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Observation of the critically endangered soupfin shark (*Galeorhinus galeus*) in the Changing Salish Sea

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1 Introduction

High trophic-order predators play a critical role in ecosystems, exerting top-down control on prey species populations through direct predation (Terborgh et al., 1999; Pinnegar et al., 2000; Feit et al., 2019) and modify the behavior and habitat utilization of lower trophic level species through their presence in these systems (Ripple and Beschta, 2004; Heithaus et al., 2007). Therefore, shifts in the abundance and distribution of top predator species within an ecosystem can have cascading effects on lower trophic levels, changing trophic dynamics and ecosystem function (Heithaus et al., 2008; Baum and Worm, 2009; Newsome and Ripple, 2015). Thus, identifying shifts in the spatiotemporal habitat utilization of predators can be critical to the management of ecologically and economically valuable systems.

As a highly migratory marine predator, the soupfin shark (*Galeorhinus galeus*; aka school shark, tope) occupies a high trophic position (Bizzarro et al., 2017) and can exert top-down effects through direct predation upon forage fish, commercially valuable fish species, and smaller sharks (Nakatsu, 1957), significantly influencing trophic dynamics and biodiversity of their system. This coastal-pelagic species possesses an amphitropical distribution, with several geographically and genetically distinct populations throughout temperate waters (Chabot and Allen, 2009; Chabot, 2015) and seasonally inhabits a diverse array of habitats, spanning from shallow estuarine systems to the mid-continental slope (Thorburn et al., 2019; COSEWIC, 2021).

The northeast Pacific (from British Columbia, Canada, to Baja California, Mexico) once supported an extensive but brief fishery for soupfin sharks in the 1930s-40s (COSEWIC, 2021), and this species is still regularly encountered in fisheries and fishery surveys throughout these coastal waters. However, while common in estuarine systems in other regions (Walker et al., 2020; Nosal et al., 2021), soupfin sharks were not thought to inhabit the Salish Sea (Pietsch and Orr, 2015; Blaine et al., 2020; Lowry et al., 2022). The Salish Sea is an expansive inland waterway covering 16,925 km² across Northwestern Washington State and Southern British Columbia (Figure 1) that serves as a nexus of economic, environmental, and cultural interests (Gaydos et al., 2008; Jones et al., 2021). Despite consistent and extensive research and fishing efforts, apart from two recent strandings and a reported commercial catch in its northernmost extent in 2016 (Figure 1), soupfin sharks have not been previously described in the Salish Sea. However, in the last few years, there have been a growing number of anecdotal reports, by recreational fishers, of soupfin sharks and the largely sympatric broadnose sevengill shark (*Notorynchus cepedianus*) in the southernmost extent of the Salish Sea (aka South Puget Sound ~about 300km from previous strandings; Schulte et al., 2024).

