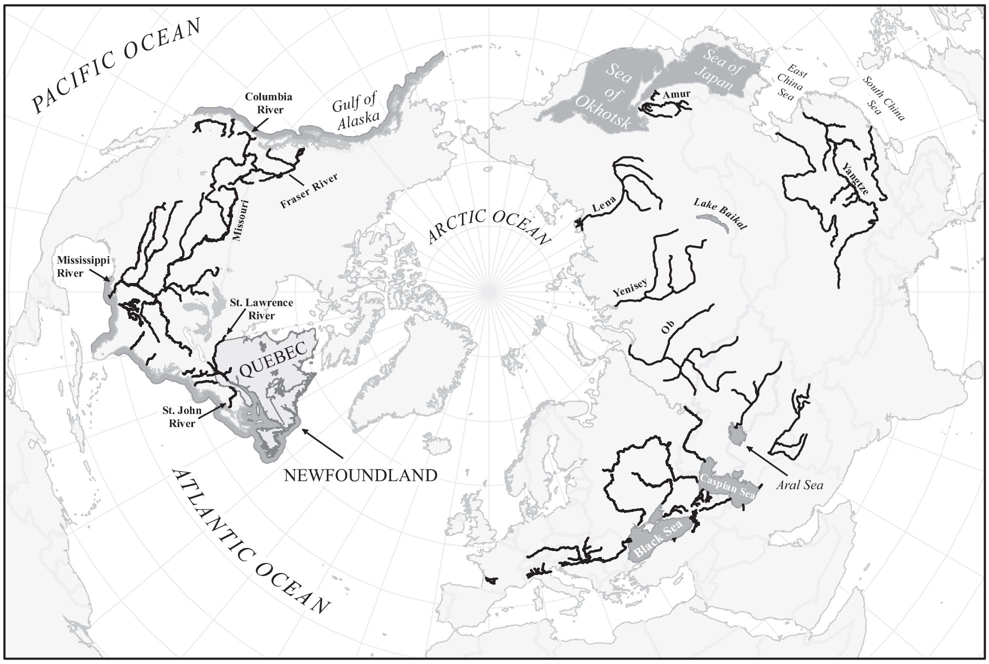

Figure 1 Range and distribution of sturgeon and paddlefish populations.

1998; Doukakis *et al.* 1999). For example, molecular evidence suggests that the Persian sturgeon (*A. persicus*) may not be a separate species from the Russian sturgeon (*A. gueldenstaedtii*), although it is referred to as such herein as it is given distinct fisheries management attention (Berg 1934; Birstein and Bemis 1997; Birstein *et al.* 2000; Birstein and Doukakis 2002).

Although life-history traits vary among species, Acipenseriformes are generally long-lived fishes that grow and mature slowly (Table 2; Fig. 2; Birstein 1993; Billard and Lecointre 2001). Most species are diadromous (migrating between marine and freshwater systems) and few are potamodromous (migrating within freshwater) with all species reproducing in freshwater, spawning in habitats with hard substrates (e.g. gravel, cobbles, boulders) of varying depths (from a few to over 20 m) and current velocities (e.g. from 0.5 to 2.2 m s^{-1}) (Bemis and Kynard 1997; Billard and Lecointre 2001). The group exhibits one of the highest levels of polyploidy in fishes, ranging from 4n to 16n with chromosome numbers from 120 to 500 (Vasil'ev 1999). It also includes the largest freshwater fish, the beluga sturgeon, *Huso huso* (Table 2).

Nearly all Acipenseriformes are considered threatened or endangered because of the combined effects of overfishing and habitat degradation (Table 1; Rochard *et al.* 1990; Birstein 1993; De Meulenaer and Raymakers 1996; Billard and Lecointre 2001). Existing since the 5th century BC and referenced in ancient Greek, Roman and Chinese literature, sturgeon fisheries have intensified as gear and shipping technology has advanced and global demand for caviar increased (Birstein 1993; De Meulenaer and Raymakers 1996; Wei *et al.* 1997; Luk'yanenko *et al.* 1999; Secor 2002). Mounting commercial pressure coincided with construction of river dams in Acipenseriformes habitat, blocking spawning ground access and altering spawning habitat, with fish passageways ineffective for mitigation and dam removal a limited option (Scarnecchia *et al.* 1989; NMFS 1998b; Dubina and Kozlitina 2000; Billard and Lecointre 2001; Friedl and Wüest 2002; Hart *et al.* 2002; Parsley *et al.* 2002; Secor *et al.* 2002). Pollution has also negatively affected reproduction, physiology and food availability as have introduced species, deforestation, water diversion, and gravel and sand extraction Shagaeva *et al.* 1993; Zaitsev 1993; Altuf'ev 1997; Bacalbasa-Dobrovici 1997; Debus 1997; Ferguson and Duckworth 1997; Gorbunenko *et al.* 1997; Graham 1997; Krykhtin and Svirskii 1997; Ruban 1997; Bickham *et al.* 1998; Petr and

Table 2 Life history and catch statistics for commercial species. General references include Billard and Lecointre (2001) and Williamson (2003). Specific references noted below.

Species	L Max (M)	W Max (kg)	A Max (years) Historic/Current	Peak catch (tonnes)	Recent catch (tonnes)
A. baerii[1]	3	200	?/60	1769 (1930's)	12 (2003)
A. fulvescens	>2	140	150/40	2500 (1885; Lake Erie);	223 (1997 Canada)
A. gueldenstaedtii	2.3	100	>50/38	>35 000 (early 1900s; Caspian)	399 (2003) (335 Caspian)
A. medirostris[2]	2.9	160	?/60	?	?
A. o. oxyrinchus[3]	4.3	350	60/?	3300 (1880; US); >200 (1880; CA)	73.6 (Canada)
A. persicus	2.4	70	38/?	?	526.2
A. ruthenus	1.1	16	26/22	?	6 (2003)
A. schrenckii[4]	3	200	?/45	607 (1891)	45 (2003)
A. stellatus	2.2	80	41/30	13 700 (1970s; Caspian)	305 (2003) (284.8 Caspian)
A. transmontanus[5]	6	816	>100/82	747 (1885; Sacramento-San Joaquin); 2500 (1892; Columbia); 512 (1897; Fraser)	200 (2002) US
H. dauricus[6]	>5.6	1000	?/55	585 (1891)	88 (2003)
H. huso[7]	>6	1300	100/56	14 800 (early 1900's; Caspian)	213.4 (2003) (Caspian 155.4)
S. platorynchus[8]	1	4.5–7	?/30	?	25 (1997)
P. spathula[9]	2.5	100	?/30	1105 (1899)	?

[1]Ruban (1997,1998); [2]EPIC (2001); in Erickson *et al.* (2002); [3]Smith and Clugston (1997); Gross *et al.* (2002); [4]Krykhtin and Svirskii (1997); Wei *et al.* (1997); Zhuang *et al.* (2002); [5]Parsley *et al.* (1993); Parsley and Beckman (1994); [6]Krykhtin and Svirskii (1997); [7]Raspopov (1993a,b); [8]Keenlyne (1997); Quist *et al.* (2002); Everett *et al.* (2003); [9]Carlson and Bonislawsky (1981); Epifano *et al.* (1996).

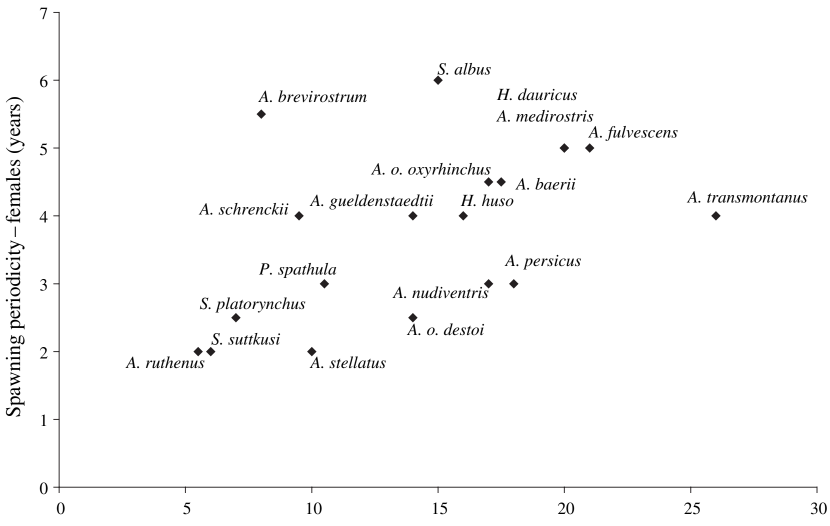

Figure 2 Sturgeon life-history traits; age at maturity and spawning periodicity for females. Values are midrange values of literature survey values. Note same point for *H. dauricus* and *A. medirostris*. Epifano *et al.* 1996; Krykhtin and Svirskii 1997; Ruban 1997, 1998; Mayden and Kuhajda 1997; Smith and Clugston 1997; Wei *et al.* 1997; Secor *et al.* 2000; Billard and Lecointre 2001; Erickson *et al.* 2002; Gross *et al.* 2002; Quist *et al.* 2002; Vecsei *et al.* 2002; Zhuang *et al.* 2002.

Mitrofanov 1998; Dubina and Kozlitina 2000; Jennings and Zigler 2000; Onders *et al.* 2001; Daskalov 2002; Friedl and Wüest 2002; Gucu 2002). Combined with late maturity and infrequent reproduction, overfished populations of low abundance have resulted.

International harvest and trade

Although commercial caviar trading has flourished globally, the geographical distribution of catch supplying trade has shifted through time. In the 19th century, the United States was the top caviar producer, exporting black caviar from the US waters (primarily from the Atlantic sturgeon *A. oxyrinchus oxyrinchus*) to Europe (Birstein 1997a; Secor 2002). By the early 1900s, US populations, production and export plummeted (De Meulenaer and Raymakers 1996; Hoover 1998). By the end of the 19th century, Russia was a major caviar trading nation and by the early 20th century Russian sturgeon harvests were seven times greater than historic peak US catches of Atlantic sturgeon (Taylor 1997; Secor *et al.* 2000). Commercial fisheries in Canada began in the late 19th century, but never commanded a substantial portion of the global market (Williamson 2003). Today, the Caspian Sea nations of Iran, Kazakhstan, Russia and to a lesser extent Azerbaijan and Turkmenistan, dominate the international trade in capture fisheries products while the US, Japan, the European Union and Switzerland are the major importers (De Meulenaer and Raymakers 1996; Hoover 1998; Raymakers 2002).

