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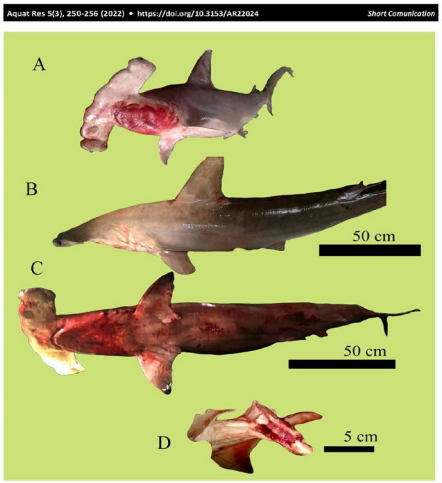

Figure 2. View of the specimen analyzed (A, B and C), clasper in extension and with mating hematomas (D). Photographs by Andrés Irigoyen-Sollis

U.S. DEPARTMENT OF COMMERCE
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INTRODUCTION

The Carolina hammerhead (*Sphyrna gilberti*) is a cryptic species that is externally morphologically identical to the scalloped hammerhead (*Sphyrna lewini*) (Quattro et al., 2006; 2013). The first record of the Carolina hammerhead is attributed to Gilbert (1967), who noted a single scalloped hammerhead captured off of South Carolina with an abnormally low vertebrae count. Molecular evidence of a cryptic lineage in the western North Atlantic was reported nearly forty years later in several studies (Abercrombie et al., 2005; Quattro et al., 2006; Duncan et al., 2006) that primarily used mtDNA in their analyses. The species was formally described shortly thereafter (Quattro et al., 2013), with the only distinguishing character between the two species being precaudal vertebrae count (83-91 in Carolina hammerheads, 92-99 in scalloped hammerheads). The validity of the species was later confirmed by reduced-representation genomics (Barker et al. 2019; 2021) and whole mtDNA sequencing (Grobler et al., 2023), with the latter study estimating a split between *S. gilberti* and *S. lewini* 3.8 - 10.8 million years ago. While the scalloped hammerhead has a circumglobal distribution, inhabiting temperate and tropical coastal and semi-oceanic waters (Compagno, 1984), the Carolina hammerhead (albeit most young-of-year and juveniles reported has been found in estuarine and nearshore waters off the southeastern United States (U.S.) with a few reported individuals found in Brazil and Trinidad and Tobago (Pinhal et al., 2012; Barker et al., 2021; Kingon and Portnoy, pers. comm.). The center of Carolina hammerheads young-of-year distribution appears to be in Bulls Bay, South Carolina, and this is the only known nursery area with a greater abundance of Carolina hammerheads (60%) relative to scalloped hammerheads (40%) (Barker et al., 2021). Relative abundance of Carolina hammerheads in nursery areas decreases in northern and southern areas with no Carolina hammerheads detected in the Tolomato River, Florida and relative abundance

only 5% Carolina hammerheads in Cape Canaveral, Florida. Despite extensive sampling, the Carolina hammerhead has not been detected in the Gulf of Mexico (Barker et al., 2021) and their full distribution in the Atlantic is unclear. The species has not yet been recorded in U.S. Caribbean jurisdictions; however, given the presence in more southern latitudes, this may be an artifact of sampling.

Similar to other sphyrnids, Carolina and scalloped hammerheads are viviparous with placentatrophy. Embryos are provided with energetic resources by their mothers in the form of a large liver. While basic life history information is deficient in terms of reproductive periodicity, gestational length, and fecundity, there is some indication that reproductive physiology may differ between species. Young-of-year comparisons found Carolina hammerheads to have both larger relative liver mass (hepatosomatic index) and higher liver lipid content in the earliest age classes of shark (Lyons et al., 2020), suggesting species-specific differences of female investment into each individual embryo. Since tradeoffs likely exist between number of offspring and quality of offspring, Carolina hammerheads may have potentially smaller litter sizes (lower fecundity) than scalloped hammerheads or produce smaller embryos (shorter length) at birth. Hypothesized differences in growth and reproduction is corroborated by field observations of Young-of-Years, where Carolina hammerheads are ~5 cm smaller on average than scalloped hammerheads (Lyons et al., 2020; Barker et al., 2021). In addition, timing of peak observations in nursery grounds of each species is offset, suggesting parturition windows may be different (Barker et al., 2021). However, confirmation of these hypotheses would be needed from directed reproductive studies of adult Carolina hammerheads.