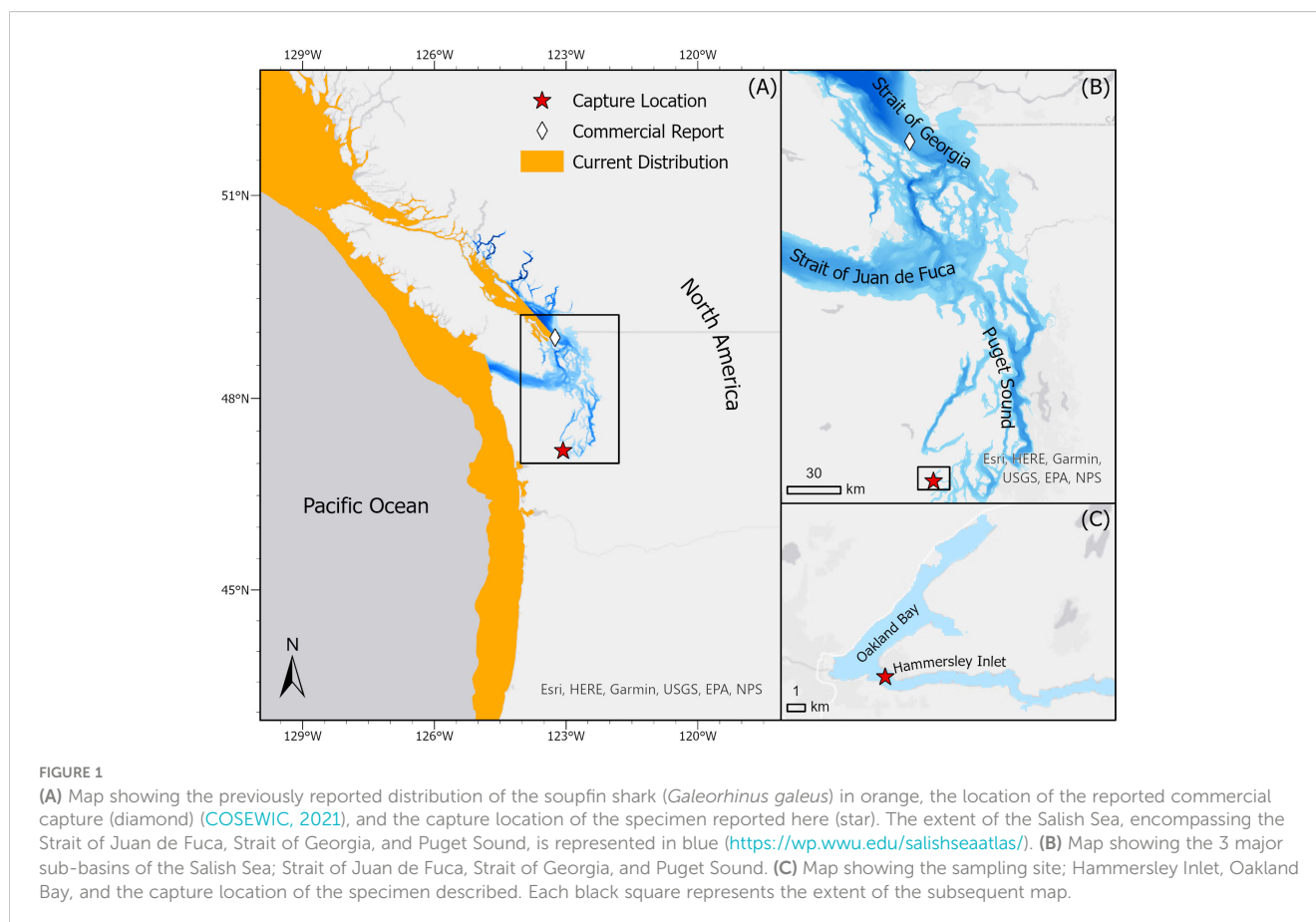
At sufficient population levels, the presence of a novel marine predator species in the Salish Sea may influence system trophic dynamics and could necessitate consideration in ecosystem-based fisheries models currently utilized in the region (Morzaria-Luna et al., 2022). In order to address the anecdotal reports of soupfin

sharks in South Puget Sound, we launched a multi-agency collaborative project aimed to: 1) confirm the presence of this species at a single site; and 2) evaluate whether reported encounters were merely stray occurrences (akin to the sporadic observations of juvenile gray whales in the Mediterranean Sea; Manfrini et al., 2023) or likely to be the result of a range extension driven by favorable climatic conditions and prey species abundance.

2 Methods

2.1 Site description — Hammersley Inlet

Hammersley Inlet is a narrow channel at the western edge of the South Salish Sea, near Shelton, WA, spanning approximately 10 kilometers in length with an average depth of 7 meters. Hammersley Inlet serves as the only connection between Oakland Bay — a shallow, highly productive, fjord-like estuary — and the greater Salish Sea (Figure 1C). Hammersley Inlet is characterized by significant current exchange, with peak flow velocities reaching 2.2 m/s, resulting in river-like hydrology throughout much of the inlet (Albertson et al., 2012). By water course distance, the eastern mouth of Hammersley Inlet is > 300 km from the mouth of the Strait of Juan de Fuca, providing extremely limited connection to open ocean waters, and the inlet is characterized by prolonged water



residency times due to a combination of complex topography and intrabasin sills at several locations along this pathway (Khangaonkar et al., 2011). The west end of Hammersley Inlet is occupied by an industrial lumber mill, a marina, and other urban infrastructure.