Sturgeon and paddlefish fisheries catch is currently at its lowest in recent decades (Fig. 3). After peaking in the late 1970s, total global production (capture and aquaculture combined) fell, levelling off in the mid-1990s (Fig. 3). Capture fisheries have accounted for a decreasing percentage of overall production, with aquaculture production recently surpassing wild fisheries production (Fig. 3). In turn, the amount of caviar in international trade has dropped while the amount of meat from aquaculture has increased (Raymakers and Hoover 2002; Raymakers 2002). Aquaculture production of caviar, although increasing, has lagged behind meat production because of the time investment required for maturity and egg production.

Trends in the production and trade in the last two decades have been tied to events in the Caspian Sea region, decreasing fisheries productivity, tightened international trade regulation, and aquaculture. The dissolution of the Soviet Union is considered to be a turning point in sturgeon fisheries management, after which increased illegal harvest and trade ensued, flooding the international market with illegal, low quality, inexpensive caviar (De Meulenaer and Raymakers 1996; Birstein 1997a; Taylor 1997; Vaisman and Raymakers 2001). Global imports of black caviar rose during the early-mid 1990s, with European imports increasing 1.5–2 times and US imports increasing by 100% (De Meulenaer and Raymakers 1996; Birstein 1997a). Fraudulent mislabelling of caviar became problematic, with low value caviar and caviar from endangered species substituted for highly prized caviar (DeSalle and Birstein 1996; Birstein *et al.* 1998).

Mounting concern about sturgeons and paddlefishes led to the 1997 listing of all species under the Convention on International Trade in Endangered Species (CITES), a voluntary international

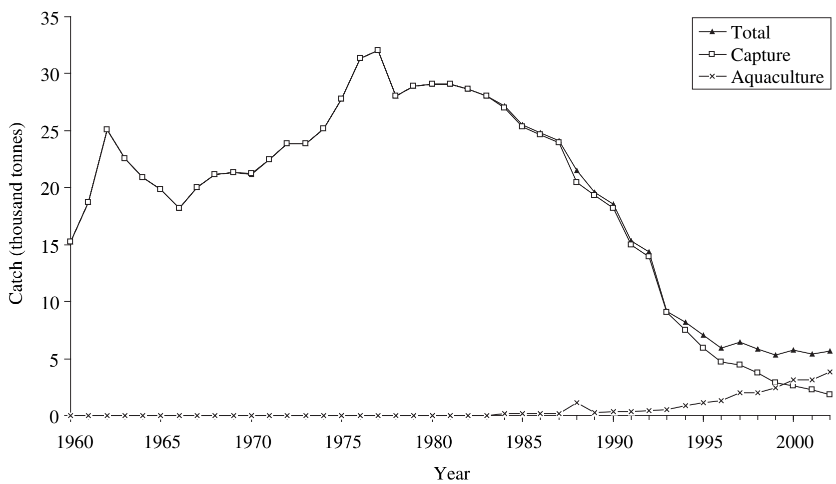

Figure 3 World catch of sturgeon and paddlefish (Source: FISHSTAT Plus, Fisheries Data Analysis Software for Windows, FAO, Rome).

agreement between governments protecting species threatened by trade and the most significant international act protecting sturgeons and paddlefish. International trade in CITES protected species is accomplished through a trade permit system, for species threatened with extinction (Appendix I) and species of concern (Appendices II and III). Two species of Acipenseriformes are listed under Appendix I, with trade permitted only in special circumstances, and the remaining under Appendix II, with controlled trade permitted (Table 1). Given the challenges of Acipenseriformes conservation, the CITES parties have adopted a series of recommendations outlining conservation measures required for continued trade, including enhanced fishery management and legislation, regional coordination, labelling and control of illegal trade (Conf. 10.12(rev); SC45 Doc.12.1, 12.2). Although implementation of these resolutions has been problematic, greater trade regulation and increased scrutiny of fisheries management have resulted.

Legal and illegal trade in black caviar remains a lucrative business. Legal trade from Russia is estimated at $40–100 million while the value of illegal Russian caviar exports has been estimated at $250–400 million (Speer *et al.* 2000; Stone 2002). Black caviar can command up to US$5000.00/kg for high quality beluga, with other wild and aquaculture caviar and roe commanding less (Table 3). Prices for both wild origin and aquaculture caviar have risen as wild origin caviar has become scarcer and the taste and quality of aquaculture caviar has been improved, prompting greater acceptance in the marketplace (De Meulenaer and Raymakers 1996; Raymakers and Hoover 2002; Raymakers 2002).

Table 3 Caviar prices ($US, 2004) in internet survey.

Product name	Species	Price ($/oz)	Price ($/kg)
Beluga	*Huso huso*	50–150	1764–5291
Osetra	*Acipenser gueldenstaedtii*	37–90	1323–3174
Sevruga	*A. stellatus*	25–80	882–2822
White	*A. transmontanus*	28–32	970–1111
Paddlefish	*Polyodon spathula*	11–38	381–1340
Hackleback	*S. platorynchus*	11–38	381–1340
Baerii	*A. baerii*	30–40	1058–1411
Persian	*A. persicus*	75	2645
Salmon		2–14	79–494
Whitefish		2–10	71–353
Trout		4–16	141–564
Bowfin		17	600

Companies surveyed included Caviar direct, Caviar express, Caviar Russe, Marky's caviar, Mackenzie limited, Petrossian, Plaza de Caviar, The Golden Egg, and Tsar Nicoulai.

The international caviar trade remains dominated by product from the Caspian and Black Sea regions. Four Caspian/Black Sea species, beluga, stellate (*A. stellatus*), Russian and Persian, have supplied over 95% of the internationally traded caviar in recent years (2003: 94.8%; 2004: 99.6%). Other commercially important species include the Caspian Sea sterlet (*A. ruthenus*), Amur River sturgeon [kaluga sturgeon (*H. dauricus*), Amur sturgeon (*A. schrenckii*)], Siberian sturgeon (*A. baerii*), and North American species [white sturgeon (*A. transmontanus*), Atlantic sturgeon (*A. oxyrinchus*), lake sturgeon (*A. fulvescens*), American paddlefish (*Polyodon spathula*), shovelnose sturgeon (*Scaphirhynchus platorynchus*), and green sturgeon (*A. medirostris*)]. Species not commercially important and not discussed herein include *A. mikadoi*, *A. naccarii*, *A. sturio*, Yangtze River species (*A. dabryanus*, *A. sinensis*, *P. gladius*), Siberian populations of the sterlet, Aral Sea watershed species (*A. nudiventris*, *P. kaufmanni*, *P. hermanni*, *P. fedtschenkoi*), and US taxa listed under the US Endangered Species Act (ESA) (*A. brevirostrum*, *S. albus*, *S. suttkusi*, white sturgeon, Kootenai river, *A. o. desotoi*) (Table 1). Ship sturgeon (*A. nudiventris*) in the Caspian and Black Sea, although commercially exploited to a small extent and highly endangered, is not considered here because of the lack of data about the fishery (Table 1).

Major global fisheries

Caspian Sea

Fed by over 100 river systems, the Caspian Sea, at 384 000 km^2, is the largest inland water body in the world and harbours the greatest abundance of sturgeon on the planet and largest and most important sturgeon fisheries (Figs 4 and 5; Dumont 1995; De Meulenaer and Raymakers 1996; Levin 1997; Secor *et al.* 2000). Six species of sturgeon occur in the basin [beluga, Russian, Persian, sterlet, stellate, ship (*A. nudiventris*)], with Russian and stellate sturgeons the most abundant and ship sturgeon the rarest (Levin 1997; CITES 2000). All species except sterlet (a potamodromous species) are anadromous, although landlocked freshwater

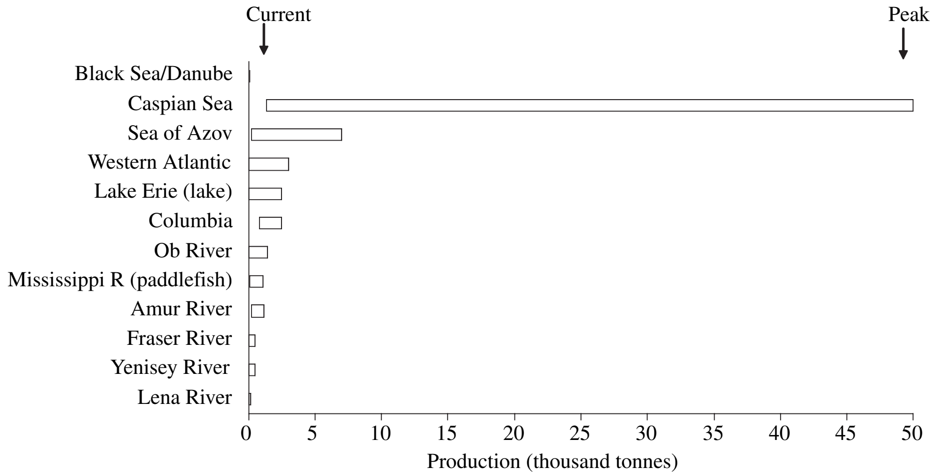

Figure 4 Peak (right/higher value) and current (left/lower value) sturgeon fishery production by region.

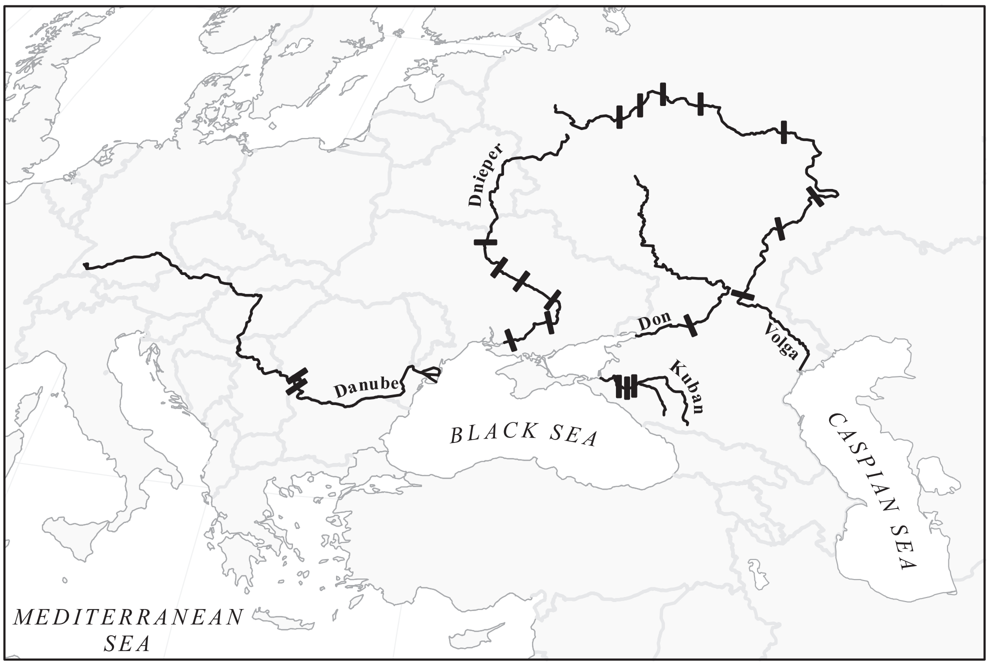

Figure 5 Caspian, Black and Sea of Azov regional map showing principal spawning rivers. Hatch marks indicate river dams.

populations occur (Sokolov and Tsepkin 1996; Hensel and Holcik 1997; CITES 2000; Arai and Miyazaki 2001; Chebanov and Billard 2001). Anadromous species typically consist of autumnal and vernal (sometimes divided into early and late races), which migrate upriver in two separate seasonal runs, coincident with fishing seasons (Hensel and Holcik 1997; Levin 1997). All anadromous species but the Persian sturgeon, which occurs mainly in the southern Caspian region, are distributed throughout the Caspian Sea, while the freshwater sterlet primarily inhabits the Volga River (Berg 1948; Artyukhin and Zarkua 1986; Vlasenko *et al.* 1989; Artyukhin 1997). These species vary in life history, with all species but the sterlet requiring at least 10 years to mature (Table 2; Fig. 2).

