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NOTE

First record of a Critically Endangered species, European sturgeon, in the stomach of harbor porpoises from the North Sea

Eileen Heße[1], Jörn Gessner[2], Ursula Siebert[1], Anita Gilles[1,*]

[1]Institute for Terrestrial and Aquatic Wildlife Research (ITAW), University of Veterinary Medicine Hannover (TiHo), Foundation, 25761 Büsum, Germany

[2]Leibniz-Institute of Freshwater Ecology and Inland Fisheries, 12587 Berlin, Germany

ABSTRACT: The European sturgeon *Acipenser sturio* has been of substantial commercial interest in the past. Today it is considered Critically Endangered, with only one remaining population in Europe. Fulfilling national conservation strategies and aiming for the conservation of biological diversity, Germany has released European sturgeons into their former habitats (Elbe River and its tributaries) as part of experimental measures to restore the population. However, little is known about their biology, sensitivity of life-stages to threats or trophic interactions within their former habitats. Here, we report on the first known predation of reintroduced sturgeons by harbor porpoises *Phocoena phocoena* and discuss predator–prey interactions in the light of sturgeon conservation. Stomach content analysis on stranded harbor porpoises revealed remains (scutes; modified ganoid scales) of European sturgeon in stomachs of 2 adult harbor porpoises (1.23%). Mean ± SD back-calculated lengths of ingested sturgeons were 26.11 ± 1.90 and 26.49 ± 1.93 cm, respectively, based on dorsal scute morphometrics. To date, no predator–prey interactions between sturgeons and harbor porpoises have been recorded in the North Sea. Future research into the diet of aquatic top predators with overlapping habitats at stocking sites of European sturgeons, transcending national boundaries, will uncover possible conservation concerns, conflicts of species-specific management interests and reintroduction success of European sturgeons.

KEY WORDS: *Acipenser sturio* · *Phocoena phocoena* · Conservation · Reintroduction · Foraging ecology · Predator–prey interactions · Cetacean · Biodiversity

1. INTRODUCTION

In 2007, France and Germany declared the restoration of European sturgeon *Acipenser sturio* to be one of the greatest challenges in terms of fulfilling the aims of national strategies for the conservation of biological diversity and, hence, underpinning its ecological relevance (Gessner et al. 2011). The European sturgeon, once of significant commercial importance, has experienced a substantial population decline, with extirpation being noted by the 1980s (Gessner 2000). Prior to the onset of the 20th century, *A. sturio* was common in German rivers entering the North Sea (Kirschbaum et al. 2009). Currently, the Gironde River in France is home to the last natural population of Europe's once widest-ranging sturgeon species (Kirschbaum et al. 2009). The decline and local extirpations of *A. sturio* resulted from man-made constructions of water bodies, anthropogenic water usage, pollution and intensive fishing (Brevé et al. 2022), all of which warrant concern for successful sturgeon conservation today.

Consequently, reintroduction programs have been developed and implemented. Between 2008 and 2015, around 19 000 European sturgeons were released in

*Corresponding author: anita.gilles@tiho-hannover.de

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their former habitats as part of experimental stocking measures in the Elbe River and its tributaries in Germany (Gessner 2021) (Fig. 1). Thus, those animals found in the Elbe River and the North Sea today all originate from stocking measures (Gessner et al. 2022). The first sexually mature returnees have recently appeared in in the Elbe River (Gessner 2021). Nevertheless, it will still take decades, given the age of sexual maturity (10–16 yr, depending upon geographical range and sex; Visser et al. 2020), before the stocks are self-sustaining (Gessner 2021). Sturgeon populations are especially sensitive to increases in mortality within the first 2 yr, during which mortality rates reaching 90% obstruct conservation efforts (Pine et al. 2001, Gessner 2021). After that, mortality drops sharply, presumably to 2–5% yr^{-1} (Jarić & Gessner 2012).

Despite all conservation actions taken, sturgeons remain the world's most endangered group of animals (Flowers et al. 2011). European sturgeon is listed on the IUCN Red List as Critically Endangered with a decreasing population trend (Gessner et al. 2022), as well as on Appendix II of the Bern Convention, Appendix I and II of the Bonn Convention and Annex II and IV of the EU Habitats Directive. Likewise, since 1983, international trade of this species is strictly banned (Convention on International Trade in Endangered Species of Wild Fauna and Flora I).