2.2 Sampling

In response to anecdotal reports from recreational fishers, we employed a systematic approach to confirm the presence of soupfin sharks in Hammersley Inlet. We integrated fishing effort with opportunistic sampling of salinity and temperature within the inlet to identify environmental covariates associated with their occurrence outside of their previously known distribution. We used two primary fishing methods; multi-hook droplines deployed via research vessel and shore-based fishing using heavy tackle fishing rods. Hooks were baited with farmed Atlantic salmon (*Salmo salar*) and striped bonito (*Sarda orientalis*). These species were chosen because they are assumed prey in other systems but do not occur naturally within the study region (Klemetsen et al., 2003; Viñas et al., 2010); they can be excluded from any dietary analyses if observed in recovered stomach contents.

Each dropline consisted of a 8mm 3-strand nylon line, and from 1-3 PVC-coated wire leaders with baited circle hooks. This configuration was anchored with a 5kg weight then suspended from an inflatable PVC buoy and is designed to oscillate vertically signaling the presence of an animal on the line when deployed in calm inland waters. The baited hook was positioned between one and three meters above the anchor weight. This placement allowed water currents to impart a more lifelike movement to the bait, enhancing its attractiveness, and serving to minimize interactions with the benthic scavengers that also inhabit the inlet. For each sampling trip, the dropline sets were initially limited to a 30-minute duration and then were adjusted based on daily shark activity. This minimized the risk of predation on captured animals.

From shore, we utilized 3m casting rods rigged with 45kg breaking-strength monofilament fishing line, a 100g sinker, and leaders specially designed to target medium shark species. These leaders consisted of a 1m strand of braided steel wire covered in a translucent green nylon coating and a single barbless circle hook. The nylon coating's semi-transparent nature helps reduce the visibility of the leader underwater and protect the sharks from wire abrasions.

2.3 Data collection

Captured sharks were brought to the surface, restrained alongside the research vessel, and positioned into the direction of the tidal current flow to better irrigate seawater over the gills. Once properly positioned, we collected morphometric data (length, sex, clasper state, and biological tissue samples) from each individual. Sharks were measured (precaudal length, fork length, and total length [TL]). For male sharks, claspers were measured from their insertion to tip, and sexual maturity was determined based on the

degree of ossification in the inner structure and clasper length in relation to the pelvic fins (ICES, 2018). A small sample of tissue from the second dorsal fin was collected for genetic cataloging. Directly prior to release sharks were then tagged with uniquely numbered ID tags to aid in the identification of recaptured individuals.

Environmental covariates measured during sampling consisted of salinity (ppt) and temperature (°C), which were recorded using a YSI Pro30 (Yellow Spring Instruments Inc., USA). These measurements were taken at both the sea surface and sea floor to address potential vertical stratification and the effect of solar surface warming. Additionally, these data were collected opportunistically during periods within the inlet without soupfin shark catches. Tidal stage data was also recorded for each captured shark.

