doi: 10.1111/emr.12266

COMMENT PIECE

Recreational fishing impacts on threatened river sharks: A potential conservation issue

By Peter M. Kyne and Pierre Feutry

Peter M. Kyne *is a Senior Research Fellow at the Research Institute for the Environment and Livelihoods, Charles Darwin University (Ellengowan Drive, Darwin, NT 0909, Australia; Email: peter.kyne@cdu.edu.au; Tel: +61 8 8946 7616).* ***Pierre Feutry*** *is a Research Scientist with CSIRO Oceans and Atmosphere (Castray Esplanade, Hobart, TAS 7000, Australia, Email: Pierre.Feutry@csiro.au; Tel: +61 3 6232 5095).*
This comment is part of a broader study on the status and ecology of threatened euryhaline sharks and rays under the National Environmental Research Program (NERP) and National Environmental Science Program (NESP) Marine Biodiversity Hub.

Summary The Adelaide River in Australia's Northern Territory is a popular recreational fishing area, as well as habitat for threatened and protected river sharks (*Glyphis* species). Both the Critically Endangered Speartooth Shark (*Glyphis glyphis*) and Endangered Northern River Shark (*Glyphis garricki*) are identified here in illegal catches from recreational angling. The identification of a decayed shark specimen using a DNA barcoding-like approach is the first such application to the identification of protected sharks in a recreational fishery. While the extent of catches by recreational anglers is unknown, the threatened status of these sharks, their suspected low population sizes, restricted distributions and importance of the Adelaide River as a nursery area call for the consideration of this as a potential conservation issue. As such, appropriate measures should be taken to reduce interactions with recreational anglers. The primary target species in the river is the iconic sportfish, Barramundi, which is predominantly caught by unbaited lure. Sharks are rarely caught on lure, allowing an opportunity for mitigation to focus on a fishing activity (baited hooks) which would limit any regulatory impact on popular lure fishing. Potential mitigation measures range from increased angler education and compliance checks, to the implementation of a spatial closure to baited hook fishing (a lure-only zone). Such measures may assist in meeting a stated objective of the Australian Government's river shark Recovery Plan to 'reduce and, where possible, eliminate adverse impacts of recreational fishing'.

Key words: *Adelaide River, DNA barcoding,* Glyphis garricki, Glyphis glyphis, *protected species.*

Introduction

Although global participation in recreational fishing is significant, effort and catch from the sector have often been overlooked in the context of fish declines (Cooke & Cowx 2004). Within Australia, a national survey showed that over 3.3 million people participated in recreational fishing in 2000/01 (Henry & Lyle 2003). While more recent national figures are not available, an increasing Australian population, particularly in the coastal zone, is likely to be driving increased participation and catches.

The management of recreational fishing varies between Australian jurisdictions, but may include recreational fishing licences, size and possession limits (including prohibited retention of protected species; Fig. 1a), gear limits and spatial management. The effectiveness of protected species conservation in recreational fisheries can be hindered by: (i) a lack of education and awareness of protected status; (ii) a lack of education and awareness of fishing regulations; (iii) a lack of enforcement of fishing regulations; and (iv) species misidentification.

Recreational fishing is an important social and cultural activity in Australia's Northern Territory; 22% of the population participate, with an estimated annual expenditure of ~$51 million in a 2009/10 survey (West *et al.* 2012). The Northern Territory does not have a recreational fishing licensing system, but activities are regulated through size, possession and gear limits, and Fish Management Zones around some key fishing areas. Rivers and wetland systems are popular fishing locations for Barramundi (*Lates calcarifer*) mainly using lines with unbaited lures (80.4% of recreational Barramundi take is by lure; West *et al.* 2012).

Barramundi habitat in northern Australia is shared with a number of threatened euryhaline sharks and rays. These species are able to tolerate a wide salinity range, from freshwater through brackish to marine waters and are a group of global conservation concern (Lucifora *et al.* 2015). This is due to the effects of fisheries (they are often taken as bycatch), coupled with intrinsic biological characteristics such as low fecundity and low levels of natural mortality, and often limited geographic ranges and specific habitat requirements (Lucifora *et al.* 2015). Northern Australia is a global hotspot of euryhaline sharks and rays, including two of the three known species of river sharks (*Glyphis* spp.; Pillans *et al.* 2010; Li *et al.* 2015; Lucifora *et al.* 2015).