Harbor porpoises *Phocoena phocoena* are equally highly protected under different European (including Annex II, IV of the Habitats Directive; Annex II of Bern and Bonn Conventions) and national (German Federal Nature Conservation Act) agreements. Conservation concerns for porpoises and sturgeons in the North Sea partly overlap, with bycatch likely being the primary threat for harbor porpoises, followed by chemical and noise pollution (Avila et al. 2018). The harbor porpoise is a top predator and has a broad and regionally diversified prey spectrum while foraging throughout the North Sea including adjacent big rivers, such as the Elbe River (e.g. Leopold 2015, Wenger et al. 2016). General knowledge of prey species of harbor porpoises in the German North Sea is foremost based on extensive studies prior to 2008, with no records of harbor porpoises preying on sturgeon (e.g. Gilles et al. 2008).

Today, the prominence of reintroduced European sturgeons might become evident in the food web as remains of individuals were found in the stomachs of North Sea harbor porpoises. Here, we report on the first known predation of reintroduced sturgeons by harbor porpoises and discuss predator–prey interactions in the light of sturgeon conservation.

2. METHODS

As part of a long-term monitoring program, harbor porpoises found dead along the coastline of Schleswig-Holstein, Germany, are necropsied and stomachs are preserved for further dietary analysis (Siebert et al. 2001; Fig. 1). Stomach content analysis of harbor porpoises (n = 162), stranded between 1997 and 2021, was performed following the methods of Leopold (2015). Prey remains such as otoliths and vertebrae were used to identify prey species, with otoliths primarily employed for fish species identification and length and weight estimation. Hard parts were foremost identified according to Camphuysen & Henderson (2017), Härkönen (1986) and our own reference collections. Sturgeon scutes (modified ganoid scales) were identified at the Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB) in Berlin, Germany. Sturgeon length was back-calculated based on dorsal scute morphometrics (Fig. 2) described by Desse-Berset (2011). We established a regression from sam-

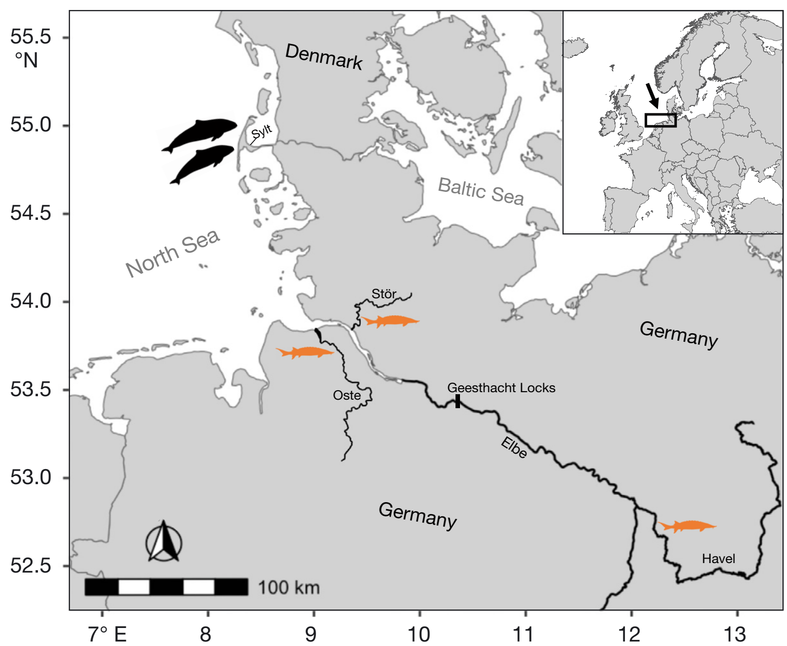

Fig. 1. Stranding locations on the island of Sylt, Germany, of the 2 harbor porpoises with sturgeon remains in their stomachs (black porpoise silhouettes) and release sites of European sturgeons (orange sturgeon silhouettes) in the Elbe River tributaries

ples of dorsal scutes based on mortalities at IGB with a linear regression for fish under 70 cm:

$$\text{TL (cm)} = 2.2323 \times X + 1.4574 \quad (1)$$

where TL (cm) is the total fish length and X is the dorsal scute width in mm (N = 8, R^2 = 0.9867). Scutes revealed a state of progressed digestion based on wear, decalcification and loss of structural patterns. The comparison suggests that digestion led to the breakdown of around 40 to 50% of the scute, as compared to unaltered bony scutes from the same species. Through the recalculation of the scute width by a mean factor of 2, digestion was accounted for when back-calculating sturgeon length.