Historically the Volga River has been the most important river for the fishery and for spawning but dam construction on the Volga River has deprived sturgeons of between 30% and 90% of their former spawning grounds (Fig. 5; De Meulenaer and Raymakers 1996; Khodorevskaya *et al.* 1997; Secor *et al.* 2000). Currently the Ural River is the only free-flowing river feeding the Caspian Sea where sturgeons reproduce unhindered by dams, although sedimentation and pollution have caused a 50% loss in spawning area (De Meulenaer and Raymakers 1996; Khodorevskaya *et al.* 1997; in Secor *et al.* 2000). The Gorganrug, Kura, Sefidrud, Sulak, Tajen and Terek rivers may also provide sturgeon habitat (Khodorevskaya *et al.* 1997; CITES 2000). After hatching in river systems, anadromous sturgeons migrate into the sea to mature, returning to river systems for spawning, with homing fidelity to natal rivers uncertain (Khodorevskaya and Krasikov 1999; Khodorevskaya *et al.* 2000; Billard and Lecointre 2001; Kynard *et al.* 2002).

The northern Caspian Sea (specifically the Volga River) historically supported the bulk of the sturgeon catch with southern Caspian Sea catch increasing in recent years (De Meulenaer and Raymakers 1996; Artyukhin 1997; Khodorevskaya *et al.* 1997). Catch in the Caspian Sea peaked in the 17th century (50 000 tonnes) followed by declines and rebounds due to reduced effort coincident with wars (e.g. 1912–1924) and fisheries regulation. In the 20th century, catch peaked in the 1970s (27 300 tonnes), but declined steadily thereafter to 1388 tonnes in 2002 (Fig. 4; FISHSTAT; De Meulenaer and Raymakers 1996; Artyukhin 1997; Birstein 1997a; Levin 1997; Khodorevskaya *et al.* 2000; Secor *et al.* 2000; Vaisman and Raymakers 2001).

Caspian Sea catch is comprised of Russian, stellate, and Persian sturgeon and to a lesser extent, beluga and sterlet (Artyukhin 1997; Khodorevskaya and Krasikov 1999; Moghim and Neilson 1999). Beluga catch has steadily declined from a peak in the early 1900s (14 800 tonnes) while catch of Russian sturgeon has been more variable, also exhibiting an overall decline (Table 2; Fig. 6a,b). Fewer data on the stellate sturgeon fishery are available with catch declines evident from 1970 to 2002 (Table 2; Fig. 6c). Although historic data on Persian and sterlet sturgeon are scarce, Persian sturgeon catch has risen in recent years while sterlet catch has never been significant (Table 2).

Published studies illustrate that population sizes of all species but Persian sturgeon have declined, with some estimates suggesting 80–90% decreases in the last 30–40 years (Khodorevskaya and Krasikov 1999; Khodorevskaya *et al.* 2002). The number of beluga sturgeon annually entering the Volga to spawn dropped from 26 000 during 1961–65 to 2800 during 1998–2002, while only 2500 individuals migrated up the Ural River in 2002 (Khodorevskaya *et al.* 1997, 2000; J. A. Armstrong, unpublished data). For beluga, Russian, stellate and sterlet sturgeon, size at maturity, growth rate and average age of the population and of spawning individuals have decreased (Raspopov 1993a,b; Khodorevskaya *et al.* 1995, 1997, 2000, 2002; Khodorevskaya and Krasikov 1999; Khodorevskaya 1999; Moghim and Neilson 1999; Kuznetsov 2000). Sex ratios have shifted, with some populations consisting of fewer than 20% females (Khodorevskaya 1999; in De Meulenaer and Raymakers 1996; Vaisman and Raymakers 2001).

In contrast, abundance estimates generated through sea trawl studies conducted by range states in compliance with CITES resolutions suggest large population sizes and increasing abundance. Independent review of the studies could not replicate the findings, suggesting erroneous calculations overestimating abundance (Pikitch and Lauck, unpublished data in Pearce 2003). Alternative calculations indicate dangerously small populations of beluga and harvest quotas equivalent to removal of nearly all mature individuals (Pikitch and Lauck unpublished data; Ginsberg 2002). Current, accepted population assessments are still unavailable.

The Caspian Sea fishery was reportedly tightly regulated in Soviet times, with fishing banned in the open sea, catch quotas, seasonal closures and gear restrictions (De Meulenaer and Raymakers 1996; Birstein 1997a; Levin 1997; Taylor 1997; Khodorevskaya *et al.* 2000; Secor *et al.* 2000). The dissolution of the Soviet Union in 1991 led to the division of fishing rights among the new independent states, sea fishing, and increased illegal harvest and trade (De Meulenaer and Raymakers 1996; Levin 1997; Taylor 1997). In 1997, the Caspian nations re-instituted the sea fishing ban, allowing harvest only in rivers, but the ban is not adequately enforced (Bauer 1997).

Fisheries are now managed and regulated by individual countries through gear, catch and seasonal restrictions, with exports managed under CITES (De Meulenaer and Raymakers 1996; CITES 2000; Khodorevskaya *et al.* 2000; Vaisman and Raymakers 2001). Recommendations set forth after a CITES Review of Significant Trade (A CITES action when Appendix II species are thought to be traded without adequate implementation of CITES provisions. Beluga, Persian, Russian, ship, sterlet, and

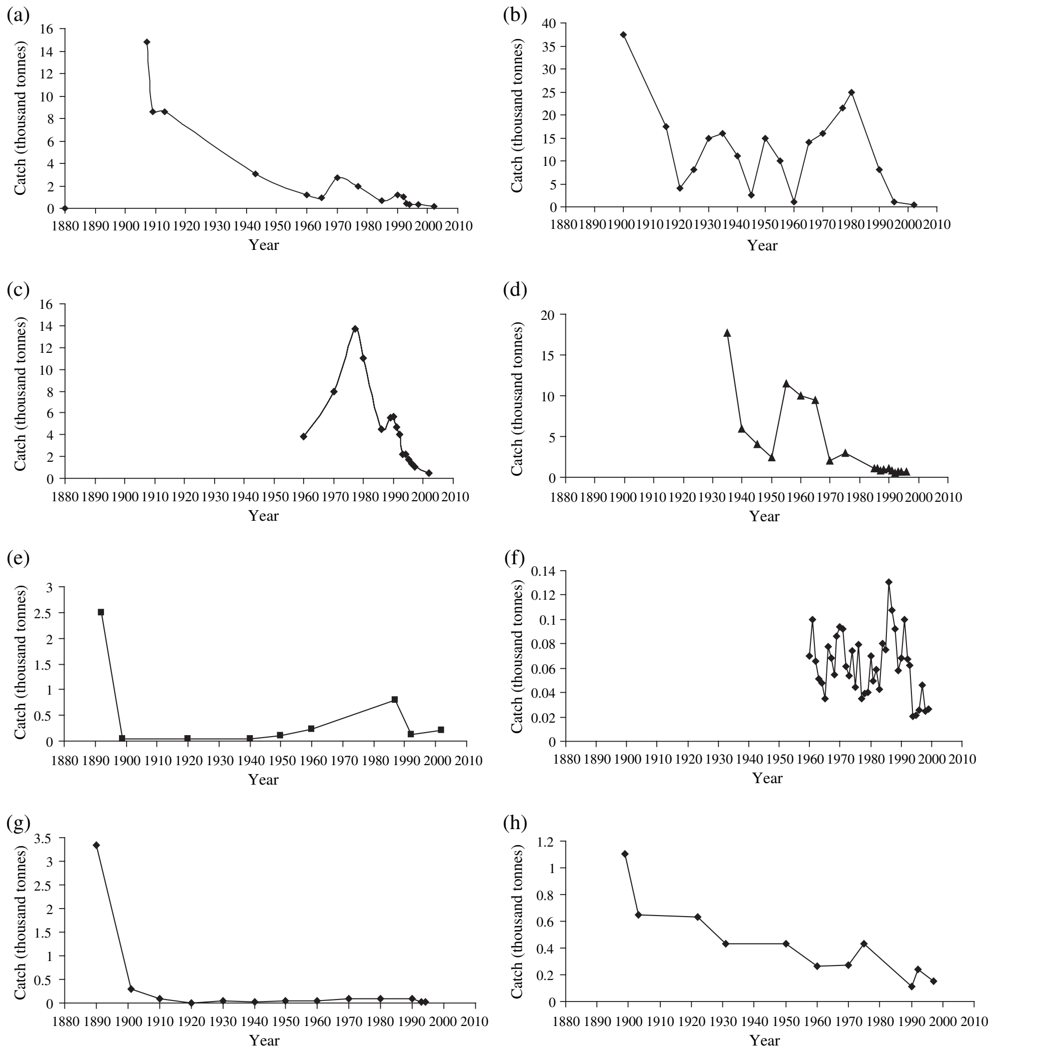

Figure 6 Catch data over time for select species. (a) Beluga (Caspian Sea) (Raspopov 1993a; in Khodorevskaya *et al.* 1997, 2000; CITES 2000; Altukhov and Evsyukov 2001; http://www.cites.org); (b) Russian sturgeon (Caspian Sea) (De Meulenaer and Raymakers 1996; Khodorevskaya *et al.* 1997; CITES 2000; Altukhov and Evsyukov 2001; http://www.cites.org); (c) Stellate sturgeon (Caspian Sea) (Khodorevskaya *et al.* 1997; CITES 2000; Altukhov and Evsyukov 2001; http://www.cites.org); (d) Siberian sturgeon (Ob, Yenisey, Lena Rivers) (Ruban 1997; CITES 2000); (e) white sturgeon (Columbia River) (Rieman and Beamesderfer 1990; Parsley and Beckman 1994; Williamson 2003); (f) green sturgeon (EPIC 2001). (g) Atlantic sturgeon (US landings only until fishery closure) (Smith and Clugston 1997; Atlantic Sturgeon Status Review Team 1998; Waldman and Wirgin 1998; Secor 2002); (h) Paddlefish (Commercial harvest only) (Carlson and Bonislawsky 1981; CITES 2000). Note different scales for each graph.

