NOTE

Updates on putative bull shark (*Carcharhinus leucas*) occurrences in the upper Mississippi River Basin of North America

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ABSTRACT. A previous paper in this journal by Shell and Gardner assessed various factors around the exploration of the Mississippi River by bull sharks (*Carcharhinus leucas* Müller and Henle, 1839) based on two twentieth-century occurrences. Recent evidence has suggested one of these occurrences is a probable hoax. Here, we provide a correction to our earlier paper, as well as additional comments on extralimital euryhaline vertebrates in the Mississippi River system, the environmental and historical contexts for their exploration into riverine systems, and suggest steps for any future effort to detect the usage of these river systems by bull sharks.

Key words: Freshwater elasmobranchs, extralimital, historic records, hoax.

Actualizaciones sobre las supuestas ocurrencias de tiburón toro (*Carcharhinus leucas*) en la cuenca superior del Río Mississippi de América del Norte

RESUMEN. En un artículo anterior de Shell y Gardner en esta revista, se evaluaron varios factores en torno a la exploración del Río Mississippi por parte de los tiburones toro (*Carcharhinus leucas* Müller y Henle, 1839) basados en dos sucesos del siglo XX. La evidencia reciente sugiere que una de estas ocurrencias es un probable engaño. Brindamos aquí una corrección a nuestro artículo anterior, así como comentarios adicionales sobre los vertebrados eurihalinos extralimitantes en el sistema del Río Mississippi, los contextos ambientales e históricos para su exploración en los sistemas fluviales, y sugerimos los pasos para cualquier esfuerzo futuro en detectar el uso de estos sistemas fluviales por los tiburones toro.

Palabras clave: Elasmobranquios de agua dulce, extralimitantes, registros históricos, engaño.

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A short summary of research into the history of bull shark (*Carcharhinus leucas* Müller and Henle, 1839) occurrences in the upper Mississippi River was published in this journal in 2021. It noted that, despite an apparent lack of information from the fossil and archeological records and pre-20th century historical accounts, bull sharks infrequently explore the Mississippi River Channel in the vicinity of the city of St. Louis, Missouri (USA) (Shell and Gardner 2021). We sought to examine this due to Mississippi River bull sharks being an oft-cited factoid, though assessments of these statements within the scholarly literature or attempts to understand this behavior in the Mississippi River such as causes or frequency were virtually non-existent.

The International Shark Attack File (ISAF) notes that bull sharks are the third most common shark species to be implicated in an unprovoked negative encounter, accounting for 12.7% of all incidents on record; with the top two species being white sharks (*Carcharodon carcharias* Linnaeus, 1758) with 37.0% and tiger sharks (*Galeocerdo cuvier* Péron and Lesueur, 1822) with 14.6%. Like many shark species, bull sharks are a declining species, previously listed as 'near threatened' (Cascio 2017) but reassessed as vulnerable in 2020 (Rigby et al. 2021). Public perception of bull sharks as a killing machine capable of exploring deep into freshwater habitats have not served the species well in popular media and are harmful to conservation initiatives. This served as an additional motivation to demystify bull shark movement in the Mississippi River Basin.

The evidence for this centered on occurrences from Alton, Illinois (USA) and the Rush Island power station near Festus, Missouri (USA). The former case is well-established in the ichthyological literature (Thomerson et al. 1977) and has never been satisfactorily falsified despite a recent claim in a newspaper that the shark was bought at a fish market in St. Louis (Cousins 2021). Thomerson et al. (1977) provided sufficient arguments against such a possibility and, despite being a local oddity for the past 85 years and part of the ichthyological literature for the past 45 years, no such first-hand evidence against its veracity has ever been brought forward.