Recent observations reported here suggest that the illegal take and possession of these protected river sharks by recreational anglers may represent a potential conservation issue. We report on several instances of illegal catch in a key nursery area (the Adelaide River, Northern Territory) and argue that mitigation measures should urgently be considered.

Threatened River Sharks of the Adelaide River

The Adelaide River originates in Litchfield National Park and flows 238 km to Van Diemen Gulf in the Northern Territory's Top End region, which experiences a

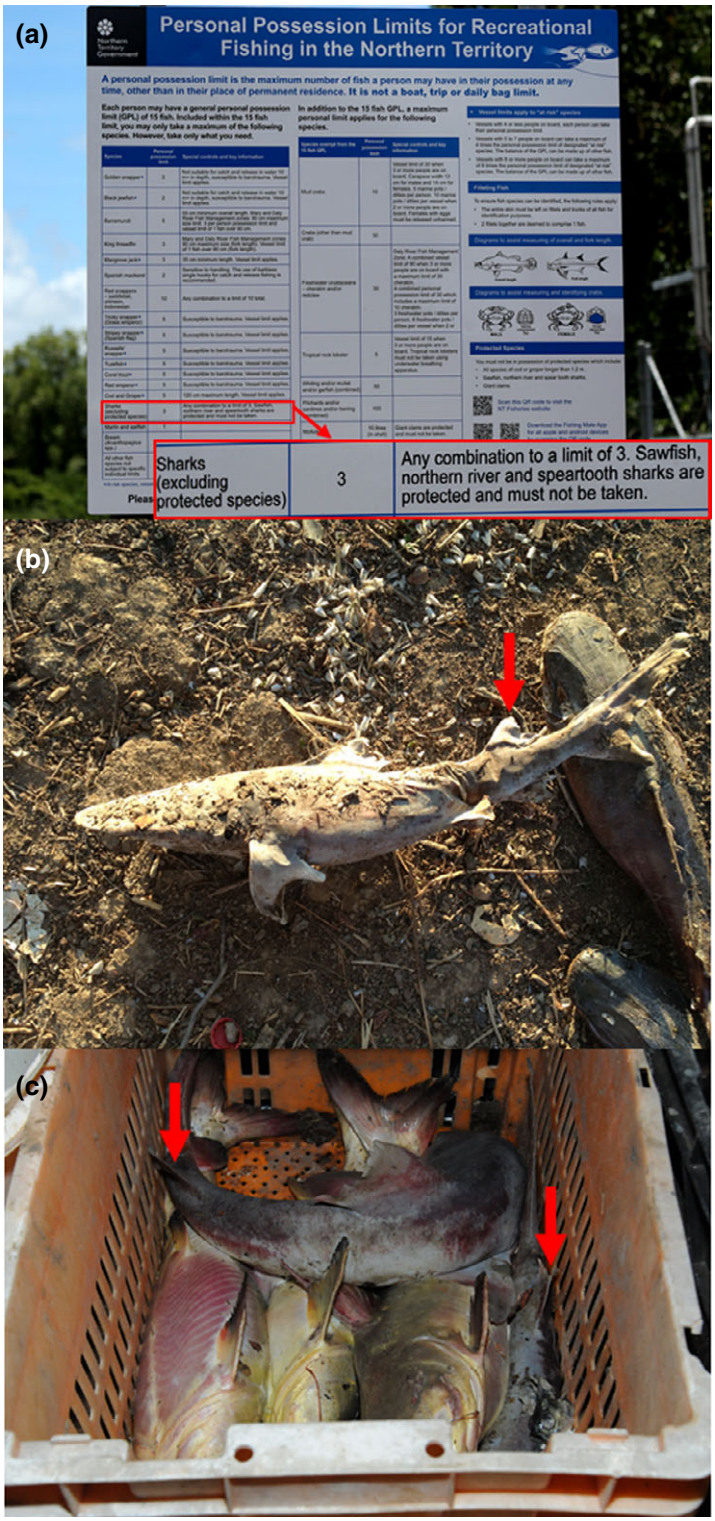

Figure 1. The illegal catch of threatened river sharks (*Glyphis* spp.) in the Adelaide River, Northern Territory. (a) 'personal possession limits for recreational fishing in the Northern Territory' sign at the Arnhem Highway Bridge boat ramp on the Adelaide River (red box indicates shark-specific regulations), (b) discarded Northern River Shark (identified through a DNA barcoding-like approach) at a fishing location beside the river, (c) two river sharks in a recreational catch from the Adelaide River. Red arrows denote large second dorsal fin characteristic of river sharks (photographs: a–b: P. Kyne; c: W. Rogers).

tropical wet–dry season climate. The lower- to mid- reaches are highly tidal, deep and meandering. The mid-reaches are accessible by a major highway from the Northern Territory capital, Darwin (~65 km), making it a popular recreational fishing location. A public boat ramp at the Arnhem Highway Bridge allows access for boat-based fishing, while land-based fishing is possible from only limited access points. Barramundi is mainly targeted using lures, while baited hook fishing can catch a range of species, including sharks. Catches of shark by lure are far less regular than by baited hook (Lowry *et al.* 2006; West *et al.* 2012). Recreational anglers are also entitled to use pots to target crustaceans. The river is closed to commercial gillnet fishing, while a commercial mud crab fishery operates in downstream reaches.

Three species of euryhaline shark occur in the tidal reaches of the Adelaide River (Pillans *et al.* 2010). The Northern River Shark (*Glyphis garricki*) and the Speartooth Shark (*G. glyphis*) have limited ranges within northern Australia and southern Papua New Guinea. The former is listed as Endangered and the latter as Critically Endangered under the Commonwealth *Environment Protection and Biodiversity Conservation Act* (*EPBC* Act). The third resident species, the Bull Shark (*Carcharhinus leucas*) has a widespread global