Young-of-year growth (mass per fork length) appears to also be faster in scalloped than Carolina hammerheads, and data are needed to understand if the presumed larger length at birth

and faster growth rate lead to larger adults for scalloped compared to Carolina hammerheads. Nursery quality may also be important in the early life history for both species as growth appeared to be slower in sharks sampled from Florida compared to South Carolina (Lyons et al., 2020). A Carolina hammerhead growth curve was generated for a Hammerhead SouthEast Data, Assessment, and Review (SEDAR) stock assessment data workshop. However, insufficient samples exist to provide reliable information on growth, but estimates of maximum for Carolina hammerheads was 21 years (Frazier et al., 2021).

As genetically-confirmed records of Carolina hammerheads are restricted to the youngest life stages, most biological information on this cryptic species to date has been gathered during their early life history. A study investigating the feeding ecology of young-of-year scalloped and Carolina hammerheads found resource partitioning in nurseries does not occur, with stomach content analysis showing a similar generalist diet in shared nursery grounds (Galloway et al., in prep). In addition to stomach content analysis, stable isotope analysis was used to make inferences on adult female hammerhead feeding ecology using stable isotope signatures gleaned from YOY captured in nursery areas. Using maternally influenced isotopic signatures, they found resource and/or spatial partitioning likely occurs between mature female scalloped and Carolina hammerheads. Differences in muscle δ13C and δ15N between species suggests that either mature individuals primarily feed from different food webs or share prey items but segregate spatially (Galloway et al., in prep.).

Overall, many data gaps exist and limit the ability to assess the health of the population(s) of this species across its range. As such, this species is currently listed as Data Deficient by the International Union for the Conservation of Nature (IUCN) (VanderWright et al., 2020) and independent stock assessments of this species in the US have not been able to be conducted.

WORKSHOP OUTLINE

A workshop was held in Atlanta, GA, at the Georgia Aquarium on the 6th and 7th of November, 2023, with the primary aim of outlining current information on the species, identifying current knowledge and data gaps, threats, and research directions with the goals of developing a conservation strategy to aid future researchers a guide for directing research.

The first day of the workshop consisted of exercises to brainstorm information that we do know and how we know it, information gaps and how we may be able to fill them, and to identify major threats. The information resulting from these exercises is summarized throughout this document. Based on the results of the exercises, the participants generated research priorities that would ultimately help fill identified data and knowledge gaps.

The second day, the participants began drafting the knowledge document before conducting morphometric and anatomical comparisons. These comparisons were between YOY scalloped and Carolina hammerhead specimens. Findings from the specimen comparisons can be found in Table 1.

DATA GAPS

A fair number of information gaps exist surrounding basic life history, ecology and physiology of the Carolina Hammerhead, which mainly stems from the lack of easy-to-determine external morphology by which to distinguish the species from the scalloped hammerhead. Data regarding these important biological characteristics require both directed and increased collaborative efforts. However, of top priority is either a revised morphological key or the

creation of a rapid genetic test for real-time field identification. Assuming one or both of these can be generated, there are several areas in need of description.

THREATS

Similar to the scalloped hammerhead, the most significant threat to the Carolina hammerhead is catch and bycatch in commercial and recreational fisheries. Juvenile and adult scalloped hammerhead sharks have at-vessel mortality rates of 62.9% when caught on bottom longlines (Gulak et al., 2015) and post-release mortality rates of 69.2% (Courtney et al., 2021). Larger scalloped hammerheads are also captured directly and as bycatch in recreational hook and line fisheries. Some states (e.g. Florida) require sharks be released alive after landing but hammerheads still suffer mortality especially if handling of the animal is poor (e.g. dragging it on the beach to remove the hook). Whitney et al. (2021) determined a post-release mortality rate of 11.8% from three directed electronic tagging studies of great hammerheads (*Sphyrna mokarran*) released alive from recreational gear as a minimum estimate of the mortality rate for hammerheads captured and released alive with recreational gear. Young-of-the-year and smaller juvenile hammerheads are also captured as bycatch in gillnet and trawl fisheries. While no estimates of mortality are available, it is assumed to be very high given the long trawl tow (Scott-Denton et al. 2012) and gillnet soak times (Courtney et al., 2021). While there are no species-specific estimates of mortality for Carolina hammerheads, due to their similarities with scalloped hammerhead, the workshop assumed the estimates for scalloped hammerheads would be similar to Carolina hammerheads. In addition, while most US states currently ban the use of nets in states waters which can provide a refuge for smaller hammerheads, outside US waters in areas like the Caribbean where Carolina hammerheads have been documented (e.g. Trinidad), fishing

