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Red eyes in juvenile bull sharks (*Carcharhinus leucas*) from Fiji

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ABSTRACT

The bull shark (*Carcharhinus leucas*) is an apex predator with a wide distribution in tropical and warm temperate waters. This species is known to utilise freshwater systems and estuaries as nursery grounds. During a wider bull shark tagging survey in the Rewa River, Fiji, in 2017 and 2018, 27 neonate bull sharks with red eye pupils were recorded. This opportunistic observation prompted an examination of water quality parameters in the Rewa River to collect preliminary data on the potential cause of pollution. Water samples were analysed for faecal indicator bacteria (*Escherichia coli*), ammonia, total nitrogen, and various metals. Results indicated high levels of *E. coli* contamination, as well as elevated ammonia and total nitrogen concentrations. However, due to the limited sample size and the likelihood of additional underlying causes, a definitive causal relationship could not be established. Hence, this finding stands as an opportunistic observation, detailed here for documentation and stimulation of discourse.

Keywords: ecology, elasmobranchs, essential habitats, eyeshine, Fiji islands, organismal biology, sharks.

Introduction

The bull shark (*Carcharhinus leucas*) is a large apex predator circumglobally distributed in tropical and warm temperate waters (Ebert *et al.* 2021). The species is currently listed as vulnerable based on the IUCN Red List Status (Rigby *et al.* 2021). This euryhaline shark has been reported from numerous freshwater systems within its global distribution range (Gausmann 2021) and is well known to use estuarine areas as nursery grounds (Heupel and Simpfendorfer 2011). Fiji's rivers provide essential habitats for bull sharks (Glaus *et al.* 2019). During a wider bull shark tagging study in the Rewa River, between December 2017 and April 2018, neonate bull sharks with eye irritations causing redness were observed during daylight surveys. This opportunistic finding depicts a first of its kind observation in this species. As the river is a source of trace metals (Morrison *et al.* 2001), examination of water quality parameters was prompted to collect preliminary data on the potential cause of the eye irritation. In this research note, we document red eyes in juvenile bull sharks, assess water quality parameters (including faecal indicator bacteria, ammonia, total nitrogen, selected heavy metals), and discuss potential contributors to eye irritation and redness.

Materials and methods

To assess the occurrence and abundance of young age classes of bull sharks in the Rewa River, Fiji's largest river, vessel-based fisheries-independent surveys were conducted during the austral summer in 2017 and 2018 (see Glaus *et al.* 2019). Surveys were primarily run in clear water conditions to mitigate potential damage to fishing equipment resulting from debris. A 150-m gillnet was deployed at various sites (Fig. 1) to capture juvenile bull sharks in water depths ranging from 50 cm to 3 m. The gillnet was checked every 15 to 20 min to minimise suffocation risk for captured sharks. The number of captured sharks was recorded for each gillnet retrieval, ranging from one to 10 individuals. For water