distribution and is not considered to be threatened. All three species use the river as a nursery area. In general, river sharks occur in mid-reaches of the Adelaide River (those accessible around the boat ramp area) in the late dry-early wet season (i.e. August-December) when the salinity in the river is tidally influenced, prior to the onset of the tropical monsoon which delivers large volumes of freshwater input into the river, and results in a general downstream movement of river sharks (Pillans *et al.* 2010; P.M. Kyne unpublished data).

In the Northern Territory, both *Glyphis* species are protected under the *Territory Parks and Wildlife Conservation Act* and the *Fisheries Regulations*. The latter also contain a general recreational possession limit of three sharks for non-protected species (including Bull Sharks).

Collection and Identification of a Discarded River Shark

A photograph in a local media report covering an interaction between a recreational angler and an Estuarine Crocodile (*Crocodylus porosus*) published on 19 August 2014 (NT News 2014) showed a small shark amongst a catch of Warrior Catfish (*Hemiarius dioctes*). One of the authors (PMK) visited the site (on the banks of the Adelaide River, just downstream of the Arnhem Highway Bridge) on 21 August 2014 and found a single discarded shark (Fig. 1b).

The shark was a female measuring 66 cm total length (TL) and was retained with a tissue sample taken for molecular analysis. On site, the individual was identifiable as a shark of the genus *Glyphis* (river sharks) by its large second dorsal fin which is approximately two-thirds the height of the first dorsal fin (Last & Stevens 2009). This feature clearly separates river sharks from the Bull Shark which has a much smaller second dorsal fin, roughly one-third the height of the first dorsal fin (Last & Stevens 2009). However, the specimen was in a state of decay making specific identification visually difficult and any morphological measurements unreliable.

Genomic DNA was extracted from the tissue sample using a DNeasy Blood and Tissue Kit (Qiagen), and the sample was typed at 4046 single-nucleotide polymorphism (SNP) loci using the complexity reduction and genotyping-by-sequencing (GBS) method described by Grewe *et al.* (2015). The GBS was undertaken as part of a broader study, which sequenced several hundred river shark and Bull Shark samples. Following a DNA barcoding-like approach, this permitted the unidentified shark sample to be compared with known samples of the three shark species occurring in the Adelaide River.