stellate, sturgeon were reviewed) called on Caspian nations to establish coordinated basin-wide management, long-term, comprehensive stock surveys, measures to combat illegal harvest and improve fishery management (SC45 Doc.12.2; Conf. 12.7). Export quotas were to be based on a cooperative management strategy, agreed upon by all Caspian nations, and submitted to the CITES Secretariat for review by December 31 of the year preceding export. Since 2001, approved quotas have been reduced for all species but Persian sturgeon (Table 4, Fig. 7). Problems with CITES compliance has resulted in temporary fishery closures, trade bans and zero quotas, but long-term bans have never been instituted despite the fact that many recommendations remain outstanding (Raymakers 2002; Raymakers

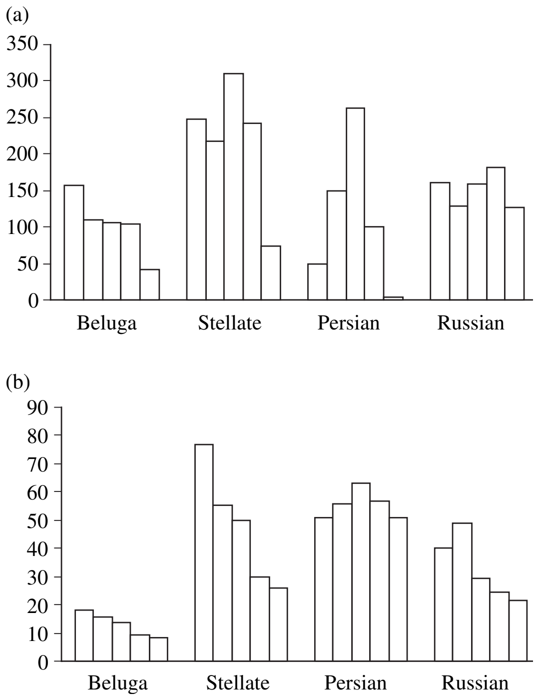

Figure 7 Evolution of CITES export quotas for four main commercial species 2001–2005. (a) Meat; (b) caviar.

and Hoover 2002; Stone 2002; Ginsberg 2002). Critics believe enforcement of resolutions has been weak and fishery collapse and/or extinction may be imminent. Illegal harvest still exceeds legal catch by several orders of magnitude and recent news suggests most black caviar in trade is illegal (Vaisman and Raymakers 2001; Agence France Presse 2004; ITAR-TASS News Agency 2004). Domestic caviar sale and consumption in Caspian range countries has reportedly increased since CITES listing, making it questionable as to whether export restrictions have resulted in decreased harvest (Vaisman and Raymakers 2001; Raymakers and Hoover 2002). Export quotas are still being approved in the absence of accepted population abundance estimates.

In the 1950s, captive propagation programmes (whereby sturgeons are bred in captivity for restocking wild populations) were created to ameliorate population declines and the loss of natural recruitment (Levin 1997; CITES 2000; Secor *et al.* 2000). In the early 1990s, 60–70 million individuals were released from hatcheries annually, including beluga, Persian, Russian, ship, stellate and sterlet (Levin 1997; CITES AC 18 Doc 17.1 2002). It is speculated that 30% (Volga River stellate and Russian sturgeon) to 90% (Volga River beluga) of wild individuals are of hatchery origin (De Meulenaer and Raymakers 1996; Khodorevskaya 1999; Khodorevskaya *et al.* 2000; Secor *et al.* 2000). As released fish have not been tagged or marked, estimating their contribution to the current population is impossible, although some programmes are beginning to address this issue (Doukakis *et al.* 2004). Hatchery programmes have been faltering in recent years because of inadequate financing and a scarcity of breeding females (Khodorevskaya 1999; Khodorevskaya *et al.* 2000; Secor *et al.* 2000; Doukakis *et al.* 2004).

Black Sea and Sea of Azov

The Black Sea, Sea of Azov, and their watersheds once harboured some of the most productive sturgeon fisheries (Figs 4 and 5; Birstein 1996; Vaisman and Raymakers 2001). The six species found in the Caspian Sea inhabit these basins and the Baltic sturgeon, *A. sturio*, formerly occurred in the Black Sea, but has been extirpated (Hensel and Holcik 1997). The region now contributes little to international trade, with 6.5 tonnes of caviar and 50 tonnes of meat (5% and 13% of total export, respectively) exported in 2004 from the Black Sea (Table 4). Beluga and ship sturgeons are scarce or extinct in the Sea of Azov, with the last records of beluga from the mid 1980s (in Khodorevskaya 1999; CITES 2000; Billard and Lecointre 2001). Sterlet is plentiful in the Danube and Dneister rivers, but its status in the Sea of Azov is uncertain (Bacalbasa-Dobrovici 1997; Hensel and Holcik 1997; CITES 2000). Persian sturgeon, with populations in Georgia (Rioni River), Russia (Don River), and Turkey, have experienced a 50% decline in the last three generations (AC 18 Doc 17.1 2002). As in the Caspian, dams have practically eliminated natural reproduction of populations in the upper and middle Danube River, and in the Dneister River and the Don and Kuban rivers of the Sea of Azov (Fig. 5; Bacalbasa-Dobrovici 1997; Gorbunenko *et al.* 1997; Hensel and Holcik 1997; CITES 2000; Billard and Lecointre 2001; Dubina and Kozlitina 2000; Friedl and Wüest 2002).

Although sturgeons historically reproduced in many Black Sea river systems, only the Danube River currently supports significant spawning populations (Fig. 5; Bacalbasa-Dobrovici 1997; Hensel and Holcik 1997; CITES 2000). Stellate, beluga and

Table 4 CITES export quotas 2001–2005 for meat (M) and caviar (C).

Species	Country/ Region	2001 (M)	2002 (M)	2003 (M/FC)	2004 (M/FC)	2005 (M/FC)	Trend (M)	2001 (C)	2002 (C)	2003 (C)	2004 (C)	2005 (C)	Trend (C)
A. gueldenstaedtii	Azov	17.0	0	5.0	0	0	↓	2.0	10.0	0.3	0	0	↓
	Black	19.1	6.0	8.5	25.0	0.8	F	1.8	1.22	1.12	1.1	0.16	↓
	Caspian	124.9	122.4	146.3	156.7	126.1	F	36.4	37.8	27.8	23.3	21.1	↓
	Total	161.0	128.4	159.8	181.7	126.9	F	40.2	49.0	29.2	24.4	21.3	↓
A. persicus	Caspian	50.0	150.0	263.1	100	4.0	F	51.0	56.0	63.0	57.6	51.0	F
A. ruthenus	Black	0	0	0	1	1	↑	0	0	0	0.1	0.1	↑
	Caspian	0	0	0	0	0	↔	0.1	0.1	0.1	0.1	0.1	↔
	Total	0	0	0	1	1	↑	0.1	0.1	0.1	0.2	0.2	↑
A. stellatus	Azov	17.0	8.0	1.5	0	0	↓	2.5	0	0.1	0	0	↓
	Black	21.0	3.0	3.5	2.2	2.2	↓	2.05	1.47	1.2	0.9	0.9	↓
	Caspian	209.2	206.3	305.9	239.3	71.8	F	72.1	53.9	48.4	29.0	25.2	↓
	Total	247.2	217.3	310.9	241.5	74.0	F	76.7	55.4	49.7	29.9	26.1	↓
H. huso	Black	40.0	19	19	21	19.5	F	5.55	4.6	4.67	4.67	4.055	↓
	Caspian	116.9	90.7	86.5	83.2	22.9	↓	12.5	11.24	12.66	4.48	4.47	↓
	Total	156.9	109.7	105.5	104.3	42.4	↓	18.02	15.84	17.33	9.15	8.53	↓
A. schrenckii	China	0	0	0	0	Ip	↔	2.15	2.51	2.51	0	Ip	↔
	Russia	4	1.5	1.5	0	Ip	↓	2.14	0.35	0.35	0	Ip	↓
	Total	4	1.5	1.5	0	Ip	↓	5.29	2.86	2.86	0	Ip	↓
H. dauricus	China	0	0	0	0	Ip	↔	3.43	3.43	3.43	0	Ip	↔
	Russia	20	5	5	0	Ip	↓	7	2.3	1	0	Ip	↓
	Total	20	5	5	0	Ip	↓	10.43	5.73	4.43	0	Ip	↓
A. fulvescens	Canada	170	170	101.5	0	–	↓	0.5	0.5	0	0	–	↓
A. o. oxyrinchus	Canada	58	58	73.6	0	–	↓	0.5	0.05	0	0	–	↓
A. transmontanus	US	3	3	3	0	–	↓	0	0	0	0	–	↓

Export quotas were not issued for wild products from *A. baerii*, *A. medirostris*, *S. platorynchus* or *P. spathula* during this period. Trend arrows display increasing (↑), decreasing (↓), steady (↔) or fluctuating trends (F) in export quotas. FC, Food and Canned Products; Ip, discussions in progress for issuing quota.

Russian sturgeon have been extirpated from the upper Danube (source-Vienna), are critically endangered or rare in the middle portion of the river (Vienna-Iron Gates Dam I), and are vulnerable in the lower river (Iron Gates Dam I-mouth) (Fig. 5; Bacalbasa-Dobrovici 1997; Hensel and Holcik 1997). Sterlet occurs in the middle and lower reaches and rarely in the upper Danube (Bacalbasa-Dobrovici 1997; Hensel and Holcik 1997). Ship sturgeon is critically endangered throughout the Danube basin, existing only as a freshwater form (Hensel and Holcik 1997). Other important rivers include the Bug, Coruh, Dnieper, Dniester, Inguri, Kizilirmak, Lenkoranka, Rioni, Supsa, Tisza and Yesilirmak in the Black Sea, and the Don and Kuban rivers in the Sea of Azov although it is unlikely that natural reproduction continues in the Sea of Azov.

