Received: 24 August 2024 | Revised: 13 November 2024 | Accepted: 14 November 2024
DOI: 10.1111/jfb.16012

BRIEF COMMUNICATION

JOURNAL OF FISH BIOLOGY fsbi

Spinal deformity in a whale shark, *Rhincodon typus* (Smith 1828), encountered in the northern Gulf of Mexico, with notes on its movement patterns

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Funding information
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Abstract

This note details the first formal report of a spinal deformation in whale sharks, *Rhincodon typus*. An individual whale shark with suspected kypholordoscoliosis was observed at Ewing Bank in the Gulf of Mexico during aggregation events in 2010 and 2013. Despite the significant deformity, the shark was observed feeding on fish eggs at the surface during both encounters. Based on satellite tag tracking, its movements, temperature preferences, and depth use were within the range of other whale sharks from the region.

KEYWORDS

depth, Ewing Bank, kyphosis, lordosis, scoliosis, temperature

Historically, the incidence of morphological abnormalities reported in elasmobranch fishes was relatively low (Heupel et al., 1999; Hoenig & Walsh, 1983); however, more recently, occurrences of these abnormalities have been more widely reported (e.g., Moore, 2015; Narváez & Osaer, 2016; Pérez et al., 2018; Ranjith et al., 2019). Most reported elasmobranch abnormities can be categorized as partial or complete albinism/leucism (e.g., Clark, 2002; Jones et al., 2016; Sandoval-Castillo et al., 2006); morphological deformities related to the development of head and fins (e.g., Driggers et al., 2012; Jones et al., 2017; Lamarca et al., 2017; Moore, 2015; Ranjith et al., 2019); and spinal deformities, including fused vertebrae and spinal curvature (e.g., Clark, 1964; Heupel et al., 1999; Hoenig & Walsh, 1983; Officer et al., 1995; Pérez et al., 2018; Thorburn & Morgan, 2004). Spinal deformities in sharks are reported more often in the embryonic stage (Dos Santos & Gadig, 2014; Driggers et al., 2012; Lopes et al., 2020; Zaera & Johnsen, 2011) and tend to be incompatible with survival. As a result, mature individuals with congenital deformities are infrequently observed in the wild (Afonso et al., 2016; Mancini et al., 2006; Moore, 2015).

Spinal deformities have been reported in a range of free-living shark species from the following families: Carcharhinidae (Afonso et al., 2016; Clark, 1964; Heupel et al., 1999; Moore, 2015; Schwartz, 1973; Thorburn & Morgan, 2004), Squatinidae (Pérez et al., 2018), Triakidae (Heupel et al., 1999; Officer et al., 1995), Odontaspidae (Anderson et al., 2012; Tate et al., 2013), and Hemiscyllidae (Heupel et al., 1999). Reported skeletal deformities in elasmobranchs are most often associated with lateral spinal curvature (scoliosis), a dorsal/convex spinal curvature (kyphosis), a ventral/

concave spinal curvature (lordosis), or vertebral fusion (Hadfield & Clayton, 2021; Heupel et al., 1999; Hoenig & Walsh, 1983; Moore, 2015). Sometimes, an individual can exhibit a combination of these spinal deformities. For example, Thorburn and Morgan (2004) reported a northern river shark *Glyphis* sp. (Agassiz 1843), with vertebral fusion and resultant kyphosis. Driggers et al. (2012) found an embryonic blacktip shark *Carcharhinus limbatus* (Müller and Henle 1839) with kypholordoscoliotic deformities (i.e., lateral, dorsal/convex, and ventral/concave spinal curvature), and Pérez et al. (2018) described two angel sharks *Squatina squatina L.* 1758 with kyphoscoliotic deformities. The direct cause of many of these skeletal deformities in elasmobranchs is unknown and can be multifactorial. Possible causes include trauma (e.g., fractures, luxations, subluxations, and compression), disease (e.g., bacterial, fungal, or fungal-like infections), degenerative disease (e.g., arthritis, proliferation, and lysis), genetic abnormality (e.g., fusion), neoplasia, nutritional deficiencies (e.g., malnutrition or obesity), environmental stressors, and marine contaminants (Afonso et al., 2016; Hadfield & Clayton, 2021; Heupel et al., 1999; Ochoa-Díaz et al., 2016; Pérez et al., 2018; Schwartz, 1973).