The latter case from Rush Island was based on limited evidence which we noted in our paper. At the time, it appeared credible, and was cited in the literature (Burr et al. 2004, p. 249: 'Indeed, another bull shark was taken in the 1990s off the screen of a power plant intake canal. This report does not appear to be the product of a hoax, but there is little information other than a newspaper report'), and was believed to be true by fish and wildlife professionals that the authors had spoken with. Our paper was well-received in the media, both by regional and national news outlets, was downloaded from the journal homepage more than 800 times, and was recently cited by another scientist documenting freshwater occurrences of bull sharks (Gausmann 2021). Our research spurred an in-progress manuscript by one of us (NG) to document hoaxes and misidentifications of sharks in freshwater and it is not without irony that we must now admit that we have accidentally propagated such a case.

Around the time our manuscript was undergoing review, RH independently examined the Rush Island occurrence for his in-progress revision of 'The Fishes of Missouri'. RH published his findings in a journal with limited regional scope the same month as our paper (Hrabik 2021). He reported that the 96 cm long recovered specimen was not a bull shark, but an Atlantic sharpnose shark (*Rhizoprionodon terraenovae* Richardson, 1836). It is not unreasonable to conclude that the Missouri Department of Conservation ichthyologist who first identified the shark could have confused the specimen as juvenile requiem sharks grossly resemble each other (Figure 1) and may have made the presumption given its appearance in freshwater that it was a bull shark considering their known usage of riverine systems and knowledge of the Alton occurrence. Confusion between species of the Carcharhinidae, a wide ranging family with at least 60 extant species, especially at different life stages is not uncommon even for ichthyologists (Branstetter 1982; Dosay-Akbulut 2008; Smart et al. 2016). This said, however, Atlantic sharpnose sharks have never been reported from riverine ecosystems even though this species utilizes estuaries as nursery grounds like many other requiem sharks (Ebert et al. 2021). This led Hrabik (2021) to conclude the Rush Island occurrence is a case of an improperly dumped individual if not an outright hoax, rather than a valid occurrence. RH brought our attention to his work and we reached out to wildlife professionals in states bordering the lower part of the Upper Mississippi River Basin to gather additional information. After doing so, we felt Hrabik

Figure 1. Supposed bull shark recovered from the Rush Island power station near Festus, Missouri, from 1995, properly identified as an Atlantic sharpnose shark *Rhizoprionodon terraenovae* by Hrabik (2021). Photograph by Michael Fuhr (Missouri Department of Conservation) provided to RH.

(2021) had established evidence as to why the supposed bull shark was misidentified by prior wildlife professionals and provided sufficient arguments as to why it could not have naturally appeared where it was found, even if there are still many unanswerable questions such as who perpetrated this likely hoax and their motivations. However, the ability of the bull shark to penetrate rivers as far inland in North America as far as Alton, Illinois as well as its similar behavior in other riverine systems worldwide apparently makes it a subject of erroneous reports and encourages false reports (compare Dukes 2016).

The discrediting of the Rush Island occurrence means that the only known record of a bull shark in the upper Mississippi River Basin was reported from Alton, Illinois before the installation of the Mississippi's current system of locks and dams. The fact that none can be verified from a time after the installation of locks strongly suggests that the bull shark's upriver range has been limited by their installation for much of the 20th century, so we must now reject our earlier proposal in Shell and Gardner (2021) that unobservable passage through the most southward locks and dams could have occurred to explain the 1995 occurrence. Regular reports of marine shark remains dumped in improbable places further hampers research into the history of this presumed habitat loss (Gausmann 2021). We are also left with additional questions about the 1937 occurrence– was this an isolated event or a previously more widespread behavior? If the evidence is lacking for the latter, then what factors led to this anomalous event?