Catch in the Black Sea watershed is conducted by Romania, Ukraine, Bulgaria and Serbia. Historic catch records, available mostly for the Danube River, indicate declines in the Danube River fishery as early as the 19th century, continuing through the 1960s (300 tonnes; 1960) the middle 1990s (9.4 tonnes; 1995) (Bacalbasa-Dobrovici 1997). Catch of Russian sturgeon has fluctuated, from 25 tonnes annually in the Danube from 1958 to 1981 to 11 tonnes in 1999 to 19 tonnes in 2003 (Table 2; CITES 2000). Beluga sturgeon declines in the Danube River were reported beginning in the 16th century, with recent catches below 60 tonnes (Hensel and Holcik 1997). Stellate catch has always been small while sterlet catch has been higher, dominated by Bulgaria and export accomplished by Romania (Table 4; CITES 2000). Published abundance estimates are not available for Black Sea populations but an increasing proportion of immature animals was observed in stellate populations in the Danube River (Ceapa *et al.* 2002).

In the Sea of Azov legal fishing by Russia and Ukraine has practically ceased and no export quotas have been issued for the last 2 years (Table 4). Peak catch from the 1930s to 1962 was 7000 tonnes, declining to 1103 tonnes in the early 1960s to 200 tonnes by 1998 to 70 tonnes in 2003, dropping up to 90% in some regions between 1993 and 1998 (Vaisman and Raymakers 2001). In the mid-1980s, the biomass of stellate and beluga sturgeon in the Sea of Azov was 12 390 tonnes and 1 170 tonnes, respectively, before pollution related die-offs that began in 1990 (Volovik *et al.* 1993 in CITES 2000). Biomass estimates for Russian sturgeon are only available for 1993 and are lower than stellate and beluga (44.8 tonnes) (CITES 2000).

Fisheries regulations in the Black Sea [Bulgaria, Romania, Serbia and Ukraine (Russian sturgeon only)] are determined by individual countries including breeding season closures, gear restriction and minimum size requirements (CITES 2000). Black Sea and Sea of Azov nations communicate export quotas to the CITES Secretariat for approval and Black Sea nations have formed a regional management group (Black Sea Sturgeon Management Group) in fulfilment of CITES recommendations. CITES export quotas have been reduced since 2001, with the exception of sterlet quotas (Table 4). Illegal fishing is still problematic in both the Black Sea and the Sea of Azov, where illegal catch is estimated to be 19–29 times higher than the legal catch (Bacalbasa-Dobrovici 1997; in CITES 2000; Navodaru *et al.* 2001; Vaisman and Raymakers 2001).

Captive propagation and release is employed in the Black Sea and Sea of Azov (CITES 2000; Chebanov and Billard 2001; in Smith *et al.* 2002a). The Sea of Azov formerly had seven hatcheries releasing 39 million juveniles annually (7% beluga, 43% Russian, 49% stellate), but many hatcheries are not functioning because of financial constraints and lack of broodstock (in Birstein 1997a; Vaisman and Raymakers 2001). Over 30 million individuals were released into the Don and Kuban rivers in 1999 and 2000 (Chebanov *et al.* 2002). Up to 100% of beluga sturgeon in the Sea of Azov are allegedly derived from hatcheries, compared with 80 to 95% of Russian and 60–98% of stellate sturgeon (CITES 2000). Without tagging and monitoring programmes it is impossible to verify stocking success.

Amur River basin

The 4000 km Amur River basin forms the border between Russia and China for one-third of its length and harbours two endemic commercially exploited sturgeons, the kaluga and Amur sturgeon (Fig. 1; Krykhtin and Svirskii 1997; Wei *et al.* 1997). Kaluga is a large, long-lived, late maturing, predominantly freshwater species while the Amur sturgeon is a smaller, strictly freshwater species maturing earlier than kaluga (Table 2; Fig. 2). Caviar produced from these species is referred to as kaluga (kaluga sturgeon) and osietra (Amur sturgeon).

Sturgeon catch in the Amur River peaked in 1891 (1195 tonnes; Table 2). In the last century, catch fluctuated between 100 tonnes to 400 tonnes annually on the Chinese side of the river and since the 1990s has been below 100 tonnes on the Russian side (Krykhtin and Svirskii 1997; Wei *et al.* 1997; CITES 2000; Zhuang *et al.* 2002). In 2003, 205 tonnes (120 tonnes China and 85 tonnes Russia) was caught overall, with 67 tonnes of Amur sturgeon and 138 tonnes of kaluga. Export quotas for both species have decreased since 2001 (Table 4).

As of 1997, population estimates for the four distinct populations of kaluga were as follows, with relatively few mature fish in any population: estuary (70 000), lower (40 000) and middle (30 000), upper Amur River (unavailable) (Krykhtin and Svirskii 1997). For Amur sturgeon, population estimates from the 1990s indicate about 3000 individuals in the estuarine populations, 95 000 in the lower Amur, and 190 000 in the middle Amur. Limits on catch in the 1970s resulted in population increases, but decreases, especially in the number of mature individuals, followed, in part, because of an illegal fishery in the lower Amur River (Krykhtin and Svirskii 1997). Catch records from the Chinese side of the Amur River indicate declines in both species, but accurate assessments are needed (Wei *et al.* 2004).

China and Russia manage Amur River populations under national regulations with export under CITES. Fishing for Amur sturgeon in China is regulated by gear, size limits, licensing, season and area (Wei *et al.* 1997, 2004; CITES 2000). Amur sturgeon fisheries have been banned in Russia since 1958 with catch for scientific purposes only, although Russia reportedly exceeds the scientific quota (Krykhtin and Svirskii 1997; CITES 2000). Implementation of regulations and illegal fishing are problematic and better joint management between Russia and China has been recommended (Krykhtin and Svirskii 1997; Wei *et al.* 1997, 2004; CITES 2000). Since 2001, CITES export quotas for kaluga and Amur sturgeon have decreased or remained constant (Table 4).

Hatchery propagation and release of Amur sturgeon occurred in the Chinese side of the Amur River from 1988 to 1998 but operations have been jeopardized by financial constraints (Wei *et al.* 1997). Hatcheries on the Russian side of the Amur were not operational as of 2001 (Krykhtin and Svirskii 1997; Chebanov and Billard 2001). Amur sturgeon is an important aquaculture species in China accounting for most of national sturgeon farm production (CITES 2000; Zhuang *et al.* 2002; Wei *et al.* 2004). Kaluga is bred in China and released into the Amur River (Wei *et al.* 2004). No assessments of the success of release projects for Amur sturgeon or kaluga in China have been conducted (Wei *et al.* 2004).

Siberian rivers

Sturgeon fisheries in Siberian river systems target the Siberian sturgeon, a freshwater, potamodromous species (semi-anadromous forms are also recognized; Solovov and Vasila'v 1989; Solovov 1997) with a mid-range maturity age and spawning frequency (Tables 1 and 2; Figs 1 and 2). Catch within these fisheries peaked in the 1930s with 79% of the catch from the Ob River (Table 2; Fig. 6d). Today, catch is <10% of peak levels (Table 2; Figs 4 and 6d; Ruban 1997; CITES 2000). Compared with peak catch, by the 1990s catch dropped by 99% in the Ob River, 96% in the Yenisey River and 95% in the Lena River (Ruban 1997; CITES 2000).

Populations of Siberian sturgeon have declined across the species range (Afanasiev and Afanasieva 1996; Ruban and Akimova 2001). Forty per cent of spawning sites and 50% of wintering grounds in the Ob have been destroyed by hydroelectric stations (Ruban and Akimova 2001). The population in Lake Baikal may no longer reproduce naturally, sustained only by hatchery stocking (Afanasiev and Afanasieva 1996).

Commercial catch of Siberian sturgeon has been banned in the Yenisey River basin since 1998. Illegal harvest of sturgeons from Siberian Rivers is problematic, with catch reportedly in excess of official statistics (Ruban and Akimova 2001). With the exception of hatchery supplementation programmes in Lake Baikal, most captive programmes for Siberian sturgeon focus on aquaculture for commercial purposes. Siberian sturgeon is one of the most common captive-bred sturgeons, with farms in Europe, China, Japan and Uruguay (CITES 2000; Rosenthal and Hilge 2000; Gisbert and Williot 2002).

Western North America

Fisheries in western North American target white, and to a lesser extent, green sturgeon. White sturgeon inhabits estuaries, rivers and near shore environments of the Pacific coast from Alaska to Baja California, spawning in the Columbia-Snake River, Fraser River and Sacramento-San Joaquin River (Table 1; Fig. 1). The largest North American freshwater-dependent fish, the species is long lived and late maturing, existing as both anadromous and freshwater forms, the latter a result of dams (Table 2; Fig. 2). Green sturgeon range from northern Mexico to Alaska, spawning in the Klamath-Trinity, Sacramento and Rogue River systems (Table 1; Fig. 1). An anadromous species, green sturgeon are small and mature relatively late (Table 2; Fig. 2). The green sturgeon was proposed for ESA listing in 2003, with a decision for further review by 2008 and the southern population segment is now a candidate for listing as threatened.

Overall, white sturgeon has supported larger fisheries than green sturgeon, with peak catches for white sturgeon in the late 1800s (Table 2). By 1902 the Sacramento-San Joaquin river fishery dropped by 95% (Parsley and Beckman 1994; Williamson 2003). Catch in the Columbia River also dropped, rebounding in the late 1980s (Fig. 6e). The Fraser River catch decreased 93% by 1905 and has not exceeded 15 tonnes since 1917 (Williamson 2003). Commercial fisheries in California and Canada have been closed since 1917 and 1994 respectively (Williamson 2003). US commercial fisheries in Oregon and Washington harvested close to 200 tonnes in 2002 and meat from the fishery has been exported under CITES (Table 4; Todd 1999; PacFin: http://www.psfmc.org/pacfin).

Only limited direct fisheries for green sturgeon have been recorded through history and at present, fisheries exist in the lower Columbia River, Klamath and Trinity rivers, Umpqua River, Sacramento-San Joaquin estuary and Willapa Bay and Grays Harbor (Moyle *et al.* 1995). Annual US commercial harvest between 1960 and 2002 peaked at 130 tonnes annually with recent catch below 10 tonnes (Todd 1999; EPIC 2001; Fig. 6f). In Canada, green sturgeon was historically targeted in the Fraser River but is now only caught as by-catch in coastal fisheries (EPIC 2001).