The whale shark *Rhincodon typus* (Smith, 1828) is a large-bodied, epipelagic filter feeder with a circumglobal distribution in warm temperate and tropical marine waters (Compagno, 2001; Rowat & Brooks, 2012). Their surface-oriented behavior has made them susceptible to ship strikes and entanglement in fishing and marine seismic survey gear (Pierce and Norman, 2016; Womersley et al., 2022). The IUCN designated whale sharks as endangered due to a more than 50% decline in global population numbers over the past 75 years (Pierce and Norman, 2016). Due to their declining status, whale sharks are also included in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES; www.cites.org), as well as Appendices I and II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS; www.cms.int). In the western Atlantic Ocean, whale sharks are relatively common in the continental shelf edge and slope waters of the Gulf of Mexico and tend to form large aggregations of primarily immature males during certain times of the year (Hoffmayer et al., 2007; Hoffmayer et al., 2021; McKinney et al., 2012). In 2010, during regular whale shark distribution monitoring in the northern Gulf of Mexico (initiated in 2003), an individual whale shark with a spinal deformation was observed during an aggregation event. The individual was encountered again in 2013 and was satellite-tagged to monitor its movement and behavior. This communication documents this rare incidence of a spinal deformation reported for a large-bodied shark in the wild and details the animal's movements compared to other tracked whale sharks without deformity throughout the Gulf of Mexico.

While conducting regular monitoring and tagging work at Ewing Bank, a known whale shark aggregation site in the northern Gulf of Mexico, on June 22, 2010, we encountered an individual with suspected kypholordoscoliotic deformities. Data collected included estimated total length (m), sex, and spot-pattern photographs for submission into the Sharkbook: Wildbook for Sharks database (www.sharkbook.ai). On June 10, 2013, a whale shark with similar spinal deformities was encountered, and estimated total length, sex, and spot-pattern photographs were collected. Further, a pop-up satellite archival transmitting (PSAT) tag (x-tag, Microwave Telemetry, Inc.) that was scheduled to track for 180 days (see Hoffmayer et al., 2021 for additional tagging and track processing details) was attached to the individual for movement and behavior monitoring (see Tag 128787 in Hoffmayer et al., 2021). The care and use of experimental animals complied with Institutional Animal Care and Use Committee animal welfare laws, guidelines, and policies as approved by the University of Southern Mississippi (09031204 and 11092203), and tagging was covered under the National Marine Fisheries Service Highly Migratory Division Exempted Fishing permit SHK-SRP-13-01.

Photo-identification analysis determined that our repeated encounters were of the same individual. The photos from the first encounter in 2010 (Figure 1a,b) did not match the spot pattern of any whale sharks in the Wildbook for Sharks database and the shark was deemed a new entry with GC-030 as its identification number. Photographs of the whale shark's spot pattern from the 2013 encounter (Figure 1c,d) matched the spot pattern of GC-030. Images of the shark show that the suspected kypholordoscoliotic deformity originates anterior to the origin of the first dorsal fin and creates a ventral vertebral subluxation that shifts dorsally again up to the base of the second dorsal fin (Figure 1). In both 2010 and 2013, this individual was estimated to be 6.0 m in total length, and based on the claspers beginning to elongate past the posterior margin of the pelvic fin, it was deemed a subadult male.

