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Reported vessel strike as a source of mortality of White Sturgeon in San Francisco Bay

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Ship strikes are a source of injury and mortality for many aquatic species worldwide (Holland 1986; Laist and Shaw 2006; Hazel et al. 2007). Over the past few years, the impact of vessel strikes involving large cetaceans has received significant attention (Laist et al. 2001; Peel et al. 2018). However, the impact of vessel strikes on large adult fishes has received considerably less attention worldwide. Currently, the knowledge base of vessel strikes and their potential impact on fishes in the scientific literature is limited to a few studies involving large, long-lived fishes such as sturgeon (Gutreuter et al. 2003; Simpson and Fox 2009; Brown and Murphy 2010; Balazik et al. 2012; Watanabe et al. 2013). Recently, both Simpson and Fox (2009) and Brown and Murphy (2010) reported vessel strike mortalities of the ESA listed Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) in the Delaware River estuary, while Balazik et al. (2012) reported vessel strike mortalities of Atlantic sturgeon in the tidal freshwater portion of the James River, Virginia. Using an-egg-per-recruit analysis, Brown and Murphy (2010) demonstrated that vessel strike mortalities could be detrimental to the population if more than 2.5% of the female Atlantic Sturgeon are killed annually in the Delaware Estuary.

Despite the potential importance of vessel strike mortalities in limiting Atlantic Sturgeon recovery on the US East Coast (Brown and Murphy 2010), very little is known about White Sturgeon (*A. transmontanus*) vessel interactions on the US West Coast, especially in the heavily trafficked waters of the San Francisco Estuary (SFE). Though anecdotal evidence and personal observations (with no supporting information) abound, we were unable to find any direct evidence of confirmed White Sturgeon vessel interactions in the scientific literature. In this short article, we report on a vessel strike that we observed which resulted in the decapitation of a White Sturgeon in the SFE.

All observations and specimen collections were made from the National Oceanic & Atmospheric Administration's R/V Heron near the Port of Benicia, California USA. Due to the incomplete and decapitated nature of the specimen encountered, we used a head to body length of 4.5:1 as reported by Ruiz-Campos et al. (2011) to estimate its total length. Using this estimate of size we applied the length at age equation, $l_t = 230.59[1-e^{-0.0533(t+2.9176)}]$)] developed by Brennan & Cailliet (1989) for White Sturgeon in the SFE, where l_t is the length at age *t* (years) to estimate a minimum age. We used ArcGIS v10.5 to visualize the location of the observed vessel strike with an added bathymetry layer of the surrounding area.

On 24 April 2018 at approximately 1000 (PDT), we observed a crude oil tanker depart from the Port of Benicia on the north shore of the Carquinez Strait, directly downstream of the Interstate 680 Bridge, in approximately 20 m of water (Figure 1). The tanker measured approximately 250 m in length with a beam of 44 m and a maximum draught of 14.8 m. Immediately after its departure, we saw what appeared to be a live White Sturgeon struggling at the surface in an area the tanker had previously occupied. Upon closer inspection, it was determined to be a recently decapitated adult White Sturgeon measuring 92 cm total length without the head (Figures 2, 3). A significant amount of blood was still present in the body, which immediately drained upon removal from the water. Several strong tail beats and a general thrashing of the body suggested that the removal of the head occurred immediately prior to our observation of the fish struggling at the surface. No marine mammals, anglers, or other potential perpetrators were observed in the immediate vicinity prior to, during or after the fish was brought on board. The clean nature of the decapitation wounds (Figure 2) suggest they were caused by something quite sharp and powerful, and are not consistent

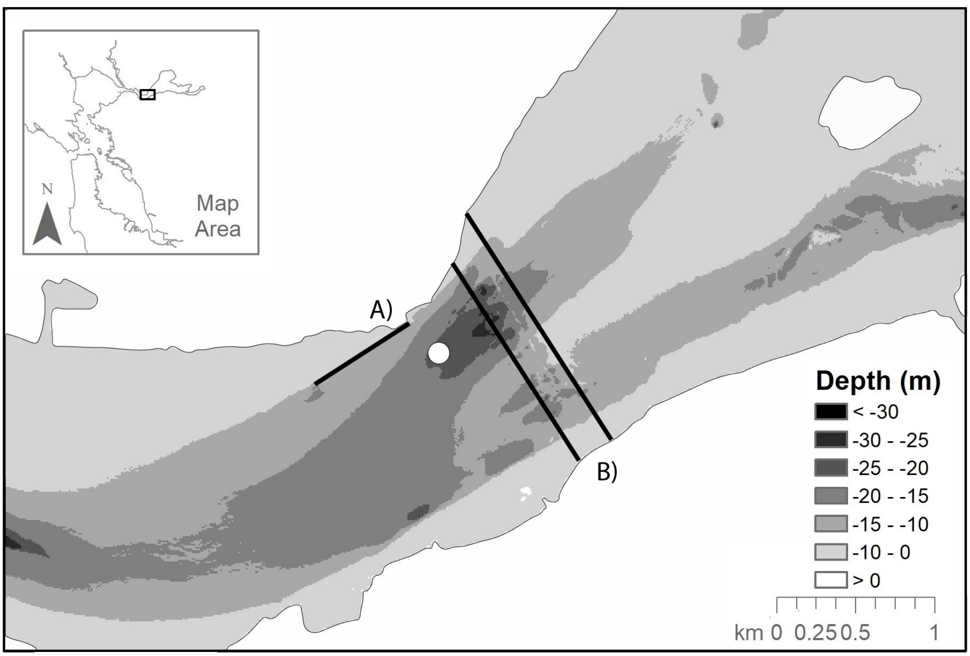

Figure 1. Location of Carquinez Strait in relation to the greater San Francisco Estuary, CA, USA (upper left). A) Port of Benicia with black line representing wharf structure. B) Parallel black lines indicate the location of the east and west spans of the I-680 Bridge. White circle denotes approximate location of observed vessel strike of White Sturgeon overlaid with the surrounding bathymetry.