3 Results

During this exploratory study, we conducted 146 hook hours of effort over 8 field excursions to Hammersley Inlet, resulting in the capture of one soupfin shark, confirming the presence of this species outside of their known distribution. Despite the effectiveness of shore-based fishing efforts in capturing other elasmobranch species within the inlet, this method did not result in the capture of any soupfin sharks. Research vessel-based techniques were solely responsible for the capture of this species during our sampling efforts. The captured individual was a mature male measuring 153 cm in TL and was identified as *G. galeus* based on species-specific distinct morphological features. These include the specimen's large body size, small second dorsal fin which closely resembled the size and shape of the anal fin, and long terminal caudal lobe which markedly distinguishes the species from other members of Triakidae (Figure 2). Capture occurred at a depth of 8 m, ~2 m above the seafloor, with a sea surface temperature and sea surface salinity of 17.6°C and 22.5 ppt, respectively, and a seafloor temperature and seafloor salinity of 16.8°C and 22.8 ppt, respectively. The individual was encountered during a rising tide, 2.88 hours before high water. Genetic material, photos, capture location coordinates, and other encounter metadata were submitted to the University of Washington's Burke Museum fish collection (accession number 2023-003, catalog number UW202516).

4 Discussion

We present the first scientifically confirmed observation and capture of a soupfin shark in South Puget Sound, the southernmost extent of the Salish Sea, well outside of their previously described distribution (~300 km). These findings suggest that soupfin sharks are likely more pervasive in the Salish Sea than previously considered. There are two likely scenarios why the soupfin shark was not previously described in the Salish Sea: 1) this observation represents the first documentation of a species that has thus far evaded scientific surveys and significant fishing effort in a highly urbanized waterway, or, 2) this observation represents a potential emergence of the soupfin shark as a novel marine predator species in the Salish Sea.

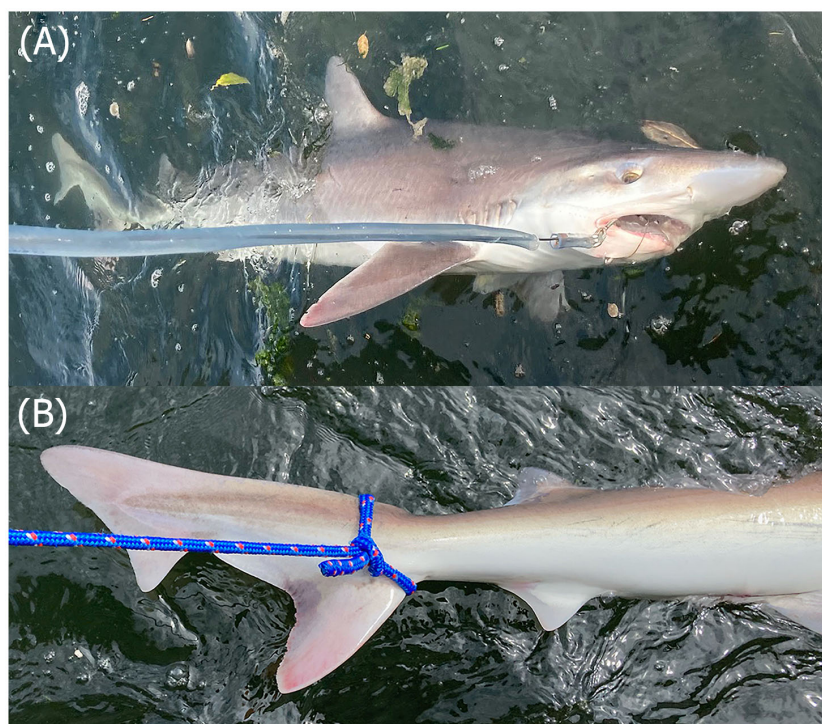


FIGURE 2

Photos of the captured 153 cm TL male soupfin shark (*Galeorhinus galeus*) in Hammersley Inlet, highlighting distinctive morphological characteristics of the (A) head, (B) tail, and second dorsal fin. Photos: (A) D. Lowry & (B) M. English.

It is conceivable that our observation of the soupfin shark in South Puget Sound represents the initial detection of an established but cryptic population of this highly mobile species within the Salish Sea (Scenario 1). However, we find this scenario unlikely. In this case, soupfin sharks would have to utilize habitats or exhibit behaviors that make them inaccessible to fishing gear (e.g., recreational, trawl, gillnet, longline gear), though these methods have been employed in the Salish Sea for over a century and are effective at catching soupfin in other regions. Further, soupfin sharks have not been observed on underwater video surveys within the Salish Sea, despite the efficacy of these methods in recording other shark species inhabiting the system (Lowry et al., 2022).