Visual observation during the encounters revealed the individual feeding on fish eggs at the water's surface, similar to all other whale sharks in the aggregation. The deformity did not appear to affect its ability to maintain position in the water column and maneuver while feeding (Supplemental Video S1). The activity level of a given species (e.g., reliance on swimming activity to catch prey and evade predators) and the location and severity of a spinal deformity are two main factors influencing the health and survival of affected individuals. For example, spinal deformities in species that rely heavily on swimming abilities to capture prey, such as pelagic sharks, could cause substantial negative impacts on their survival, whereas benthic predators, such as angel sharks, may be less impacted (Afonso et al., 2016; Moore, 2015; Pérez et al., 2018). Pérez et al. (2018) reported the first case of spinal deformities in two specimens of angel sharks, *S. squatina*, from the Canary Islands, with kyphoscoliotic curvatures in their spines. Because angel sharks are ambush predators, they may not have been as impacted, as swimming agility and maintaining position in the water column are not essential for ambush prey capture (Pérez et al., 2018). Clark (1964) and Schwartz (1973) reported spinal deformities in mature bull sharks *Carcharhinus leucas* (Müller and Henle 1839). They suggested that the spinal deformities observed probably affected the swimming performance of the sharks, but both individuals survived to adulthood, indicating the deformity did not impede survivability. Similarly, Afonso et al. (2016) and Moore (2015) reported spinal deformities in the caudal regions of two adult bull sharks and three adult blacktip sharks, respectively, and suggested the

FIGURE 1 Photographs of the whale shark, *Rhincodon typus*, with kypholordoscoliotic deformities from encounters in (a, b) 2010 and (c, d) 2013.

deformities were relatively minor and must have had limited impact on their swimming activity, as all appeared to be healthy despite the spinal deformities. Conversely, several reports of spinal deformities in shark embryos have been reported, with most representing severe deformations that would not be compatible with survival (Dos Santos & Gadig, 2014; Driggers et al., 2012; Lopes et al., 2020; Zaera & Johnsen, 2011).

Although spinal deformities change the body shape of affected sharks and increase the drag an animal experiences while swimming, whale sharks do not have a great need for speed compared to their prey, like other pelagic sharks, as they are filter feeders (Colman, 1997; Compagno, 2001; Taylor, 1996). The PSAT tag attached to the shark reported herein confirmed routine movement and behavior. The tag remained attached to the individual for 98 days, and during this time, the shark traveled 2062 km (e.g., total track displacement) across the Gulf of Mexico. The shark remained along the continental shelf edge and slope waters of the northwestern Gulf of Mexico during summer. It then moved into the southern Gulf of Mexico during the fall, where the tag popped off in Campeche Bay, Mexico (Figure 2a). Based on the tagging data, the shark spent 85% of its time between 26 and 30°C and 96% of this time in the top 100 m of the water column (Figure 2b). Although whale sharks are typically solitary outside of feeding aggregations, the behavior of this shark showed similar movement and water temperature preferences compared to other whale sharks in the Gulf of Mexico. Based on the PSAT data, the shark's daily rate of movement (21.3 ± 1.5 km day^{-1}) was within the normal range of other whale sharks in the region (Hoffmayer et al., 2021; Hueter et al., 2013). Five additional whale sharks tagged during the 2013 encounter exhibited similar daily movement rates ranging from 17.1 to 24.1 km day^{-1} (Hoffmayer et al., 2021). The spinal deformity did not appear to result in this individual being unable to transit long distances, as it was one of three of the tagged sharks from the 2013 encounter that moved 145 km west to Bouma Bank approximately 30 days later (Hoffmayer et al., 2021). Furthermore, the temperature and depth preferences derived from the tagging data (Figure 2b) were well within the mean temperature and depth ranges reported for whale sharks tagged in the region (Graham & Roberts, 2007; Tyminski et al., 2015; E. Hoffmayer unpublished data). Finally, based on the estimated total length of 6.0 m, the whale shark survived to subadulthood.