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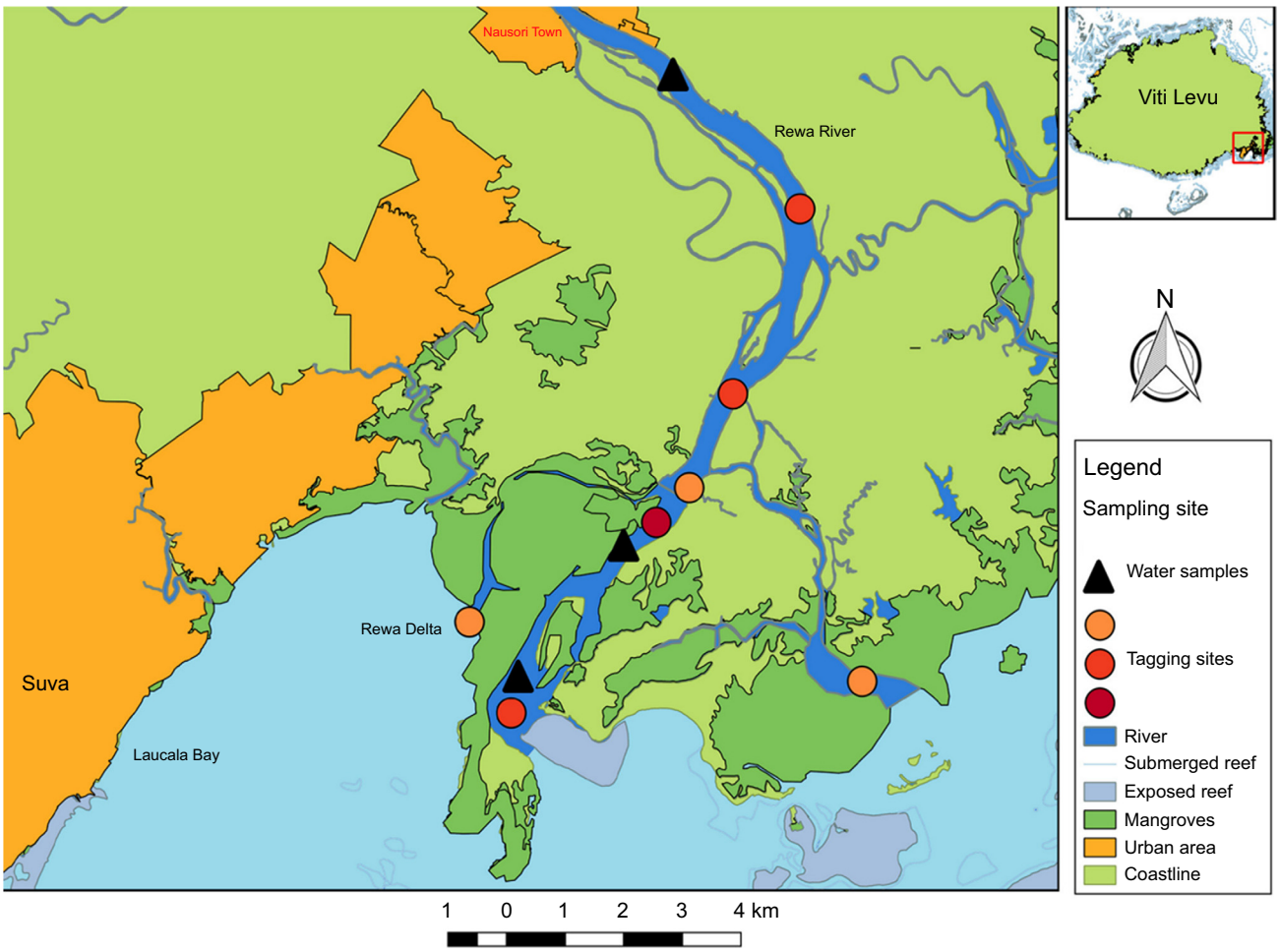

Fig. 1. Catch and water sampling sites within the Rewa River. Darker circles indicate locations where a larger number of bull sharks were caught. Triangular shapes indicate sites where water samples were collected.

quality analysis, nine water samples were collected at three main sites where bull sharks were caught between the Rewa Estuary up to Nausori town (Fig. 1).

Results

Of the 75 bull sharks caught during daylight surveys from December 2017 to the end of March 2018, 27 individuals (36%) had red eyes (Fig. 2*a*). Red-eye colouration was documented independent of the hour of the day and sex of the shark. Despite uneven site sampling efforts, juvenile bull sharks with eye irritations were captured at multiple locations. Moreover, this distinctive eye colouration persisted throughout the pupping season, spanning from early December to late March (Glaus *et al.* 2019). Total *Escherichia coli* concentrations ranged between 1400 and 20 000 cfu/100 mL, indicating high faecal contamination. Ammonia levels ranged from 0.02 to 0.05 mg/L, exceeding recommended water quality parameters by a factor of five according to the Environmental Protection Agency's Aquatic Life Criteria Table. Similarly, total nitrogen was increased with <2–2.86 mg/L. Contrastingly, no contamination with metal compounds was detected, with iron concentrations ranging between 42.9 and 200 μg/L, chromium <1 μg/L and lead <2 μg/L. Red-eyed bull shark photos from the Rewa River were shared with 11 researchers from Fiji and globally studying shark sensory systems, bull shark nurseries, and shark behaviour to find similar observations elsewhere. As a result, a juvenile bull shark with red eyes was reported from the nearby Navua River, Fiji, captured in April 2014 (Fig. 2*b*).