Instead, we suggest the presence of soupfin sharks likely represents an expansion of the seasonally occupied foraging habitat of this species (Scenario 2), potentially mediated by ongoing shifts in thermal conditions and prey species community composition within the Salish Sea. As a result of significant local anthropogenic pressure and influenced by broader climatological regimes and human-caused climate change, the Salish Sea has experienced pervasive shifts in trophic structure and species composition (Harvey et al., 2010; Greene et al., 2015; Ruggerone et al., 2019). For example, over the past century, the Salish sea forage fish community has been dominated by Pacific herring (*Clupea pallasii*), Pacific sand lance (*Ammodytes personatus*), surf smelt (*Hypomesus pretiosus*) and other smelt species (Osmeridae) (Kincaid, 1919; Therriault et al., 2009; Greene et al., 2015; Frick et al., 2022), while earlier accounts indicate periodic spikes in the abundance of Northern anchovy (*Engraulis mordax*) that were

closely correlated with increased sea surface temperature and likely primary productivity throughout the Salish Sea (Morin et al., 2023). Forage fish play a critical role in marine systems, facilitating the flow of energy from basal trophic levels to higher-order predators, while simultaneously exerting top-down effects through predation upon planktonic species and the early life stages of their predators (Cury et al., 2000; Hallfredsson and Pedersen, 2009; Minto and Worm, 2012; Pikitch et al., 2014). The most recent significant spike in anchovy abundance in the Salish Sea began around 2014, aligning with a period of elevated sea surface temperatures in the region (Amos et al., 2014; Duguid et al., 2019), simultaneous with the increase in anecdotal reports of soupfin sharks by recreational fishers, which prompted this investigation.

Though we only report one capture, it is important to note that our catch per unit effort (CPUE) may be understated; we balanced our sampling between soupfin sharks and broadnose sevengill sharks, which were also recently discovered to inhabit the inlet (Schulte et al., 2024). For example, the 14/0 and 16/0 hooks, which are sufficiently large to minimize bycatch, likely discriminated against smaller soupfin sharks which are more selective feeders. Bait quality and fishing gear conspicuity may have been limiting factors as well. Expanding upon this initial exploration, future work should use smaller size 5/0 and 10/0 hooks which have proven effective in capturing an increased number of soupfin sharks across numerous size and age classes in other regions (Eliás et al., 2005). Additionally, long-term acoustic tagging and monitoring has been utilized to identify highly migratory behavior and the periodicity of interannual site

fidelity in soupfin sharks in other regions (Nosal et al., 2021). Therefore, we recommend additional sampling efforts for this species, incorporating both satellite and acoustic tagging, to understand the residency and habitat utilization of soupfin sharks within the Salish Sea and connectivity to the broader Northeast Pacific.

Our work contributes to a preliminary understanding of soupfin shark distribution and habitat preferences within the Salish Sea ecosystem that can both inform our understanding of changing regional ecosystem dynamics and the management of this critically endangered shark species.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Ethics statement

The animal study was approved by Oregon State University IACUC-2023-0373. The study was conducted in accordance with the local legislation and institutional requirements.

Author contributions

EP: Conceptualization, Investigation, Visualization, Writing – original draft, Writing – review & editing, Data curation, Project administration. JS: Conceptualization, Investigation, Writing – review & editing, Data curation, Project administration, Writing – original draft. DL: Conceptualization, Investigation, Writing – review & editing, Data curation, Funding acquisition, Project administration, Resources, Writing – original draft. LH: Investigation, Writing – review & editing, Funding acquisition, Project administration, Resources, Writing – original draft. ME: Investigation, Writing – original draft, Writing – review & editing,

Data curation, Visualization. TC: Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing, Data curation, Funding acquisition, Project administration, Resources, Supervision.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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