The shark's swimming pattern, daily rate of movement, long-distance movements throughout the Gulf of Mexico, and temperature and depth preferences all support that this shark survived and thrived despite the spinal deformities. Although reports of spinal deformities in mature sharks in the wild are relatively rare, they are becoming more widely reported in sharks in captivity (Delaune et al., 2021; Huber et al., 2013;

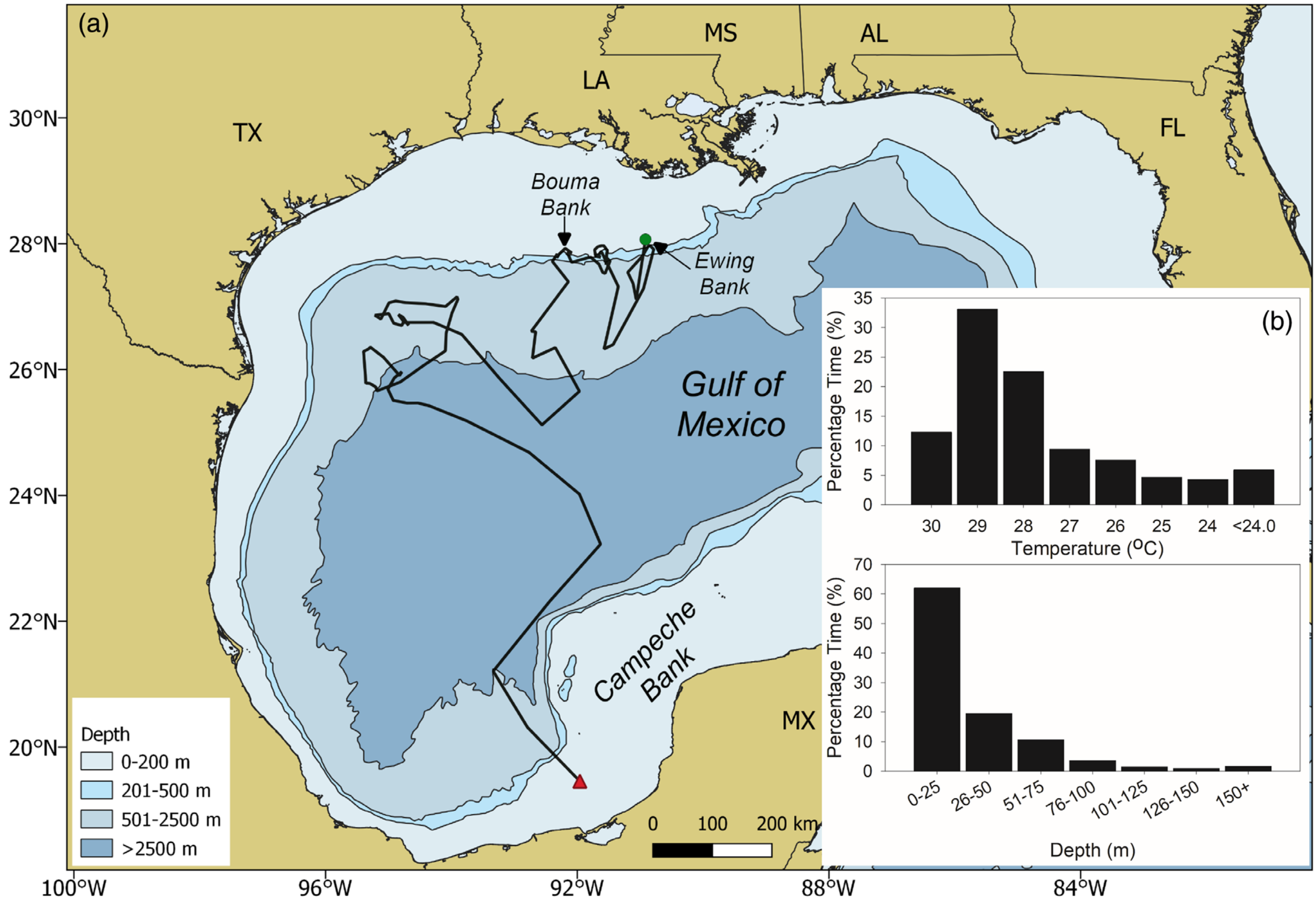

FIGURE 2 (a) The Gulf of Mexico map shows satellite tag-based movements for a whale shark, *Rhincodon typus*, with kypholordoscoliotic deformities. The green circle denotes the tagging location (Ewing Bank), and the red triangle denotes the pop-off location. (b) Histograms of time spent at temperature (°C; top) and depth (m; bottom) used during the track shown in (a).