The proportion of genotype mismatch averaged across shark species, and across SNP loci for each species pair and the unidentified sample allowed for its specific identification as a Northern River Shark (Table 1). The proportion of mismatches between the unidentified sample and the Northern River Shark is consistent with intraspecific values, and mismatches with the other two species are consistent with interspecific values (Table 1).

DNA barcoding has previously been utilised to identify shark products including illegal commercial catches of threatened and protected species (e.g. Holmes *et al.* 2009). As far as we know, this method has not been previously employed to identify catches of protected sharks from recreational fishing. Here, DNA effectively identified an illegal catch of the Endangered Northern River Shark by examining thousands of SNPs as part of a broader study on river sharks. A simpler barcoding approach, involving the mitochondrial gene COX1, could also have been used to distinguish between the three shark species (Wynen *et al.* 2009). The GBS approach, however, has the potential to accurately identify and count individuals where only body parts (such as meat or fins) are available for examination.

Table 1. Proportion of genotype mismatch averaged across fish and across SNP loci for each species pair and the unidentified sample collected at a fishing location beside the Adelaide River. The lower the value the more similar the samples being compared. Bold font indicates intraspecific comparisons; bold and italic font indicates the mismatch between the unidentified sample and the Northern River Shark

	Unidentified sample	Northern River Shark	Speartooth Shark	Bull Shark
Unidentified sample	–			
Northern River Shark	***0.0072***	**0.0073**		
Speartooth Shark	0.3860	0.3878	**0.0112**	
Bull Shark	0.9224	0.9219	0.9358	**0.0073**

An additional photograph from the shark collection site was provided to the authors by a third party (Fig. 1c). This image showed another two individual sharks, both identifiable as *Glyphis* species based on the visible large second dorsal fins. These specimens were not available for inspection or tissue sampling for molecular analysis, and so specific identification was not possible.

Additional Observed Catches

Two opportunistic observations of the illegal possession of protected river sharks were made while undertaking field work on the Adelaide River in December 2015:

1 On 01 December 2015, a recreational vessel was observed retrieving crustacean pots at the mouth of Beatrice Creek, upstream of the Arnhem Highway Bridge boat ramp. One pot was baited with the anterior half of a small shark and the other with the posterior half. It was assumed that these represented the same individual as the proportions of the two observed halves appeared to match. The large second dorsal fin characteristic of the genus *Glyphis* was observed on the posterior half of the shark. As the same vessel had been earlier observed fishing in the river with baited hooks, and as the shark was in a fresh state, it was assumed that the shark was caught in the river. Field sampling at the location on the same day recorded both neonate Speartooth Shark (n = 4) and Northern River Shark (n = 2), but species-level identification of the specimen used for bait was not possible based on this observation.

2 On 19 December 2015, a discussion with a land-based recreational angler at the Arnhem Highway Bridge boat ramp revealed that a Speartooth Shark was being used as bait for line angling. The shark was briefly examined, was sexed as a male, determined to be a neonate (by the presence of a visible umbilical scar on the ventral surface) and estimated to be ~60 cm TL. The angler stated that he was unaware of the protected status of the species.

Ecological Management & Restoration published by Ecological Society of Australia and John Wiley & Sons Australia, Ltd

Conservation Implications

The retention of protected species discussed in this article represents a legal (given protection under Northern Territory legislation) as well as a conservation issue, although several questions remain unanswered: What is the full extent of the recreational catch? Do these observations represent a common interaction between recreational anglers and protected sharks? Does retention or catch-and-release constitute the bulk of interactions? If sharks are released, what is the survival rate? Importantly, is the recreational catch aiding a continuing population-level decline?

Further onsite research and monitoring of fishing activities could shed light on these questions. The status of river sharks as rare species with limited distributions (Pillans *et al.* 2010), however, warrants consideration of mitigation in the absence of more detailed data on recreational interactions. Population sizes of river sharks are currently under investigation (M. Bravington, P. Feutry, P. M. Kyne., R. D. Pillans, R. M. Hillary, P. M. Grewe, G. Johnson, N. J. Bax, unpublished data), and this will allow more informed considerations of the potential impact of threatening processes on these species. The species' threatened listings on the *EPBC* Act, however, are related to suspected low population sizes, and thus even low levels of illegal take may have negative population-level effects. For example, very low anthropogenic mortality rates have been modelled to cause decline towards quasi-extinction in the Critically Endangered Grey Nurse Shark (*Carcharias taurus*) (Otway *et al.* 2004). The Speartooth Shark exhibits river-specific female reproductive philopatric behaviour; a depleted stock in any river (including the Adelaide River) is unlikely to be replenished by other populations (Feutry *et al.* 2014).