Back-calculations of fish weight were carried out based upon a length–weight regression determined for 850 captive-reared European sturgeons at release:

$$W = 2.9569e^{0.1153 \times X} \quad (2)$$

where W is the fish weight (g) and X is the total fish length (cm).

3. RESULTS

Two adult female harbor porpoises, moderately and badly decomposed, respectively, found on the island of Sylt in April 2015 and May 2017, had remains of European sturgeon in their stomachs. Based on the number of dorsal scutes retained (n = 5 and 7, respectively), both porpoises had preyed on at least 1 sturgeon. The mean ± SD sturgeon lengths were back-calculated to be 26.11 ± 1.90 and 26.49 ± 1.93 cm, and weights were estimated to be 60.02 ± 8.35 and 62.70 ± 9.96 g, respectively. Besides *A. sturio*, 7 other prey species were found in the stomachs of the 2 harbor porpoises (Table 1).

4. DISCUSSION

Prior to this study, there were no records of predator–prey interactions between sturgeon and harbor porpoise in the North Sea. Although sturgeon could have been a common prey in the past, there are no historical data to underpin this. However, there are

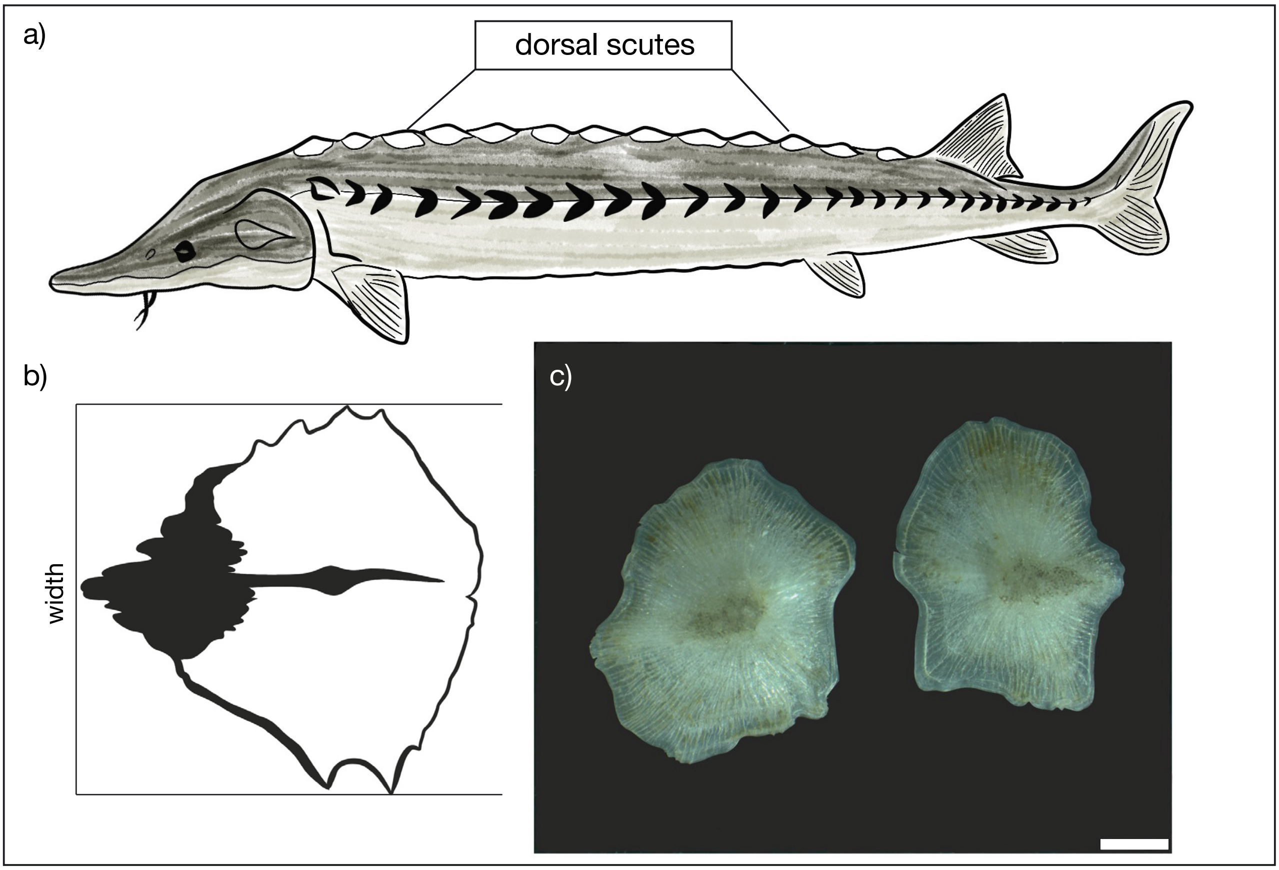

Fig. 2. (a) Location of dorsal scutes on European sturgeon, (b) representation of a dorsal scute and (c) dorsal scutes found in the stomach of an adult female harbor porpoise stranded in 2017 (scale bar = 2 mm)

Table 1. Back-calculated mean ± SD length and weight, and number of recovered individual fish (n) found in the stomachs of 2 harbor porpoises stranded on the island of Sylt in 2015 (Animal 1) and 2017 (Animal 2) based on otoliths (common sole, dragonet, hooknose, sand goby, sandeel spp., solenette and whiting) and scutes (European sturgeon). Empty fields indicate that a prey species was not present. The mean length and weight of sturgeon were determined based on the average across various wear classes of their scutes