Figure 2. Close up of wound with noticeable slice marks presumably caused by the vessel's propeller.

Figure 3. Lateral view of the white sturgeon with noticeable lacerations and trauma to the head region.

with the dentition of the California sea lion (*Zalophus californianus*), the dominant marine mammal predator in the area (Sinai et al. 2014).

The size of the fish and presence of male gonads suggest that the fish may have been at least 10 to 12 years old and possibly of breeding age (Moyle 2002). Using the measured body length of 92 cm and a head to body length ratio of 4.5:1, as reported by Ruiz-Campos et al. (2011), we estimated the total length *including* the head, at approximately 112 cm. The length at age equation, developed by Brennan and Cailliet (1989) for White Sturgeon in the SFE supports the minimum age estimate of our specimen at approximately 10 years old. This length at age equation relies in large part upon age data inferred from annual rings laid down in the cross section of White Sturgeon pectoral fins. However, this method may underestimate the true age of White Sturgeon by as much as 30-60% in some cases (Paragamian and Beamesderfer 2003).

Though we are aware of anecdotal and speculative reports of vessel strikes involving San Francisco Bay-Delta White Sturgeon in the scientific literature (Hildebrand et al. 2016), we are unaware of any previously published eyewitness accounts. The Carquinez Strait, within the greater SFE complex, is a heavily trafficked passageway that connects San Pablo Bay to Suisun Bay and the interior Sacramento-San Joaquin Delta. Both San Pablo and Suisun Bay are the primary, non-spawning habitat of adult White Sturgeon in the SFE and they move regularly between the two (Israel et al. 2011). This effectively acts as a bottleneck through which all fishes must pass and results in a deep channel with increased tidal flow suitable for the navigation of large vessels.

The characteristic bathymetry and tidal flow of the Carquinez Strait may increase the spatial overlap of White Sturgeon and large vessels in shipping channels as observed by Hondrop et al. (2017) in Lake Sturgeon (*A. fulvescens*) from the Detroit River. In addition, a growing body of research has shown that many Sturgeon species may not be as benthic oriented as once believed (Kelly and Klimley 2012; Watanabe et al. 2013; Beardsall et al. 2016; Taylor et al. 2016; Breece et al. 2018). Using vector analysis, Kelly and Klimley (2012) found that Green sturgeon spent the majority of their time in the upper water column, often at the surface, while undergoing rapid long-distance movements in deep, high-current areas such as the Carquinez Strait. To compound matters, Dijohnson (2019) found that Atlantic Sturgeon did not exhibit a behavioral avoidance response in the presence of vessel traffic. While similar vector analysis data is lacking for White Sturgeon, and behavioral data in the presence of vessel traffic is lacking for both Green and White Sturgeon, it may be reasonable to suggest that they behave similarly. Taken together these factors may lead to an increased risk of vessel strikes for both species in the Carquinez Strait.

While the impact of vessel strikes in the SFE on the White Sturgeon population may currently be of minor importance on its own, the cumulative impact when taken into consideration along with other stressors may present significant future challenges (Moyle et al. 2015). At this time, vessel strikes may have a greater impact on the population persistence of the ESA listed southern distinct population segment (sDPS) of Green Sturgeon (*A. medirostris*) due to their smaller population sizes. Southern DPS Green Sturgeon regularly pass through the SFE and the Carquinez Strait from late winter to spring in route to spawning grounds in the Sacramento and Feather Rivers (Mora et al. 2017; Seesholtz et al. 2015). However, we were unable to find any reports (anecdotal or otherwise) of vessel strikes involving Green Sturgeon in the SFE. This lack of observed vessel strikes may reflect upon the much smaller population size of Green Sturgeon in comparison to White Sturgeon in the SFE (Heublein et al. 2017). The apparent use of the Carquinez Strait primarily as a migration corridor by adult Green Sturgeon, as opposed to White Sturgeon that regularly transit the Carquinez Strait between feeding grounds, may limit the vessel strike susceptibility of adult Green Sturgeon to specific periods of migration (Heublein et al. 2009). However, sub-adult Green Sturgeon, similar to the size of our specimen, have been recorded in and around the Carquinez Strait, and may be vulnerable to vessel strikes as well (NMFS 2009).

It is apparent through both anecdotal reports and now eyewitness accounts that vessel strikes pose a risk of both injury and mortality to White Sturgeon in the Carquinez Strait, the SFE, and possibly elsewhere. However, the magnitude and extent of the threat, not only in the SFE but also throughout its entire range, is not fully understood. As a first step, a registry to report Sturgeon vessel strikes would provide a centralized repository of data that is currently lacking, similar to NOAA Fisheries National Marine Mammal Stranding Network (https://www.westcoast.fisheries.noaa.gov/protected_species/marine_mammals/national_stranding_network.html) or that of the International Whaling Commission's Ship Strikes database (https://iwc.int/ship-strikes). Such a database could assist fishery managers in making future decisions in regard to White Sturgeon, a long-lived fish that faces significant threats throughout its native range.

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Author Contributions

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