Preziosi et al., 2006; Tate et al., 2013), and one of the contributing factors is trauma sustained from capture (Anderson et al., 2012; Preziosi et al., 2006; Tate et al., 2013). Although trauma caused by a ship strike or entanglement in fishing gear occurring early in the life of the shark cannot be definitively ruled out, direct observation of this whale shark in the wild on two occasions and further inspection of photographs and videos showed no obvious indication of this level of trauma (e.g., scarring or restitching of the spot pattern), suggesting the spinal deformities were most likely indicative of being congenital, having slowly progressed over time. Ultimately, without advanced radiographic diagnostics, it is difficult to discern the origin of the deformities. This whale shark has survived in a pelagic habitat replete with large predators, and it would be suspected that decreased swimming efficiency, especially at a small size, would also significantly decrease its survivability. However, young whale sharks are born at a size of 40–70 cm total length (Joung et al., 1996) and are thought to occupy deep water habitats during the initial years of their lives to increase prey consumption and reduce the incidence of predator encounters (Rowat et al., 2008). This could explain how this whale shark survived this critical life stage with these spinal deformities. A whale shark with an albinism/leucism abnormality survived to adulthood and was observed swimming in waters surrounding the Galapagos Islands on August 25, 2007 (Rohner et al., 2022). The physical anomaly removed its camouflage capabilities (Wilson & Martin, 2003) and could have made the whale shark more susceptible to predation. However, living at deeper depths may have minimized their vulnerability to predators until they achieved the juvenile size of 2 m when they would be less susceptible.

Although the movements and habitat use patterns of the individual reported here are unknown for its early life, this whale shark has survived to subadulthood in its environment and has exhibited normal feeding behaviors, habitat use, and depth preferences. This report makes the case that other animals with seemingly substantial injuries or deformities could be tagged with satellite tags to determine if they also model normal behaviors. In addition, repeat encounters of individuals with similar spinal deformities over time may allow for the determination of how their fitness and health are influenced by these conditions, highlighting the importance of citizen scientists reporting these encounters on platforms such as www.sharkbook.ai

AUTHOR CONTRIBUTIONS

E.R.H., J.S.F., J.A.M., and J.M.H. designed the study and secured the funding. E.R.H., B.J.F., J.M.H., and J.A.M. performed the fieldwork to generate the data. E.R.H. and J.A.M. performed the data analysis.

E.R.H., W.B.D., J.P.S., and J.S.F. interpreted the results, and all authors contributed to the manuscript and provided final approval for the publication of this manuscript.

ACKNOWLEDGMENTS

We wish to thank B. Schumaker of On Wings of Care, and T. Collins and D. Abrams for being our eyes in the sky, helping spot the whale sharks. We would also like to thank volunteers P. Sweat, P. Kent, and B. Ball. Finally, we are indebted to the following individuals who supported this research, including J. Levenson, S. Earle, R. Nixon, and B. Groark.

REFERENCES

Afonso, A. S., Niella, Y. V., Cavalcanti, E., Andrade, M. B., Afonso, J. S., Pinto, P. S., & Hazin, F. H. V. (2016). Spinal deformities in free-ranging bull sharks, *Carcharhinus leucas* (Müller and Henle, 1839), from the western South Atlantic Ocean. *Journal of Applied Ichthyology*, *32*(6), 1217–1220.

Anderson, P. A., Huber, D. R., & Berzins, I. K. (2012). Correlations of capture, transport, and nutrition with spinal deformities in sandtiger sharks, *Carcharias taurus*, in public aquaria. *Journal of Zoo and Wildlife Medicine*, *43*(4), 750–758.

Clark, E. (1964). Spinal deformity noted in bull shark. *Underwater Naturalist*, *2*, 25–28.

Clark, S. (2002). First report of albinism in the white-spotted bamboo shark, *Chiloscyllium plagiosum* (Orectolobiformes: Hemiscyllidae), with a review of reported color aberrations in elasmobranchs. *Zoo Biology: Published in Affiliation with the American Zoo and Aquarium Association*, *21*(6), 519–524.