While a recreational fishing survey of the Northern Territory reported that a large proportion (95%) of sharks and rays caught recreationally are released or discarded (West *et al.* 2012), this survey did not specifically address the capture of protected species, or species-specific interactions. Furthermore, surveys such as this do not account for post-release mortality; for example, it has been suggested that post-release mortality is the greatest source of shark and ray mortality from recreational fishing in Australia's Great Barrier Reef (Lynch *et al.* 2010).

Mitigation Options for Limiting the Impact of Recreational Fishing

The Australian Government's Recovery Plan for river sharks includes the objective 'Reduce and, where possible, eliminate adverse impacts of recreational fishing' (DOE 2015). Mitigating any recreational catch in the Adelaide River will help to realise that objective. Angler education and the effective enforcement of current regulations (i.e. prohibited retention) provide a mitigation option within the existing management framework. Information is readily available to the public on Northern Territory recreational fishing regulations through signage (Fig. 1a), and online and print materials, but it is clear that at least some anglers are unaware of, or unwilling to accept, the protected status of river sharks. Education and increased angler awareness are therefore key components of management. Effective management also requires that agencies responsible for enforcement (in this case, the Northern Territory Police Service and Northern Territory Parks and Wildlife Commission who manage conservation reserves adjacent to the river including Djukbinj National Park) are adequately resourced and trained. Regular compliance checks are needed to enforce regulations, while ongoing training can provide knowledge of protected species identification and fisheries regulations for these agencies.

Alternative mitigation options include measures such as (i) the protection (mandated release) of *all* sharks in the Adelaide River; (ii) the protection (mandated release) of *all* sharks in the Adelaide River, in combination with hook regulations for baited hook fishing (circle hook only); or (iii) implementation of a lure-only zone in the Adelaide River.

These measures would require differing considerations of education, compliance and enforcement. For example, releasing all sharks circumvents species identification issues for both anglers and compliance officers. For this measure, safe-release and handling guidelines and education would be required, but post-release mortality may limit the benefits of this management option. Regulating hook type (allowing only circle hooks which limit gut hooking) provides captured sharks with a higher chance of post-release survivorship over traditional 'J' hooks (see review by Godin *et al.* 2012).

The implementation of a lure-only fishing zone in the Adelaide River would effectively remove the fishing gear that is most likely to interact with threatened sharks (i.e. baited hooks) and may provide a more effective precautionary management approach. There is precedence locally for the use of this management approach, which is in place in other areas of the Northern Territory (for the management of targeted recreational species). This precedence may aid public acceptance and compliance and importantly does not focus on the dominant fishing activity for Barramundi (lure fishing); sharks are far less regularly caught on lure than baited hooks (Lowry *et al.* 2006; West *et al.* 2012). The boundaries of the closed area could be determined using movement data from acoustically tagged sharks in the system (P.M. Kyne unpublished data), as well as ensuring minimal impact on recreational fishing activities around the river mouth where a variety of marine fishes is targeted. Monitoring of angler activities would be important to gauge the effect of any mitigation measures enacted, and its transferability to other locations where interactions with protected species may be found to occur.

Despite the low number of observations reported here, the threatened status of river sharks, their suspected low population sizes, restricted distributions and importance of the Adelaide River as a nursery area call for the consideration of their illegal take by recreational anglers as a potential conservation issue, and the implementation of appropriate mitigation measures.

Acknowledgements

This work was supported by the Marine Biodiversity Hub, a collaborative partnership supported through funding from the Australian Government's National Environmental Research Program (NERP) and National Environmental Science Program (NESP). Additional support was provided by the NERP Northern Australia Hub and the North Australia Marine Research Alliance. Thanks to the Northern Territory Police, Fire and Emergency Service for providing information and photos of captured sharks. Thanks to Mark Grubert, Grant Johnson, Thor Saunders, Tim Lynch and Nic Bax for valuable comments on the manuscript.