Information on population size and structure is increasingly more available for white and green sturgeon. White sturgeon are abundant in the lower Columbia River where populations are considered stable (Hildebrand *et al.* 1999; Parsley *et al.* 2002). The Sacramento-San Joaquin estuary population declined from about 128 000 individuals in 1984 to 27 000 individuals in 1990 (Kohlhorst 1995). In Canada, the largest population is in the Fraser River system, with an estimated 47 000 individuals in the lower River (Nelson *et al.* 2002). Canada's Nechako River and upper Columbia River populations are reportedly small and experiencing recruitment failure (Korman and Walters 2001). Two distinct populations of green sturgeon exist, northern (north of and including the Eel River) and southern (south of Eel River). Spawning populations were thought to be small (Musick *et al.* 2000), but research in the Rogue River (northern population segment) suggests populations are larger than previously thought (Erickson *et al.* 2002). Southern populations are more threatened due to dams (50 CFR 223 70 Fed. Reg. 17386 April 6, 2005). Green sturgeon populations in Canada are thought to be small (in EPIC 2001).

In the US, white and green sturgeon fisheries are managed by state and tribal agencies, using size, temporal and spatial limits restrictions (Rieman and Beamesderfer 1990; Beamesderfer and Farr 1997). Commercial fishing (trawl, gill net) is permitted in Oregon and Washington, although no directed green sturgeon commercial fisheries exist in these states. Since 1952, fisheries in California have been restricted to sport angling. Sports fishing is also permitted in Idaho, Oregon and Washington and regulated by strict size, season and bag limits: in Oregon and Washington, states that manage their fisheries cooperatively, an annual bag limit of 10 fish per fisherman is imposed. White sturgeon sport fisheries in Idaho are catch and release only. Commercial fisheries for green and white sturgeon are not active in Canada and all sport fisheries are catch and release. Canada's programmes in the Columbia, Fraser and Nechako river systems are actively monitoring and managing sturgeon populations.

White sturgeon in the US reaches of the Columbia River are monitored and managed through regular stock assessments, review and revision of fisheries regulations, and public awareness programmes (Rieman and Beamesderfer 1990; Beamesderfer and Farr 1997). Illegal poaching of white sturgeon is problematic in the US, with active smuggling rings reported as recently as May 2005 and white sturgeon caviar fraudulently sold as beluga and osetra (Cohen 1997; Enkoji 2005). Illegal harvest of green sturgeon is also suspected (EPIC 2001).

Commercial aquaculture and hatchery propagation (Kootenai River, upper Columbia River) programmes exist for white sturgeon with white sturgeon aquaculture caviar increasingly gaining prominence as high quality caviar (Logan *et al.* 1995; Ireland *et al.* 2002a,b; Williamson 2003).

Anadromous species in eastern North America

The eastern coast of North America is home to one commercially important species, the anadromous Atlantic sturgeon (*A. o. oxyrinchus*) (Table 1). The second largest species in North America, Atlantic sturgeon historically occurred in 34 river systems, and currently inhabits 32 systems, spawning in 14 (NMFS 1998b). Eighty to ninety per cent of historic Atlantic sturgeon landings occurred in the US with peak catch occurring in the late 1880s and declining thereafter until fishery closure in 1998 (Table 2; Fig. 6g). US fishery closure is projected to last 41 years in order to protect 20 year classes of females in each spawning stock (NMFS 1998b). Canadian catch displayed a similar pattern to US catches in the late 1800s and early 1900s, but increased in the late 1900s and a viable fishery still remains (Smith and Clugston 1997).

Comprehensive information on the abundance of Atlantic sturgeon is lacking (NMFS 1998b). There are six distinct population segments along the eastern seaboard, and US and Canadian stocks genetically distinct (Waldman *et al.* 1996; NMFS 1998b; Wirgin *et al.* 2000, 2002; King *et al.* 2001). Age-specific abundance estimates exist for a few US Rivers (e.g. Hudson and Delaware rivers) and restoration goals have been set for select rivers based on reconstructed historic population size estimates (Secor and Waldman 1999; Peterson *et al.* 2000; Armstrong and Hightower 2002; Secor 2002). Canada's St Lawrence River population is thought to be in good health (Caron *et al.* 2002; Hatin *et al.* 2002).

Commercial fisheries in Canada [St Lawrence River, Quebec (Canada's largest sturgeon fishery), St John River, Newfoundland] are managed through periodically revised licenses, quotas, and temporal and spatial closures (Caron and Tremblay 1999; Caron *et al.* 2002). Regulations specify a maximum size limit and large mesh size to protect the adult breeding population and a 60 tonnes annual limit in the St Lawrence fishery (NMFS 1998b; Caron *et al.* 2002; Trencia *et al.* 2002). Canadian maritime fisheries are managed through licensing but not quotas, with a sunset clause on commercial fishing licenses (Trencia *et al.* 2002; Williamson 2003). Canada has exported product from the fishery, mostly to the US (Table 4; Williamson 2003).

Atlantic sturgeon was one of the first sturgeons to be cultured in North America. Experimental restocking programmes have been conducted in the Hudson River and a tributary of the Chesapeake (NMFS 1998b; St. Pierre 1999; Peterson *et al.* 2000; Secor *et al.* 2000).

Potamodromous species in inland and eastern North America

Three commercially important potamodromous species of Acipenseriformes inhabit inland North America (shovelnose, paddlefish, lake sturgeon) (Table 1).

Shovelnose sturgeon inhabits the Missouri and Mississippi River basin with a range spanning 24 states (Keenlyne 1997). One of the smallest North American sturgeons, shovelnose sturgeon matures early and grows quickly (Table 2; Fig. 2). The caviar of this species is marketed as 'hackleback' roe. Catch of shovelnose sturgeon became important in the early 20th century but little historic catch data exist (Billard and Lecointre 2001; Quist *et al.* 2002; Williamson 2003). Currently, commercial harvest of shovelnose sturgeon is permitted in eight states (AZ, IL, IN, IA, KT, MO, TN, WI) with a 25-tonnes annual harvest (Keenlyne 1997; Mosher 1999; Todd 1999; Williamson 2003). Harvest of this species in the Missouri River has increased in recent years (Quist *et al.* 2002).

The American paddlefish once inhabited 26 US states with a range including the Great Lakes and Canada but now exists in only 22 US states within the Mississippi River basin and Gulf coastal drainage. Paddlefish mature early and grow rapidly (Table 2; Fig. 2). Paddlefish caviar appears commercially as 'American' and 'American paddlefish' caviar. The commercial fishery for paddlefish caviar, particularly in the Mississippi River, increased after lake sturgeon became overfished with catches declining from the 1899 peak (Carlson and Bonislawsky 1981; Table 2; Fig. 6h). As of 2003, paddlefish was considered a sport fish in 15 states (AR, IL, IN, IA, KS, KY, MS, MO, MT, NE, ND, OH, OK, TN, SD), with late 1990s catch estimates ranging from 0.2 to 20 tonnes per state annually (Mosher 1999; CITES 2000).

Lake sturgeon inhabits the US and Canada and is considered threatened in 20 US states and seven Canadian provinces (Table 1). The species is more plentiful in Canada, existing in Alberta, Saskatchewan, Manitoba, Ontario and Quebec, and is classified as rare over much of its US range, abundant only in Wisconsin (Ferguson and Duckworth 1997; Williamson 2003). Lake sturgeon matures late and reproduces relatively infrequently (Table 2; Fig. 2). Within 20 years of opening, the fishery for lake sturgeon in the Great Lakes reached peak harvest levels and subsequently collapsed (Baker and Borgeson 1999). Catches in Lake Erie fell 80% between 1885 and 1895 (Ferguson and Duckworth 1997). In the upper Mississippi River, yield decreased by 97% (Knights *et al.* 2002). Currently, US lake sturgeon fishing is allowed only for sport and aboriginal harvest. Commercial catch in Canada (New Brunswick and Quebec) was 223 tonnes in 1997, 90% of which occurred in the St Lawrence River (CITES 2000). The sport fishery in Canada is reportedly small (CITES 2000). Canada has exported lake sturgeon meat and caviar under CITES, with much of the meat imported by the US (Table 4; Williamson 2003).

Few published studies exist on population size and structure of these species and management is challenged by a lack of understanding of species status (Graham 1997; Keenlyne 1997; Runstrom *et al.* 2001; Williamson 2003). Information on shovelnose sturgeon is particularly scarce and studies conflict on species status, agreeing only that the species is stable in four states (IA, MT, NE, ND) and extirpated from 25% of its historic rivers and at least three states (Table 1; Keenlyne 1997; in Williamson 2003). Most states managing paddlefish lack basic demographic and catch information and studies conflict regarding paddlefish status (Graham 1997; Runstrom *et al.* 2001). Graham (1997) reported that as of 1997 paddlefish populations were stable in 14 states (AL, AR, IN, IA, KS, KY, LA, MN, MS, MO, MT, NE, OK, SD), increasing in three (TX, WV, WY), declining in two (IL, ND), of unknown status in three (OH, VA, TN) and extirpated in four (NY, MD, NC, PA). A separate study indicated declines in five states (IA, MN, AR, MS, SD) and unknown status in six states (IL, MS, MO, MT, OH and WI) (in Runstrom *et al.* 2001). Lake sturgeon have been extirpated from at least four states (AL, AR, MS, WV) and reduced to 1% of their former abundance in the Great Lakes (Table 1; Peterson *et al.* 2002). Populations are structured on a watershed scale (Ferguson and Duckworth 1997) and population size estimates exist for some populations (e.g. Winnebago system; Threader and Brousseau 1986; Kempinger 1996; Bruch 1999; McLeod *et al.* 1999; Thomas and Haas 2002).

Little published information exists regarding shovelnose sturgeon fisheries management. Sport fishing regulations vary by state and include size limits and bag limits, but there are no uniform management standards (Keenlyne 1997; Mosher 1999). Overall the species is managed under state regulations similar to those for paddlefish (Williamson 2003).

Commercial catch of paddlefish is permitted in six states (AR, IL, KY, MS, MO, TN) with regulations varying by state and including limits on size and season (Graham 1997; Mosher 1999; Todd 1999; CITES 2000; Williamson 2003). Many states that permit commercial fishing do not require catch statistics reporting (CITES 2000; Williamson 2003). Most sport fisheries specify a daily bag limit of two individuals (normally without size limits), regulate the number of individuals harvested per year, and institute seasonal closures. Paddlefish is managed cooperatively among states in certain areas (e.g. MT/ND, NE/SD, Ohio River basin) and by Mississippi Interstate Cooperative Resource Agency (MICRA), a non-regulatory agency of 28 Mississippi river basin states (Williamson 2003). MICRA has initiated basin-wide tagging and assessment programmes and plans for a coordinated interstate management system. With no federal appropriations or management authority, MICRA has only limited capacity and influence (Williamson 2003). Poaching of paddlefish is problematic, especially in the Mississippi River and paddlefish caviar has been fraudulently sold as Russian caviar (CITES 2000; Williamson 2003).