Colman, J. G. (1997). A review of the biology and ecology of the whale shark. *Journal of Fish Biology*, *51*, 1219–1234. https://doi.org/10.1111/j.1095-8649.1997.tb01138.x

Compagno, L. J. V. (2001). *Sharks of the world: An annotated and illustrated catalogue of shark species known to date: Heterodontiformes, Lamniformes, Orectolobiformes*. FAO Species Catalogue for Fishery.

Delaune, A. J., Perry, S. M., Tims, M. B., Cole, G. C., Cox, J. T., Smith, J. D., Lowrey, J., & Boylan, S. M. (2021). Successful spinal surgery in a sand Tiger (*Carcharias taurus*) shark. In *Proceedings from the 2021 Meeting of the International Association for Aquatic Animal Medicine*. Veterinary Information Network. https://www.vin.com/apputil/project/defaultadv1.aspx?pid=27093&catid=&id=10200669&meta=generic&authorid=

Dos Santos, C. M. H., & Gadig, O. B. F. (2014). Abnormal embryos of sharpnose sharks, *Rhizoprionodon porosus* and *Rhizoprionodon lalandii* (Elasmobranchii: Carcharhinidae), from Brazilian coast, western South Atlantic. *Marine Biodiversity Records*, *7*, e55.

Driggers, W. B., III, Hannan, K. M., Hoffmayer, E. R., & Jensen, J. (2012). Abnormal blacktip shark, *Carcharhinus limbatus*, embryo from the northern Gulf of Mexico. *Journal of Applied Ichthyology*, *28*(5), 827–828.

Graham, R. T., & Roberts, C. M. (2007). Assessing the size, growth rate and structure of a seasonal population of whale sharks (*Rhincodon typus* Smith 1828) using conventional tagging and photo identification. *Fisheries Research*, *84*, 71–80. https://doi.org/10.1016/j.fishres.2006.11.026

Hadfield, C. A., & Clayton, L. A. (2021). *Clinical guide to fish medicine* (p. 624). Wiley-Blackwell.

Heupel, M. R., Simpfendorfer, C. A., & Bennett, M. B. (1999). Skeletal deformities in elasmobranchs from Australian waters. *Journal of Fish Biology*, *54*(5), 1111–1115.

Hoenig, J. M., & Walsh, A. H. (1983). Skeletal lesions and deformities in large sharks. *Journal of Wildlife Diseases*, *19*(1), 27–33.

Hoffmayer, E. R., Franks, J. S., Driggers, W. B., III, Oswald, K. J., & Quattro, J. M. (2007). Observations of a feeding aggregation of whale sharks, *Rhincodon typus*, in the north central Gulf of Mexico. *Gulf and Caribbean Research*, *19*(2), 69–73.

Hoffmayer, E. R., McKinney, J. A., Franks, J. S., Hendon, J. M., Driggers, W. B., III, Falterman, B. J., Galuardi, B., & Byrne, M. E. (2021). Seasonal occurrence, horizontal movements, and habitat use patterns of whale sharks (*Rhincodon typus*) in the Gulf of Mexico. *Frontiers in Marine Science*, *7*, 598515. https://doi.org/10.3389/fmars.2020.598515

Huber, D. R., Neveu, D. E., Stinson, C. M., Anderson, P. A., & Berzins, I. K. (2013). Mechanical properties of sand tiger shark (Carcharias taurus) vertebrae in relation to spinal deformity. *Journal of Experimental Biology*, *216*(22), 4256–4263.

Hueter, R. E., Tyminski, J. P., & de la Parra-Venegas, R. (2013). Horizontal movements, migration patterns, and population structure of whale sharks in the Gulf of Mexico and northwestern Caribbean Sea. *PLoS One*, *8*, e71883. https://doi.org/10.1371/journal.pone.0071883

Jones, C. M., Driggers, W. B., III, Hoffmayer, E. R., & Galle, L. E. (2017). Capture of a one-eyed bull shark, *Carcharhinus leucas* (Valenciennes 1839), from the northern Gulf of Mexico. *Gulf and Caribbean Research*, *28*(1), SC8-SC11.