A north-south migration following coastlines has been observed in bull sharks. Along the east coast of the United States it is observed that bull sharks tend to summer in northern latitudes and then move further south with cooler waters (Castro 2011). They commonly migrate as far north as the Chesapeake Bay or even off the coast of New England, which is further north latitudinally than Alton, Illinois (38.8906° N latitude). These northward migrations when in estuarine environments can lead to riverine explorations such as the

reports of sharks in the Patuxent and Potomac Rivers from the Chesapeake Bay (Alderman 2014; Hedgpeth 2015; Chason 2018) or the more infamous, but not definitively proven example in Matawan Creek from the Raritan Bay in New Jersey in 1916 (McCormick 1963; see also Gausmann 2021). This may help contextualize the 1937 occurrence.

Other euryhaline marine vertebrates are capable of widespread dispersals into freshwater systems, and the environmental influences on this behavior are complex (currents, depth, salinity, temperature, food availability, etc.). Understanding what may represent rare or previously unobserved behavior versus actions of wayward individuals will depend on confirming the frequency of valid observations. Other brackish or marine vertebrates for which osmoregulatory competency is not a factor in freshwater survivability have demonstrated surprising long-distance dispersals into riverine systems.

One notable instance of a wayward euryhaline marine vertebrate in the lower Mississippi River Basin was that of a 3 m long West Indian manatee (*Trichechus manatus* Linneaus, 1758) (Mammalia: Sirenia) which wandered more than 1,200 km upriver to near Memphis, Tennessee (USA) (Manatee... 2006; Romero 2006). First spotted on October 23, 2006 only to ultimately be found dead 49 days later, the individual evaded detection by teams of federal and state wildlife and law enforcement professionals as well as an independent private team from SeaWorld Orlando who utilized aerial and boat-based spotting, side-scan sonar, and FLIR imaging (Officials... 2006). Though no cause of death was reported, hypothermia seems most probable and starvation less likely given healthy sirenians may last up to seven months without depleting their fat reserves (Best 1983) and variation in water salinity is not a stress inducer for manatees when invading riverine systems (Ortiz et al. 1998; Callejas-Jiménez et al. 2021), unlike other marine mammals (Pemberton 2011). This large-scale movement upriver may have taken 36-44 days to complete based on modest estimations of migratory behavior in *T. manatus* (27.3-33.5 km d^{-1} typically over 10-15 days according to Deutsch et al. 2003).

Consequently, if such a large and otherwise conspicuous species such a manatee, for which salinity is not an ecological barrier, can navigate this far upriver without detection and evade concentrated human effort to locate it, it raises questions as to the potential to evade human detection by smaller species such as bull sharks. These sharks also engage in difficult to observe behaviors in freshwater and brackish systems, such as swimming low in the water column when moving upriver during the daytime (Heupel et al. 2010), a behavior retained during migrations (Daly et al. 2014).

Similar accounts of long-range dispersals upriver in the lower Mississippi River Basin have been made by other typically brackish or offshore elasmobranchs, such as dasyatids (McCormick 1963; Brown 2010), and common freshwater species which frequently grow larger than bull sharks (alligator gars, blue catfishes, Gulf sturgeon, and paddlefishes) often move up and down the Mississippi River without being detected until they are caught on a line or in a net (Broom 2015) (Figure 2).

Despite the near lack of information in the upper Mississippi River Basin, archeological reports indicate an indigenous interest in the recovery of non-fossil shark material in central Louisiana (USA) from approximately 1,300 years before present (though extra regional trade cannot be ruled out to explain its presence) (Springer 1980). Furthermore, a supposed white shark was captured in Natchez, Mississippi (USA) in 1829 more than 500 km up-river from the Gulf (Another… 1829), though the size of the animal and its freshwater location are more suggestive of a bull shark. Its identification as *C. carcharias* is probably more reflective of the limited ichthyological knowledge of that time