Lake sturgeon commercial fisheries in the US waters in the Great Lakes were closed in 1977 (Baker and Borgeson 1999). Canadian commercial fisheries (Quebec, Ontario) are reportedly well managed, regulated by gear, size and season, with periodic closures based on stock estimates (Ferguson and Duckworth 1997; Nilo *et al.* 1997; McLeod *et al.* 1999; CITES 2000). Sport fishing for lake sturgeon is restricted to their northern range under strict regulation and periodic assessments (Ferguson and Duckworth 1997; Thuemler 1997; Baker and Borgeson 1999; Mosher 1999). Some sport fisheries allow catch and release only while others allow take under strict quotas: US sport fisheries are restricted to one fish per angler annually (Mosher 1999; CITES 2000). The sport fishery in the Winnebago system in Wisconsin is regarded as a model of management and recovery, implementing population monitoring, harvest assessments, habitat protection programmes, enforcement and public involvement (Bruch 1999; Secor *et al.* 2002). Population size estimates for Winnebago System lake sturgeon are available from the 1950s to the present and illustrate an increasing trend (Bruch 1999). Sturgeon management in Alberta, Canada, also uses an iterative process based on catch information (McLeod *et al.* 1999). However, a great deal of basic information (management units, key habitats, population sizes) is still lacking for the species (Knights *et al.* 2002).

Captive propagation and commercial aquaculture programmes for caviar production exist for paddlefish and lake sturgeon while only captive propagation programmes exist for shovelnose sturgeon (Williamson 2003). A 1998 study reported that 11 states had developed and/or were implementing restocking and re-introduction plans for shovelnose sturgeon. Restocking programmes for paddlefish exist in eight states and farms/hatcheries have been developed in four states and internationally (China, Russia, Moldavia, Romania; CITES 2000; Billard and Lecointre 2001). Artificial propagation techniques for paddlefish include reservoir ranching and monosex culturing (Carlson and Bonislawsky 1981; Mims and Shelton 1998; Onders *et al.* 2001). Lake sturgeon were re-introduced into Lake Superior and Oneida Lake, propagation programmes in Wisconsin have been ongoing since 1979, and additional programmes exist in five US states (MO, MN, NY, ND, WI) (Schram *et al.* 1999; CITES 2000; Jackson *et al.* 2002).

Sturgeon fisheries of the world: observations and recommendations

Status of Acipensiformes populations and fisheries

The comprehensive synopsis presented herein demonstrates that, with extremely few exceptions, sturgeon and paddlefish populations are imperilled across the globe and their long-term survival in the wild is in jeopardy (Table 1). Extinction of some populations (e.g. ship sturgeon, Aral Sea; beluga, Adriatic Sea) has already occurred, and 19 of the 27 species have experienced range contractions (Table 1). All extant species are acknowledged as threatened by CITES and only two species are considered Lower Risk by the IUCN (Table 1). Four of the nine species that occur in the US have populations listed under the US ESA, three of the non-listed US taxa have been petitioned for listing, and the non-native beluga sturgeon is also now listed as threatened (Table 1). Two of Canada's six species are considered of special concern, one as endangered and one as extirpated (Table 1).

Despite widespread recognition of their precarious status, commercial fisheries continue for 15 of the 27 species. The geographical focus of commercial fisheries production has shifted over time, moving to the Caspian region after North American and European fisheries were exhausted. Recent catches are at least 40% smaller than historic peak catch levels for all major sturgeon fisheries (Figs 3, 4 and 8), and are <15% of historic levels for 70% of the populations examined (Fig. 8). Caspian Sea fisheries, although currently the most important on a global basis in absolute terms, are among the most depleted relative to former production levels, with present catches below 10% of historic peak landings (Fig. 8). Six of the fisheries examined here crashed within 7–20 years of opening, with catch levels at the end of the period ranging between 1% and 10% of peak catch values. Only a few depleted sturgeon populations currently protected by bans on fishing show signs of rebounding (e.g. Winnebago lake sturgeon, Fraser river white sturgeon); while other species thus protected have estimated recovery times exceeding 40 years (US Atlantic sturgeon, Canadian white sturgeon).

Clearly the life-history characteristics of sturgeons and paddlefishes, particularly their late onset of maturity and only periodic reproduction thereafter (Fig. 2) leave them ill-equipped to handle intensive harvest pressure, and make recovery following collapse at best a long-term proposition. These considerations, as well as their anadromous lifestyle and specific environmental requirements account for their extreme vulnerability, inevitably demanding a precautionary approach to their exploitation. While biological vulnerability is of vital importance, it is not the sole determinant of status or sustain-

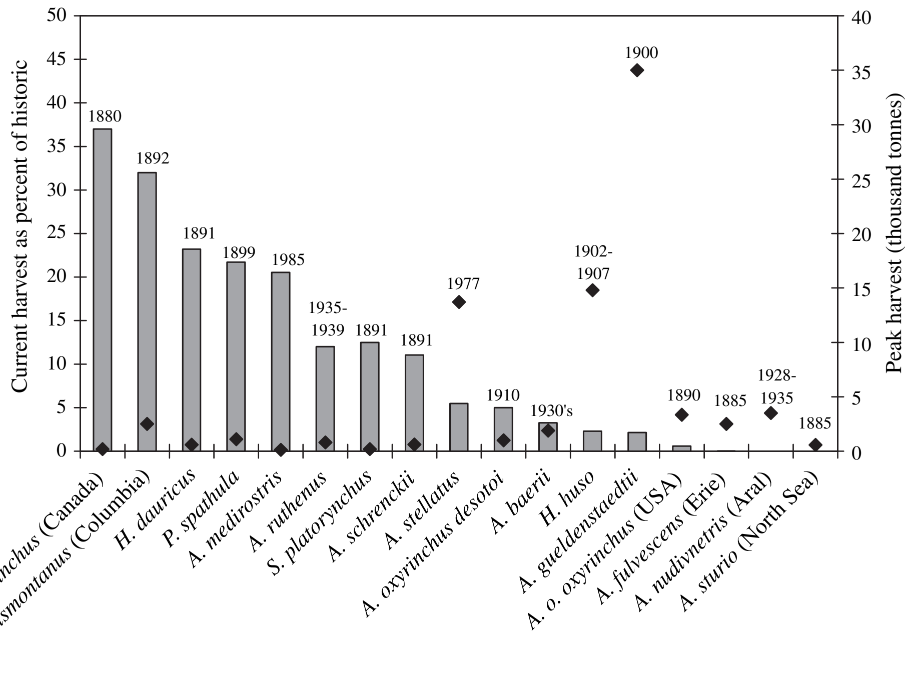

Figure 8 Historic and present species production. Bars indicate current production (or production recorded before fishery closure) as percentage of historic peak production. Diamonds represent peak production values and their respective dates.

ability. For example, white sturgeon have the most delayed onset of maturity yet their status and prognosis is good relative to other species, whereas ship sturgeon have maturity and spawning periodicity near the median for the group yet are among the most endangered (Table 1; Fig. 2). Clearly current management effectiveness, restoration capacity, and habitat quality and quantity are important explanatory variables for differences among species and areas.

Our compilation of a simple 'report card' for a series of indicators critical to population persistence and restoration shows that, with only a few exceptions, current management practices, restoration capacity and habitat characteristics fall far short of that needed to provide a reasonably good prognosis for focal populations (Table 5). Of the 16 populations examined, only three had total scores exceeding 50% of the maximum, two had scores at or near 50% of maximum, and the remaining 11 species had scores at or below 25% of maximum (Table 5). Overall, the North American populations fared substantially better than populations in other regions. Interestingly, the North American populations with the highest scores (white and Atlantic sturgeon) are those for which fishing is currently prohibited, although this was not an explicit criterion in the scoring. The major categories for which North American population scores surpassed those of Caspian, Black Sea, European and Asian populations were related to measures of management effectiveness (Table 5). In turn, management effectiveness appears closely related to political stability and the existence of effective intraregional cooperative agreements for populations covering more than one jurisdiction. Consistent with this notion is the finding that two of the North American populations with extremely low scores (shovelnose and paddlefish) are species whose populations span multiple states in the central US for which a regional agreement exists but lacks strength. The Caspian and Black Sea populations, with the lowest management effectiveness scores, are regions containing newly emerged independent states plagued by relatively high levels of poverty and corruption, the latter of which encompasses high rates of illegal fishing and trade. Clearly these are overarching, difficult problems that are beyond the scope of fisheries agencies to resolve, and are likely to remain problematic for a long time to come.

In terms of restoration capacity, it is encouraging that captive breeding technology is now available for all focal species, providing the potential for restoring populations with captive animals in the event that fishery and habitat pressures cannot be effectively controlled. The effectiveness of present and future restocking programmes is, however, uncertain given that measures to gauge their effectiveness (e.g. tagging and monitoring of recaptures) are generally lacking or inconsistently implemented (Table 5). It is also possible that restocking programmes may do more harm than good. This is of particular concern in areas where substantial amounts of spawning habitat and wild spawner abundance exist, and/or where genetic diversity of broodstock is not adequately maintained in captive breeding programmes. In fact, we found that genetic considerations are largely ignored for the vast majority of captive breeding programs examined (Table 5).

Identification, protection and restoration of critical habitat could be improved for all species. A particular challenge for sturgeon restoration is that, with the exception of a few European and Asian species the principal rivers of historic importance for spawning are no longer free flowing. Given the lack of effective dam bypass systems for sturgeon, elimination of existing dams is the only effective mechanism for meaningful habitat restoration.

Recommendations on conservation priorities

Given their imperilled status, extreme vulnerability, and poor management and restoration prognosis, recovery of the world's sturgeon and paddlefish populations is at best a precarious and long-term proposition. To ensure their future survival, priority should be given to those actions that have the best chance of stemming and reversing the decline of wild populations in the near term.

For Caspian Sea, Black Sea, Amur river and wild Siberian sturgeon populations, we recommend that urgent priority be given to reducing fishing pressure on wild populations through enforcement of existing international and domestic regulations and development of new, more restrictive measures. For the most threatened species, such as beluga and ship sturgeon, fisheries must be closed or harvest levels drastically reduced to allow rebuilding and to facilitate effective enforcement. Focus must shift towards preserving large, mature fish now rather than relying upon hatchery supplementation, future recruitment or habitat restoration. Lack of adequate wild broodstock at Azov and Caspian

Table 5 Status of reviewed species in terms of management effectiveness, restoration capacity and habitat.