Jones, C. M., Hoffmayer, E. R., & Gropp, R. P. (2016). First record of a leucistic *Narcine bancrofti* (Elasmobranchii, Narcinidae) from the northern Gulf of Mexico. *Cybium*, *40*(3), 249–251.

Joung, S. J., Chen, C. T., Clark, E., Uchida, S., & Huang, W. Y. (1996). The whale shark, *Rhincodon typus*, is a livebearer: 300 embryos found in one 'megamamma'supreme. *Environmental Biology of Fishes*, *46*, 219–223.

Lamarca, F., Ribeiro, N., Galheigo, F., & Vianna, M. (2017). The first record of *Diprosopus tetrophthalmus* in the South Atlantic Ocean: The case of *Prionace glauca* (Elasmobranchii: Carcharhiniformes: Carcharhinidae) in Brazil. *Acta Ichthyologica et Piscatoria*, *47*(4), 385–389.

Lopes, E. Q., Valverde, C., de Mello, L. H. C., de Lima, T. G., & de Melo, L. F. (2020). Record of morphological abnormality in embryos of Caribbean sharpnose shark, *Rhizoprionodon porosus* (Elasmobranchii, Carcharhinidae), from the south coast of São Paulo state, Brazil. *Brazilian Journal of Animal and Environmental Research*, *3*(3), 1844–1854.

Mancini, P. L., Casas, A. L., & Amorim, A. F. (2006). Morphological abnormalities in a blue shark *Prionace glauca* (Chondrichthyes: Carcharhinidae) foetus from southern Brazil. *Journal of Fish Biology*, *69*(6), 1881–1884.

McKinney, J. A., Hoffmayer, E. R., Wu, W., Fulford, R., & Hendon, J. M. (2012). Feeding habitat of the whale shark *Rhincodon typus* in the northern Gulf of Mexico determined using species distribution modelling. *Marine Ecology Progress Series*, *458*, 199–211.

Moore, A. B. M. (2015). Morphological abnormalities in elasmobranchs. *Journal of Fish Biology*, *87*(2), 465–471.

Narváez, K., & Osaer, F. (2016). Morphological and functional abnormality in the spiny butterfly ray *Gymnura altavela*. *Marine Biodiversity Records*, *9*(1), 1–4.

Ochoa-Díaz, M. R., Rodriguez-Romero, J., López-Martínez, J., & Maldonado-García, M. C. (2016). First record of spine malformation of the round stingray *Urobatis halleri* off the Western coast of Baja California Sur, México. *Marine Biodiversity Records*, *9*(1), 1–5.

Officer, R. A., Clement, J. G., & Rowler, D. K. (1995). Vertebral deformities in a school shark, *Galeorhinus galeus*: Circumstantial evidence for endoskeletal resorption? *Journal of Fish Biology*, *46*, 85–98.

Pérez, A. E., Borges, S. M., Olivares, F. R., & Raredon, S. J. (2018). First case of morphological abnormality in common angel sharks *Squatina squatina* (Chondrichthyes: Squatinidae), from the Canary Islands. *Turkish Journal of Fisheries and Aquatic Sciences*, *19*(3), 267–270.

Pierce, S. J. & Norman, B. (2016). Rhincodon typus. *The IUCN Red List of Threatened Species*, *2016*, e.T19488A2365291. https://dx.doi.org/10.2305/IUCN.UK.2016-1.RLTS.T19488A2365291.en

Preziosi, R., Gridelli, S., Borghetti, P., Diana, A., Parmeggiani, A., Fioravanti, M. L., Marcer, F., Bianchi, I., Walsh, M., & Berzins, I. (2006). Spinal deformity in a sandtiger shark, *Carcharias taurus* Rafinesque: A clinical–pathological study. *Journal of Fish Diseases*, *29*(1), 49–60.