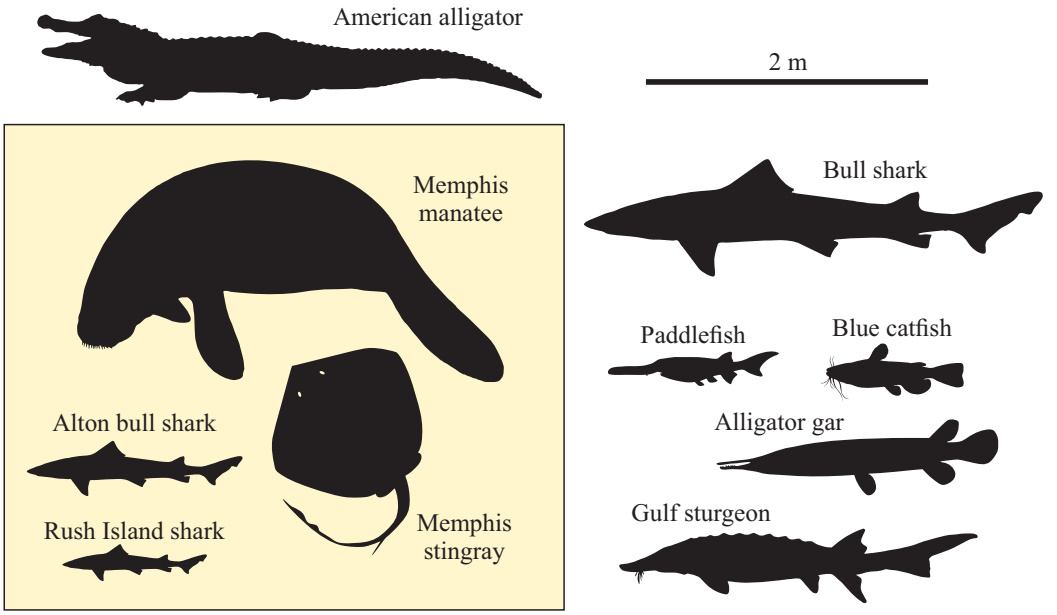

Figure 2. Relative sizes of wayward individuals of marine species (inside yellow box) compared with large regular freshwater or brackish species of the Lower Mississippi River Basin and the average size of male and female bull sharks (*Carcharhinus leucas* Müller and Henle, 1939). Silhouettes courtesy of Phylopic (http://phylopic.org) unless noted otherwise in acknowledgements. Sizes for species derived from common lengths reported in FishBase (http://www.fishbase.org) or Animal Diversity Web (https://animaldiversity.org). The average length of the bull shark was derived from Ebert et al. (2021: 535).

(*Carcharhinus leucas* was not yet described until 1839). This is much further than other reported cases of freshwater penetrations by bull sharks in the Mississippi River system by Gunter (1938) at 300 km up-river for Simmesport, Louisiana and 440 km up-river for Jonesport, Louisiana, although Matich et al. (2020) gave information on a bull shark record from 950 km up-river in the Red River, Louisiana, Arkansas, Oklahoma, and Texas. Thomerson et al. (1977) cited Gunter (1938) and observed '[Bull sharks] undoubtedly occur much more commonly in the lower Mississippi than the scientific record discloses, and the wonder is that they have not been reported much farther up the river than they have' (p. 168). It would therefore seem that the exploration, even if not long term habitation, of North American rivers, as a behavior, has a deep Holocene history in bull sharks, and the presence of their DNA in the Alabama-Tensaw River of Alabama (USA) as recently as 2018 (Drymon et al. 2021) indicates that this pattern is ongoing in the lower reaches of the Mississippi River Basin, exploration in other rivers along the Atlantic and Gulf coastal plains is documented though not fully understood. The same applies to sustained migrations of the species in coastal and oceanic environments (Carlson et al. 2011; Daly et al. 2014; Lea et al. 2015). For now, however, evidence of bull shark exploration into the upper Mississippi River Basin is given only by a singular occurrence, and it is possible river impediments prevent bull sharks (and other anadromous fish) to move into the upper stretches of the Mississippi River. If this occurrence represents anomaly rather than evidence of a more common, yet difficult to detect, behavior, reasons for that conclusion have not been explained to date, and the post-1937 manmade impediments on the river may have impeded subsequent occurrences as

suggested by Thomerson et al. (1977). However, historic reports of bull shark records from further large streams of the world such as the Tigris River, Iraq (Günther 1874) and the Amazon River in Brazil, Colombia, and Peru (Thorson 1972) suggest that long-distance movements of bull sharks up to thousands of kilometers are exceptional and rare events, and the majority of immature bull sharks presumably utilize the lower reaches of rivers.