mortality from artisanal fisheries is likely high. In addition to mortality associated with fisheries, as a species that uses coastal nurseries, Carolina hammerheads may suffer from habitat loss due to climate change or anthropogenic modifications.

Natural threats to Carolina hammerheads were also identified at the workshop. Competition with scalloped hammerheads for space and food as well as the hybridization of scalloped with Carolina hammerheads (Barker et al., 2019) could reduce the viability of the Carolina hammerhead population.

RESEARCH PRIORITIES/FUTURE DIRECTIONS

- The ability to distinguish Carolina hammerheads from scalloped hammerheads in the field is critical to management and conservation efforts. Traditional ratio-based morphometric analyses produced no viable distinguishing characters, but additional efforts should include investigating other morphological characters that may be useful in distinguishing the two species through ontogeny. In addition, the development of genetic assays that are field ready and could be used by observers on commercial vessels as well as recreational fishers would be helpful.

- Collection of tissues for genetic analyses have been geographically limited, primarily to the region from North Carolina to Florida of the U.S. Increased sample collection from Virginia north along the east coast of the U.S. as well as throughout the greater Caribbean basin, Central America, and northern South America is critical to understanding the distribution and stock structure of the Carolina hammerhead.

- Telemetry studies using satellite transmitters (SPOT and PSAT) are needed to understand spatial and vertical habitat use patterns and determine the core distribution of adult Carolina hammerheads and to assess how these patterns compare with those of scalloped hammerheads. Morphological or molecular field assays to reliably identify the species are critical for tags to be confidently and judiciously deployed on target species.

- Increased genetic sample collection by fisheries observers and port samplers throughout the known range of the Carolina hammerhead is needed to assess interactions with longline, trawl and gillnet fisheries and estimate directed fishing and bycatch mortality.

- Life history research to understand the age, growth, and reproductive biology of the Carolina hammerhead is needed to assess the species vulnerability to overfishing and how these characteristics compare to scalloped hammerheads. To facilitate this, biological sample collection from known Carolina hammerheads is needed by researchers, port samplers and observers.

ANATOMICAL EXAMINATION

Six genetically-identified specimens (previously frozen) were examined in detail for any distinguishing morphological features (Table 1). No clear difference was found between peduncle height and length, contrary to former reports (Rosales-Vasquez 2022). Pre-caudal vertebral counts were performed on each specimen via X-ray images (Figure 1). Genetically-confirmed Carolina and scalloped hammerheads had the expected number of pre-caudal vertebrae (84-87 versus 96, respectively). Interestingly, the hybrid specimen had vertebral counts

consistent with scalloped hammerhead (97) along with a number of vertebral deformities (fused vertebrae; Figure 2).

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Table 1. Morphometrics taken of six genetically-identified individuals specimens examined at Georgia Aquarium.

Specimen ID	Species	Cephalofoil Width (mm)	Peduncle Height (mm)	Fork Length (mm)	Stretch Total Length (mm)	Precaudal Vertebrae (#)
SC-4080	Carolina	120.6	16.12	293	388	86
SC-4082	Carolina	137.98	20.75	356	465	84
SC-4092	Carolina	133.01	19.48	365	473	87
SC-4091	F1 Hybrid	158.7	20.3	400	521	97
SC-4088	Scalloped	166.9	26.07	425	572	96
SC-4093	Scalloped	151.86	24.08	412	537	96