	Caspian and Black Sea					Europe and Asia			North America							
	AG	*AP*	*AR*	*AS*	*HH*	*HD*	*ASC*	*AB*	*AT (CA)*	*AT (US)*	*AM*	*AOO (CA)*	*AOO (US)*	*AF*	*SP*	*PS*[1]
Management effectiveness																
Management plan applied across the species range	–	–	–	–	–	+	+	–	+	+	–	+	+	+	–	–
Biological targets and timeframes for management	–	–	–	–	–	–	–	–	+	+	–	+	+	–	–	–
Current population size estimates available for most populations	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–
Management decisions based on monitoring and stock assessment for most populations	–	–	–	–	–	–	–	–	+	+	–	+	+	–	–	–
Effective enforcement programme	–	–	–	–	–	–	–	–	?	–	–	+	+	+	–	–
Management effectiveness totals	0	0	0	0	0	1	1	0	4	4	0	4	4	2	0	0
Restoration capacity																
Species can be reared in captivity	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Restoration planning comprehensive and includes marking and monitoring	–	–	–	–	–	–	?	–	+	+	–	–	+	–	–	–
Genetic considerations	–	–	–	–	–	–	?	–	+		–	–	+	–	–	–
Restoration capacity totals	1	1	1	1	1	1	1	1	3	3	1	1	3	1	1	1
Habitat																
Critical habitat identified for species range	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Critical habitat protected	–	–	–	–	–	?	?	–	–	–	–	–	–	+	+	+
Principal spawning rivers free flowing	–	–	–	–	–	+	+	+	–	–	–	–	–	–	–	–
Pollution management and water quality management programmes	+	+	+	+	+	–	–	–	+	+	+	+	+	+	+	+
Habitat totals	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2
Total for species and regions	2	2	2	2	2	3	3	2	8	8	3	6	9	5	3	3

Points allocated to each species in response to questions as follows: –, 0 points; +, 1 point; ?, insufficient information.

[1]AG, *Acipenser gueldenstaedtii*; AP, *A. persicus*; AR, *A. ruthenus*; AS, *A. stellatus*; HH, *Huso huso*; HD, *H. dauricus*, ASC, *A. schrenckii*; AB, *A. baerii*; AT, *A. transmontanus*; AM, *A. medirostris*; AOO, *A. oxyrinchus oxyrinchus*; AF, *A. fulvescens*; SP, *Scaphirhynchus platorynchus*; PS, *Polyodon spathula*.

hatcheries and observed recruitment failures in Canadian white sturgeon populations underscore the priority of conserving existing mature fish over other options whose benefits are less reliable and less immediate.

The resolutions set forth by CITES should be more aggressively enforced. Although CITES listing has resulted in improved trade regulation, cooperative management of transboundary populations, and reduced export quotas, more could be accomplished (Raymakers 2002; Raymakers and Hoover 2002; Pikitch *et al.* 2004a,b). Non-zero trade quotas are routinely approved despite non-compliance with CITES resolution requirements, the absence of accurate population structure and abundance information, and illegal harvest and trade. While more research is needed to adequately monitor and manage sturgeon populations, adequate demographic information is already available, and essential measurements can be obtained using non-lethal sampling methods. Thus, in contrast to current practice, scientific quotas permitting fish kills should be banned.

For CITES to be most effective, the parties should adopt a precautionary approach with decisions on quotas considering uncertainty of population status, evidence of decline and rates of illegal fishing. In so doing, zero quotas will likely result for many species. Although the CITES parties have agreed to temporary trade bans in the past, the use of trade bans and zero quotas should be applied in all cases of non-compliance. The burden of proof should be shifted making compliance a prerequisite for non-zero quotas, creating an incentive for responsible management. An independent scientific authority should evaluate the impact of total harvest on wild populations, and establish and oversee standardized monitoring, assessment and quota-setting procedures for each watershed.

Conservation priorities for North American sturgeon and paddlefish populations vary among geographical regions. Shovelnose and paddlefish populations in inland North America are most in need of improvements in management effectiveness. Coordinated, interstate, transboundary management among states harbouring common populations should be strengthened and mandatory reporting of commercial and recreational landings should be instituted in all fisheries. Management effectiveness is relatively strong, and commercial fisheries are already prohibited for depleted coastal populations, so that recovery in these areas may be best facilitated through focused attention on habitat protection and restoration efforts and targeted research and monitoring programmes. Overall, although knowledge about some North American species has improved (Van Winkle *et al.* 2002 and references therein) basic demographic information is still lacking for some species (e.g. green sturgeon, shovelnose sturgeon, American paddlefish).

Only a few sturgeon fisheries are managed based upon frequent monitoring of population size, age and abundance and periodic stock assessment (Columbia River white sturgeon fishery, Canadian Atlantic sturgeon fishery, Canadian and Winnebago Lake sturgeon fisheries). Advances in modelling the response of sturgeon population to different management schemes are revealing whether sustainable sturgeon fisheries are indeed possible and quantifying acceptable levels of mortality (Rieman and Beamesderfer 1990; Boreman 1997; Root 2002; in Secor *et al.* 2002). The lessons learned must now guide management of other species. Consideration might be given to convening the international community of sturgeon and paddlefish conservationists to set guidelines for population monitoring, stock assessment and fisheries management programmes. Established as a textbook or manual for policymakers, managers and scientists, this effort would set a universal basis for acceptable management standards and could guide decision-making on commercial exploitation and trade.

Domestic legislation, management and education must also be strengthened globally. Many sturgeons and paddlefish populations are likely candidates for national protection and nations should move to review species within their jurisdiction. As fisheries in the Caspian decline, pressure may shift toward species not currently commercially valued and foresight is needed to review the adequacy of protection and management schemes now, especially for North American paddlefish and shovelnose sturgeon. Within the Caspian region, sturgeon conservation will require national commitments to fair, transparent, tightly regulated fisheries that embrace long-term sustainability goals. As corruption is problematic even within the agencies protecting sturgeons and many CIS nations have poor economic and unstable political outlooks, this will be difficult. Scientific entities in these nations are often closely tied to commercial interests, with profits from caviar and meat sales from scientific catch supporting hatcheries and science and scientific studies funded by fishing companies. As CIS nations transition, international efforts should focus on joint projects and training initiatives that build capacity and raise awareness among national scientists and that examine the long-term economic benefits of a sustained commercial fishery and the immediate alternatives to sturgeon fishing. Funding for such studies could be derived from an international trade tax and illegal trade and harvest penalties.

As natural populations, habitats and wild sources of caviar dwindle, captive rearing holds promise for an alternative source of caviar and wild population restoration. Captive populations are currently used for production of market-worthy aquaculture caviar and restoration of endangered populations (Speer *et al.* 2000; Mims 2001; Collins *et al.* 2002; Ireland *et al.* 2002a; Williamson 2003). Increased international trade in aquaculture products and live specimens and greater acceptance of aquaculture alternatives has ensued (Raymakers and Hoover 2002; see http://www.caviaremptor.org). Should aquaculture product continue to provide an alternative to wild caught product, pressure on wild populations could be relieved.

Both commercial aquaculture and hatchery propagation pose certain risks. Aquaculture can negatively affect the environment through disease introduction, escapement, pollution and use of wild fish for feed (Tsvetneko 1993). Farming non-native sturgeons can lead to non-native escape and threats to native species, as has happened in Europe and South America (Arndt *et al.* 2002; Bauer *et al.* 2002; Pikitch *et al.* 2004a,b). Commercial ventures can be conduits for illegal trade, increase market demand and illegal harvest pressure, and exacerbate enforcement problems (Czesny *et al.* 2000; Gessner *et al.* 2002; Williamson 2003). For critically endangered species like beluga, aquaculture can place further demands on deteriorating populations by removing broodstock from the wild (Pikitch *et al.* 2004b). As such, aquaculture of sturgeons must proceed cautiously, embracing best management practices, use of native species, adequate labelling and control of products, and beneficial linkages to conservation efforts in the wild.

Hatchery propagation for re-introduction must also proceed cautiously. Genetic issues of inbreeding and genetic swamping must be considered. For anadromous species harbouring population structure corresponding to natal river, released individuals can stray to non-target rivers (Quattro *et al.* 2002; Smith *et al.* 2002a,b). Concentrated focus on captive rearing can divert attention from important management issues such as catch limitation and habitat restoration (Raymakers 2002; Williamson 2003). Recently developed restoration plans for sturgeon have made strides to consider these risks (e.g. Atlantic and shortnose sturgeon; NMFS 1998b; St. Pierre 1999; reviewed in Williamson 2003), and should guide restoration planning for other species, including Sea of Azov beluga and Lake Baikal Siberian sturgeon. Overall, re-introduction should be a used for only the most endangered populations with little hope of natural recovery, in cases where fishing pressure has been relieved, and with the objective of restoring the population and using and ecosystem-based approach (Pikitch *et al.* 2004a,b).

Merging aquaculture and captive propagation projects could prove beneficial. As captive populations harbour insufficient genetic diversity, are of mixed stock origin, or consist of hybrids, they generally cannot be used for restoration projects (Williot *et al.* 2001). Encouraging the development of joint programmes that produce commercial products using captive populations also suitable for restoration programmes could benefit species for which aquaculture but not restoration programmes exist (Siberian sturgeon) and for which commercial products are highly valued and captive propagation is an important conservation tool (Caspian species). At the very least, all aquaculture production facilities should be required to contribute to *in situ* conservation or participate in captive gene exchange programmes. Establishment of these types of programmes in the Caspian region could provide alternative livelihood options to commercial fishermen and reduce pressure on wild populations.

Technological improvements are needed to develop methods to mark/tag released individuals, distinguish aquaculture from wild-caught products, and cryo-banking. Methods to quantify recruitment of hatchery-released individuals are needed, especially for fisheries where restocking is heavily used, quotas are established based upon the number of hatchery fish released, and/or stock assessment models consider the contribution of hatchery fish. Lastly, much of the research on culture, tagging, monitoring and enhancing the survivability of released individuals is occurring in areas and for species not currently under the greatest harvest pressure making knowledge transfer a priority.

Programmes that inform the public about sturgeon conservation, such as through participatory research and media and outreach campaigns, exist in the US, Canada and Europe, and can inspire public action to change domestic and international policy. Consumer awareness campaigns such as Caviar Emptor have affected consumer and retailer behaviour towards beluga and Caspian caviar, stimulated the development of high-quality alternatives and brought greater international attention to the plight of sturgeon. Programmes that educate and encourage consumers to purchase sturgeon products only from legal, environmentally sound and sustainable fisheries should continue. Most importantly, public education and awareness campaigns are needed in the Caspian region to inspire fisheries reform. While farmed caviar and sturgeon meat production has been increasing, the rate of increase is not likely to keep pace with the reduction in wild fishery production in the near term, and meeting global demand for caviar may become increasingly more difficult. Thus, efforts to shift demand away from the most highly endangered species and to reduce overall demand are likely to be important components of a global sturgeon conservation strategy.

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