Prey species	Binomial	n		Length (mean ± SD) (cm)		Weight (mean ± SD) (g)	
		Animal 1	Animal 2	Animal 1	Animal 2	Animal 1	Animal 2
Common sole	*Solea solea*	8	10	20.8 ± 1.9	12.6 ± 3.2	79.6 ± 23.3	20.1 ± 15.6
Dragonet	*Callionymus lyra*		7		17.0 ± 10.8		70.4 ± 119
European sturgeon	*Acipenser sturio*	1	1	26.1 ± 1.9	26.5 ± 1.9	60.0 ± 8.4	62.7 ± 10
Hooknose	*Agonus cataphractus*	4		11.6 ± 1		11.8 ± 3.24	
Sand goby	*Pomatoschistus minutus*	4	39	5.2 ± 0.8	4.7 ± 0.5	1.33 ± 0.57	0.99 ± 0.29
Sandeel spp.	*Ammodytes* spp.	1	4	16.8 ± 0	15.0 ± 0.2	14.8 ± 0	10.7 ± 4.72
Solenette	*Buglossidium luteum*		3		9.3 ± 2.3		9.33 ± 5.98
Whiting	*Merlangius merlangus*		2		19.5 ± 2.4		58.6 ± 21.7

cases of predation on sturgeon species in other regions, for instance Steller sea lions *Eumetopias jubatus* preying on white sturgeons *Acipenser transmontanus* in the Columbia River, USA (Madson et al. 2017).

Here, we have reported on 2 recent cases of consumed sturgeon out of 162 analyzed harbor porpoise stomachs (1.23%) from the German North Sea (Gilles et al. 2008, TiHo-ITAW unpubl. data). Stomachs of both individuals were not full; however, their stomach contents reflected known dietary patterns of stranded porpoises along the southern North Sea, which tend to have a mixed diet of energy-rich species, in this case sandeels, and lean prey species like whiting *Merlangius merlangus* or gobies (e.g. Gilles et al. 2008, Leopold 2015). Sturgeons as secondary prey can be excluded given their lengths (>26 cm) in relation to the overall prey species composition from stomach contents (Table 1).