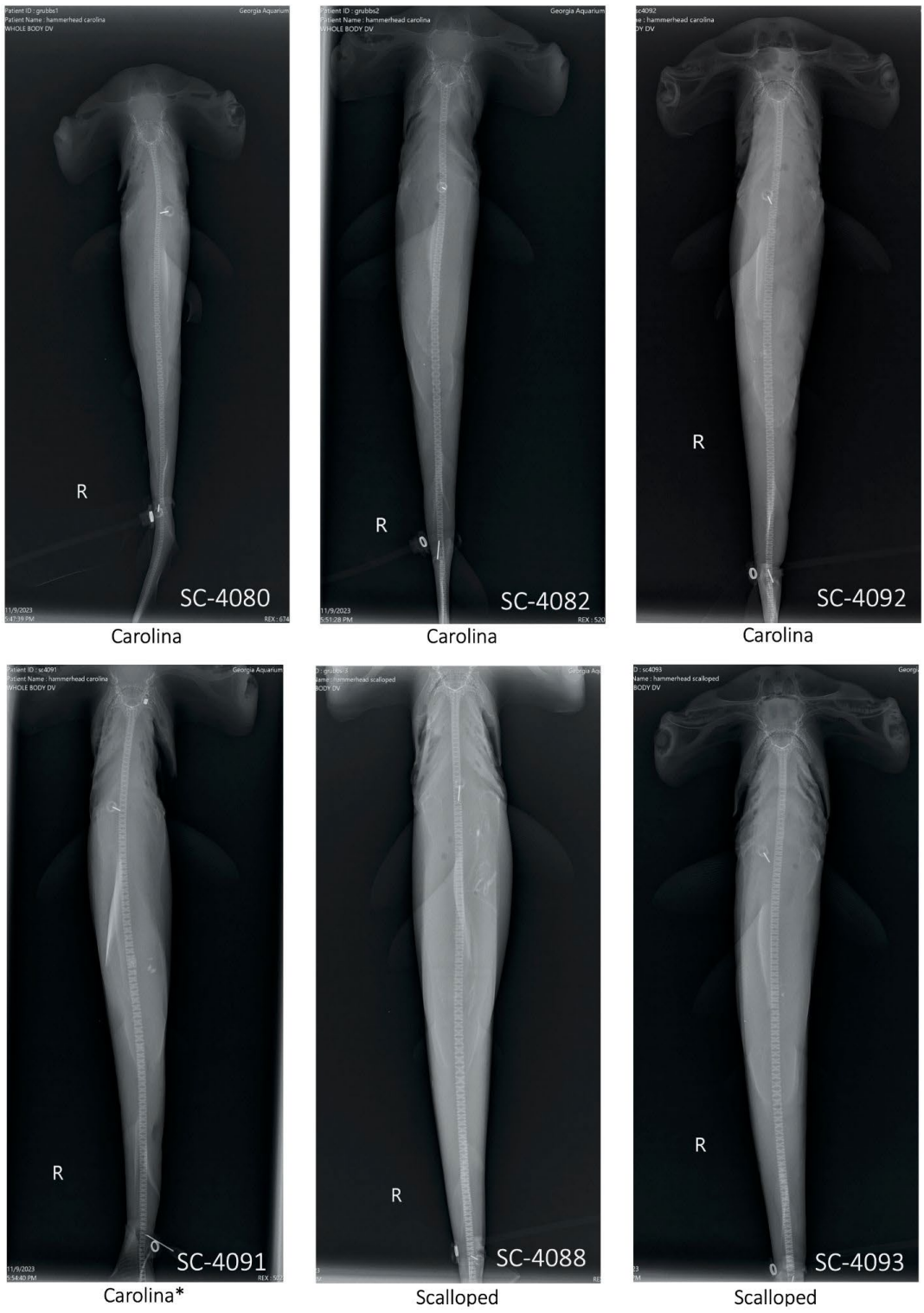

Figure 1. Dorsal X-rays taken of six young-of-year hammerheads for pre-caudal vertebral counts. Specimen identification is provided in lower right-hand corner and species below each photograph.