Ranjith, L., Saravanan, R., Kalidas, C., Kavitha, M., Ramkumar, S., Joshi, K. K., & Manojkumar, P. P. (2019). Morphological deformities in *Neotrygon kuhlii* (Muller & Henle, 1841) from gulf of Mannar, bay of Bengal, India. *Thalassas: An International Journal of Marine Sciences*, *35*(1), 49–56.

Rohner, C. A., Norman, B., Araujo, G., Holmberg, J., & Pierce, S. J. (2022). Population ecology of whale sharks. In A. D. M. Dove & S. J. Pierce (Eds.), *Whale sharks: Biology, ecology, and conservation* (pp. 130–147). CRC Press.

Rowat, D., & Brooks, K. S. (2012). A review of the biology, fisheries and conservation of the whale shark *Rhincodon typus*. *Journal of Fish Biology*, *80*(5), 1019–1056.

Rowat, D., Gore, M. A., Baloch, B. B., Islam, Z., Ahmad, E., Ali, Q. M., Culloch, R. M., Hameed, S., Hasnain, S. A., Hussain, B., Kiani, S., Siddiqui, J., Ormond, R. F., Henn, N., & Khan, M. (2008). New records of neonatal and juvenile whale sharks (*Rhincodon typus*) from the Indian Ocean. *Environmental Biology of Fishes*, *82*, 215–219.

Sandoval-Castillo, J., Mariano-Melendez, E., & Villavicencio-Garayzar, C. (2006). New records of albinism in two elasmobranchs: The tiger shark *Galeocerdo cuvier* and the giant electric ray *Narcine entemedor*. *Cybium*, *30*(2), 191–192.

Schwartz, F. J. (1973). Spinal and cranial deformities in the elasmobranchs *Carcharhinus leucas*, *Squalus acanthias*, and *Carcharhinus milberti*. *Journal of the Elisha Mitchell Scientific Society*, *89*, 74–77.

Tate, E. E., Anderson, P. A., Huber, D. R., & Berzins, I. K. (2013). Correlations of swimming patterns with spinal deformities in the sand tiger shark, *Carcharias taurus*. *International Journal of Comparative Psychology*, *26*, 75–82.

Taylor, J. G. (1996). Seasonal occurrence, distribution and movements of the whale shark, *Rhincodon typus*, at Ningaloo reef, Western Australia. *Marine and Freshwater Research*, *47*(4), 637–642.

Thorburn, D. C., & Morgan, D. L. (2004). The northern river shark *Glyphis sp. C* (Carcharhinidae) discovered in Western Australia. *Zootaxa*, *685*(1), 1–8.

Tyminski, J. P., de la Parra-Venegas, R., González Cano, J., & Hueter, R. E. (2015). Vertical movements and patterns in diving behavior of whale sharks as revealed by pop-up satellite tags in the eastern Gulf of Mexico. *PloS one*, *10*(11), e0142156.

Wilson, S. G., & Martin, R. A. (2003). Body markings of the whale shark: Vestigial or functional? *Western Australian Naturalist*, *24*(2), 115–117.

Womersley, F. C., Humphries, N. E., Queiroz, N., Vedor, M., da Costa, I., Furtado, M., Tyminski, J. P., Abrantes, K., Araujo, G., Bach, S. S., & Barnett, A. (2022). Global collision-risk hotspots of marine traffic and the world's largest fish, the whale shark. *Proceedings of the National Academy of Sciences*, *119*(20), e2117440119.

Zaera, D., & Johnsen, E. (2011). Foetal deformities in a smooth-hound shark, *Mustelus mustelus*, from an oil exploited area in Angola. *Cybium*, *35*(3), 231–236.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Hoffmayer, E. R., Driggers, W. B. III, Falterman, B. J., Franks, J. S., Hendon, J. M., McKinney, J. A., & Shelley, J. P. (2024). Spinal deformity in a whale shark, *Rhincodon typus* (Smith 1828), encountered in the northern Gulf of Mexico, with notes on its movement patterns. *Journal of Fish Biology*, 1–6. https://doi.org/10.1111/jfb.16012