Discussion

Compared to a normal bull shark eye (Fig. 2*c*), red eyes are peculiar. The documentation of red eyes in young bull sharks in their natural habitat represents a previously unreported and unexpected observation. Eye disorders in fish are caused by a variety of external and internal factors, including disease, infection, physical trauma, and genetics (Hargis 1991). High

Fig. 2. Neonate and juvenile bull sharks with red eyes caught (*a*) in the Rewa River in February 2018 and (*b*) in the Navua River in April 2014; (*c*) typical eye appearance of a bull shark photographed in Fiji.

levels of organic matter in water can promote the growth of pathogens, as observed in cases such as *Pangasius sutchi* developing red-eye infection caused by *Acinetobacter schindleri* (Reddy and Mastan 2013), and *Channa striata* being associated with eye infection from *Acinetobacter baumannii* (Rauta *et al.* 2011). The analysis of water samples from sites where red-eyed bull sharks were caught indicated high concentrations of *E. coli*, which may be attributed to runoff from surrounding lands. Elevated *E. coli* concentrations in water can also arise from resuspended sediments acting as pathogen reservoirs, rather than solely from runoff (Pachepsky and Shelton 2011). Notably, the Rewa River and adjunct smaller streams have been subject to dredging since 2015. In *P. sutchi*, the causative bacterial agent caused a pop eye and red arched region around the eye (Reddy and Mastan 2013). Our observation of red eyes in bull sharks is that the redness is restricted to the shark's pupil, with the sclera appearing white (Fig. 2*a*). Consequently, an external infection is less likely, implying an internal ocular process.

The red colouration of bull sharks' eyes could be a result of light reflected out of the eye; a phenomenon known as eyeshine. Sharks possess a tapetum lucidum, a reflective layer behind the retina made of guanine crystals (Heath 1990). This layer reflects light that was not absorbed on the initial pass through the retina, giving it a second opportunity to be absorbed by the light-sensitive photoreceptors (Hart *et al.* 2006). Carcharhinid sharks' rod pigment is highly absorbent in the blue-green spectrum at ~500 nm, causing less absorption of longer wavelength yellow and red light, which can be reflected out of the eye. In bull sharks, mean wavelengths of maximum absorbance of rod and cone visual pigments is at 518 nm and 554 nm, respectively, which provides even stronger absorption of green light (Hart *et al.* 2011). Hence, green light gets absorbed by the pigments of the retina while the red light is reflected back out of the eye by the tapetum lucidum. The combination of a tapetum that reflects longer wavelengths, along with ocular media that blocks short wavelength blue light, can result in a prominent eyeshine dominated by red. This would be particularly noticeable in sharks that were caught at night or from murky water, i.e. when the dim ambient illumination would cause the pupil of the eye to dilate to let more light in and out of the eye, and the rod pigments would be largely unbleached and thus most able to absorb a significant portion of the incident light. It could further be possible that both visual pigments are closer together in juvenile bull sharks from Rewa, intensifying the reddish eyeshine. Also, eye shine colouration can vary among conspecifics, between juveniles and adults, as well as among juveniles from distinct populations, and the red eyes may represent an adaptation to diverse visibility conditions within the respective habitats (Litherland *et al.* 2009). What is intriguing here is that this phenomenon has been observed in sharks caught in clear shallow water during the day and at various sites within the Rewa River. Also, within the same gillnet retrieval, individuals with and without red eyes were recorded.

Red-eye colouration is also commonly observed in albino animals; however, albinism does not appear to be the underlying cause for the bull sharks depicted in Fig. 2*a*. Yet, bull sharks from Fiji are genetically distinct (Glaus *et al.* 2020; Devloo-Delva *et al.* 2023) and show a high degree of relatedness (Glaus 2019). Although the overall high prevalence of

red-eye bull sharks makes albinism an unlikely explanation, albinism and other genetic mutations as potential causes cannot be ruled out. Further research is needed to determine the potential causes and implications of this finding, such as the identification of loss-of-function mutations in core genes that may interact to generate an albinism phenotype (Bian *et al.* 2021). If red eyes are indeed found to be caused by water pollution from agricultural or industrial chemicals, dredging or sewage effluents, and have negative impacts on juvenile bull sharks, mitigation strategies can be devised and implemented. Our opportunistic finding reported here should stimulate discourse and encourage colleagues who encounter red-eyed sharks to share them with the research community.

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Data availability. Analytical results will be made available on DataDryad.org.

Conflicts of interest. The authors declare that they have no conflicts of interest.

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Author contributions. KG and JM outlined the Research Note. KG and FG did the field work and interpreted the analytical results. All authors wrote and revised the Research Note.

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