It can be debated whether *A. sturio* in the North Sea may be suitable prey or whether it was targeted by porpoises in the absence of other prey. Harbor porpoises have high energy demands given their relatively small body mass to surface ratio (Spitz et al. 2012). Compared to other common prey species of harbor porpoises like sandeel (5.72 kJ g^{-1}), European sturgeons have rather low energy densities around 3.77 kJ g^{-1} (based on Siberian sturgeon *A. baerii*). Harbor porpoise prey rarely exceed 30 cm in length (Leopold 2015), suggesting that the ingested sturgeons were likely within their optimal prey size range. Their elongated body shape and demersal presence is in line with other preferred demersal prey species such as whiting (Leopold 2015). However, unlike most other prey species, sturgeons have scutes which may function as armor, impeding successful predation attempts. Further, handling sturgeons might be energetically more costly compared to smoothed-surfaced prey (e.g. sandeels), and scutes likely have long retention times. To date, no studies have focused on possible harm that sturgeon scutes may cause to predators during feeding events. However, other fish with defensive structures, such as catfish (Bosher et al. 2006), are known to impede ingestion and possibly cause injuries.

Little is known about the biology and sensitive lifecycle stages of European sturgeons and trophic interactions within former habitats, challenging appropriate conservation measures (Gessner et al. 2011). Harbor porpoises could have targeted sturgeons in the Elbe River, the Elbe estuary or farther offshore, as distribution patterns of both species partly overlap given the anadromous nature of *A. sturio* and known distribution patterns of porpoises in the area.

Generally, the emigration of released sturgeons from the Elbe River and its tributaries was noted to be quick based upon bycatch data of the regional fisheries. Sturgeons released at age 1, up to 25 cm, were found moving in the Elbe estuary between Hamburg Harbor and the Kiel Canal for 1 yr before out-migrating to the Wadden Sea and moving north towards Denmark (Gessner et al. 2014). As such, overlap with the foraging habitats of harbor porpoises starts as early as age 1. Here, especially individuals migrating out from the tributaries Stoer and Oste, 20–30 km from the river mouth, experience a high risk of early encounters when reaching the Elbe River (Fig. 1).

All 162 analyzed harbor porpoises stranded north of the Elbe River. Of those, the majority was found on the island of Sylt (n = 117). Yet, stranding location does not necessarily reflect where animals foraged prior to death. The decomposition state indicated that porpoises likely died a few days prior to stranding. Also, currents in coastal areas in the German Bight are relatively stable due to its topography with prevailing cyclonic (anti-clockwise) circulations throughout all seasons (Klein & Frohse 2008). Consequently, feeding in the Elbe River or estuary prior to death and then stranding farther north is not unlikely. Given the complex distribution patterns, sturgeons could have been targeted anywhere between the Elbe River and farther offshore near the island of Sylt. Further research, including telemetry studies, is required to accurately pinpoint where predator–prey interactions most likely occur.

While the possibility that other non-native sturgeon species were ingested by the porpoises cannot be disregarded, the likelihood is relatively low due to a lack of overlap in habitat use. Most sturgeons reared in German aquaculture facilities and private ponds are *A. baerii* and *A. ruthenus* (Bronzi et al. 1999), 2 freshwater species which are known to have been released into the wild by fishers or have escaped from aquaculture facilities (Spratte 2014). Other sturgeon species have been reported from the region only as large juveniles (Spratte 2014). In any case, the exotic species that have predominantly been reported from the Elbe River and its catchments are unable to withstand salt water at the sizes observed in the stomachs of the porpoises and have only been reported immediately south of Hamburg Harbor. To our knowledge, porpoise sightings south of Hamburg Harbor have not been documented, further limiting their potential overlap. At the same time, porpoise stranding sites and the occurrence of *A. sturio* as determined from bycatch records largely overlap.

Since different sturgeon species are challenging to separate morphologically from one another (Desse-Berset 2011), even more so when retrieved from a predator's stomach, it would be important to analyze samples via metabarcoding, which excels in prey identification down to species level depending on the primer applied (Boyi et al. 2022). Metabarcoding applied to stomach content samples could serve as a biodiversity monitoring tool by indirectly identifying the presence of sturgeon species in the ecosystem (Valentini et al. 2016).

To conclude, besides the importance of conservation and management measures such as stocking and habitat improvements, monitoring and quantifying predator–prey interactions should not be disregarded in the reintroduction process of the European sturgeon. This study highlights the first record of a marine top predator preying on reintroduced *A. sturio*. The magnitude and frequency of predation on European sturgeon remains unknown at this stage but is likely relatively infrequent. Ongoing research into the diet of aquatic top predators with habitats overlapping stocking sites of *A. sturio* and transcending national boundaries will help to uncover possible conservation concerns and conflicts amongst species-specific management interests and to monitor reintroduction success of European sturgeons.

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