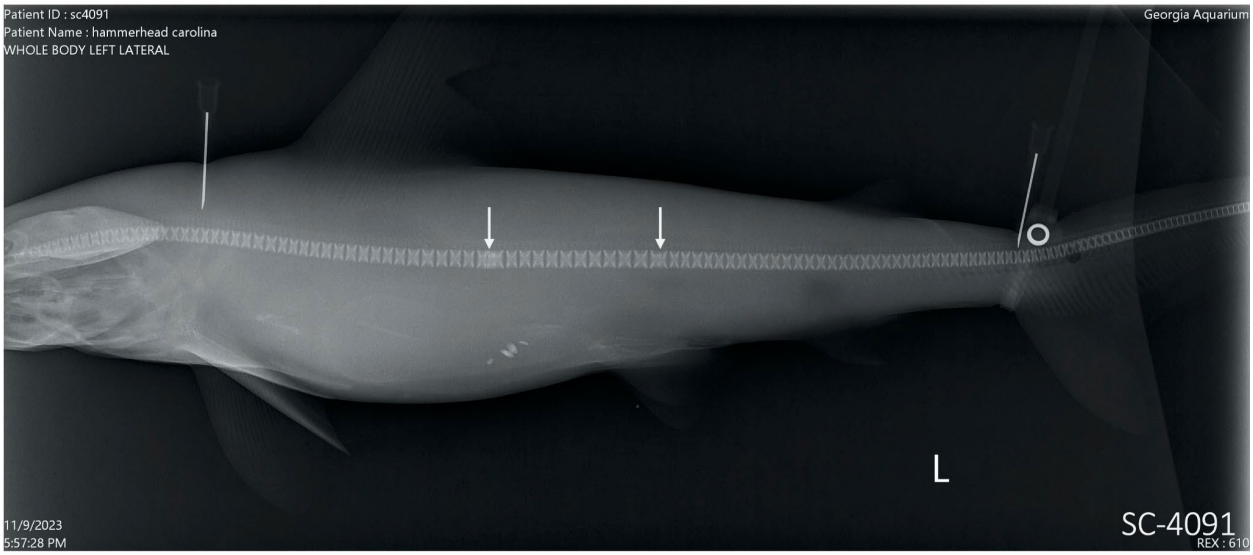

Figure 2. Lateral view of SC-4091 (potential hybrid). Arrows indicate vertebral deformities (fusions).

Appendix I: Workshop agenda

Monday, November 6th, 2023 to Tuesday, November 7th, 2023
Georgia Aquarium, Atlanta

Monday 6th November 2023
Day 1

TIME	TITLE	OBJECTIVES	FORMAT	LEADER
8:30	**BREAKFAST AVAILABLE**			
9:00	Welcome	Welcome & introduction	Lecture	KH
9:05	Patricipant introductions	Provide an opportunity for participants to introduce themselves and share their area of expertise/experience, both generally and in regard to Carolina HH	Discussion	KH
9:15	Icebreaker	Icebreaker activity	Activity	KH
9:30	Overview of objectives, goals, and products	Quick overview of the meeting objectives and goals, the agenda and tools we'll use, and the final product	Discussion	KH
9:45	Document Detail	Discuss knowledge document preferences - layout, format, sections, other contributors, etc.	Discussion	KH
10:00	What do we know? How do we know it?	Work as a group to brainstorm everything we know about Carolina HH and how we know it (publication, raw data, anecdotal, etc)	Activity/Discussion	KH
10:45	**BREAK**			
11:00	What don't we know? How could we find it out?	Work as a group to brainstorm everything we do not know and ways to find out	Activity/Discussion	KH
11:45	**LUNCH**	Walk to Margaritaville for lunch		
1:15	What do we assume?	Work as a group to brainstorm everything we assume about Carolina HH and why (similar species does it? Etc.)	Activity/Discussion	KH
2:15	Threats Analysis	Conduct a threats analysis to determine threats to the species	Activity	KH
3:30	**BREAK**			
3:45	Information Recap	Go over information generated and clarify or remove any information as needed	Discussion/Activity	KH
4:15	Who does what?	Determine responsibility of document sections and timelines	Discussion	KH
4:30	Parking lot	Discuss any issues that may have arisen throughout the day and been placed in the parking lot	Discussion	KH
4:45	Recap & wrap-up	Recap and refresh on outcomes from today's sessions, next steps, timelines, and owners of tasks.	Lecture	KH
5:00	**END**			

Tuesday 7th November 2023
Day 2

TIME	TITLE	OBJECTIVES	FORMAT	LEADER
8:30	**BREAKFAST AVAILABLE**			
9:00	Knowledge recap	Recap day 1 and the information generated	Discussion	KH
9:15	Document work	Individually begin working on agreed upon sections	Individual work	KH
11:45	**LUNCH**	Walk to lunch at Ted's		
1:30	**EXAMINATIONS**	Specimen examinations in the necropsy suite		
5:00	**END**			