References

Cooke S. J. and Cowx I. G. (2004) The role of recreational fishing in global fish crises. *BioScience* **54**, 857–859.

Department of the Environment (DOE) (2015) *Sawfish and River Sharks Multispecies Recovery Plan*. Department of the Environment, Canberra.

Feutry P., Kyne P. M., Pillans R. D., Chen X., Naylor G. J. P. and Grewe P. M. (2014) Mitogenomics of the Speartooth Shark challenges ten years of control region sequencing. *BMC Evolutionary Biology* **14**, 232.

Godin A. C., Carlson J. K. and Burgener V. (2012) The effect of circle hooks on shark catchability and at-vessel mortality rates in longlines fisheries. *Bulletin of Marine Science* **88**, 469–483.

Grewe P. M., Feutry P., Hill P. L. *et al.* (2015) Evidence of discrete yellowfin tuna (*Thunnus albacares*) populations demands rethink of management for this globally important resource. *Scientific Reports* **5**, 16916.

Henry G. W. and Lyle J. M. (2003) The National Recreational and Indigenous Fishing Survey. NSW Fisheries Final Report Series No. 48. for FRDC project 99/158. Australian Government Department of Agriculture, Fisheries and Forestry, Canberra.

Holmes B. H., Steinke D. and Ward R. D. (2009) Identification of shark and ray fins using DNA barcoding. *Fisheries Research* **95**, 280–288.

Last P. R. and Stevens J. D. (2009) *Sharks and Rays of Australia*, 2nd edn. CSIRO Publishing, Collingwood.

Li C., Corrigan S., Yang L. *et al.* (2015) DNA capture reveals transoceanic gene flow in endangered river sharks. *Proceedings of the National Academy of Sciences of the United States of America* **112**, 13302–13307.

Lowry M., Steffe A. and Williams D. (2006) Relationships between bait collection, bait type and catch: A comparison of the NSW trailer-boat and gamefish-tournament fisheries. *Fisheries Research* **78**, 266–275.

Lucifora L. O., de Carvalho M. R., Kyne P. M. and White W. T. (2015) Freshwater sharks and rays. *Current Biology* **25**, R971–R973.

Lynch A.-M. J., Sutton S. G. and Simpfendorfer C. A. (2010) Implications of recreational fishing for elasmobranch conservation in the Great Barrier Reef Marine Park. *Aquatic Conservation: Marine and Freshwater Ecosystems* **20**, 312–318.

NT News (2014) Remains found after fisherman taken by croc known as Michael Jackson at Adelaide River. [Accessed 19 Aug 2014.] Available from URL: http://www.ntnews.com.au/news/northern-territory/remains-found-after-fisherman-taken-by-croc-known-as-michael-jackson-at-adelaide-river/news-story/6afdf51721186c090e57ad0d9f493f15

Otway N. M., Bradshaw C. J. A. and Harcourt R. G. (2004) Estimating the rate of quasi-extinction of the Australian grey nurse shark (*Carcharias taurus*) population using deterministic age- and stage-classified models. *Biological Conservation* **119**, 341–350.

Pillans R. D., Stevens J. D., Kyne P. M. and Salini J. (2010) Observations on the distribution, biology, short-term movements and habitat requirements of river sharks *Glyphis* spp. in northern Australia. *Endangered Species Research* **10**, 321–332.

West L. D., Lyle J. M., Matthews S. R., Stark K. E. and Steffe A. S. (2012) Survey of recreational fishing in the Northern Territory, 2009–10. Northern Territory Government, Australia. Fishery Report No. 109.

Wynen L., Larson H., Thorburn D. *et al.* (2009) Mitochondrial DNA supports the identification of two endangered river sharks (*Glyphis glyphis* and *Glyphis garricki*) across northern Australia. *Marine and Freshwater Research* **60**, 554–562.

Ecological Management & Restoration published by Ecological Society of Australia and John Wiley & Sons Australia, Ltd