Increased surveillance for large predatory fish in the lower Mississippi River Basin may help to better understand exploration of riverine systems by bull sharks and other marine fishes. This increased surveillance could take the form of environmental DNA monitoring (such as that of Drymon et al. 2021), through the tagging of individual bull sharks in nearshore ecosystems which could reveal riverine exploration, or a wider population survey of fishes in near shore and upstream localities. The authors encourage an extensive investigation of the Mississippi River Basin as a potential nursery area for bull sharks, as the few records from this river systems indicate this function, and moreover, the influence of anthropogenic impact such as water pollution on the fish fauna that inhabit this system. Currently, the Mississippi River must be valued as a data-poor area regarding the occurrences of sharks, and the importance of this river system for elasmobranchs is unclear.

While the behavior of bull sharks in estuarine and riverine environments has been the subject of previous studies (Heupel and Simpfendorfer 2008; Ortega et al. 2009; Heupel et al. 2010; Curtis et al. 2011; Curtis et al. 2013), it is important to continue to monitor for behavioral changes associated with climate change for which temperature increases and sea level rises are predicted to alter or increase the frequency in which bull sharks may utilize these near-coastal brackish to freshwater environments (Heithaus et al. 2009; Matich et al. 2020). Recent studies have already demonstrated that given their reliance on these ecosystems as nurseries, bull sharks are susceptible to climate change-driven alterations of estuaries (Niella et al. 2022). There is already evidence for these behavioral shifts in the global fossil record of bull sharks dating back at least as far as the Pleistocene (Lopes et al. 2020) and opportunistic exploration by bull sharks into man-made waterways are well documented worldwide (Alive... 1896; Montoya and Thorson 1982; Werry et al. 2012; Curtis et al. 2013). There are increased reports of bull sharks in these environments globally (Gausmann 2021; Hasan et al. 2021; Gausmann and Hasan 2022), though it could be due to increased effort to gather these records rather than a behavioral shift.

Additionally, the widespread digitization of historical records such as newspapers or archival image and manuscript collections have provided a powerful new tool in understanding the past geographic distributions and relative abundance of fishes (Cochran 2007; McClenachan 2009; Cochran and Elliott 2012; Cochran 2015; Palsson and Astthorsson 2017; Disspain et al. 2018; Keevin and Lopinot 2019; Bom et al. 2020; Brevé et al. 2022). However, it is crucial to acknowledge that unusual cases such as these must be approached with greater scrutiny and a higher standard of evidence. While many euryhaline elasmobranchs are known to invade (if only ephemerally) freshwater habitats, verification of riverine elasmobranchs in North America would ideally happen through securing voucher specimens (which was not done in the Rush Island occurrence) and improved photographic techniques that would permit identification (as thankfully had been done for the Rush Island occurrence). In the event of reported occurrences of euryhaline elasmobranchs invading far into riverine systems (such as Brown 2010), if wildlife professionals can take steps to document these specimens clearly even if voucher specimens cannot be obtained, it will be helpful for illuminating our understanding how sharks and other marine fishes utilize these systems, in this case the widely

branched Mississippi River system. Finally, when accounts must be taken from news reports online, we urge the use of web archiving tools which capture and preserve those records, such as Archive Today (https://archive.today) which we have used in this paper. These occurrences are often reported in the popular press or through social media which often exist online ephemerally, possibly anywhere from 40-100 days without being updated or modified (LaFrance 2015).

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