First identification of probable nursery habitat for critically endangered great hammerhead Sphyrna mokarran on the Atlantic Coast of the United States

Catherine Macdonald, Jacob Jerome, Christian Pankow, Nicholas Perni, Kristina Black, David Shiffman, Julia Wester

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First identification of probable nursery habitat for critically endangered great hammerhead *Sphyrna mokarran* on the Atlantic Coast of the United States

Catherine Macdonald[1,2] | **Jacob Jerome**[1] | **Christian Pankow**[1] | **Nicholas Perni**[1] | **Kristina Black**[3] | **David Shiffman**[4,5] | **Julia Wester**[1,6]

[1]Field School, Miami, Florida

[2]Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida

[3]Department of Integrative Biology, University of Texas at Austin, Austin, Texas

[4]New College of Interdisciplinary Arts and Sciences, Arizona State University, Glendale, Arizona

[5]David Shiffman Scientific and Environmental Consulting, Inc., Silver Spring, Maryland

[6]Abess Center for Ecosystem Science and Policy, University of Miami, Coral Gables, Florida

Correspondence
Catherine Macdonald, 3109 Grand Ave. #154 Miami, FL 33133, USA.
Email: catherine.macdonald@rsmas.miami.edu

Abstract

Great hammerheads (*Sphyrna mokarran*) have undergone significant global population declines and were assessed as Critically Endangered by the IUCN in 2019. Identification and protection of critical habitat, particularly during early life stages, is considered imperative for species conservation and management. We report the first identification of a probable nursery area for young-of-the-year and juvenile great hammerheads off the Atlantic coast of the United States. Notably, these animals were all encountered within highly human-impacted marine habitats near Miami, Florida. The capture of nine individuals under 200 cm total length in a 10-month period supports the hypothesis that this area represents a primary or secondary nursery habitat for great hammerheads.

KEYWORDS

elasmobranch, great hammerhead, habitat, juvenile, nursery, reproduction, *Sphyrna mokarran*

1 | INTRODUCTION

The concept of "nursery areas" in marine science dates back more than a century, and most broadly, it has been used to refer to areas where juveniles are found in higher densities, avoid predation more successfully, or grow faster than in other areas (Beck et al., 2001). In recent years, shark-specific definitions have emerged to apply to larger-bodied, mobile elasmobranch species. Heupel, Carlson, and Simpfendorfer (2007) described three key criteria for identification of shark nursery habitat: (1) juvenile sharks are more commonly encountered in that habitat than elsewhere, (2) sharks remain in the area for extended periods, and (3) the area is used as a nursery repeatedly across years. Despite the clarity of these criteria, identifying nursery habitat for many shark species remains a challenge (see Heupel et al. 2018).

The great hammerhead shark is the largest member of the family Sphyrnidae, yet data on nursery habitat for this species in US waters remains limited and largely speculative. Great hammerheads can be found in coastal and pelagic tropical and warm temperate waters circumglobally (Castro, 2010; Compagno, 2001). Due to species-specific physiological characteristics (reviewed in Giles et al., 2014) and frequent interactions with fisheries as a target species and as bycatch, great hammerheads have faced significant population declines throughout their range. In late 2019, they were categorized as Critically Endangered by the IUCN (Rigby et al., 2019). Great hammerheads were also considered for listing under the US Endangered Species Act (ESA) in 2014, but were not listed based on a lack of species-level data available to infer population trends with high confidence, highlighting the conservation and management difficulties presented by identification across hammerhead species (Miller, Carlson, Hogan, & Kobayashi, 2014). Great hammerheads have been the subject of recent conservation concern and rule-making in Florida (e.g., in relation to land-based shark fishing) and are protected from commercial and recreational harvest in Florida waters (see Miller et al., 2014; Gallagher & Klimley, 2018; Shiffman et al. 2017; Shiffman 2020). Studies of great hammerhead movement ecology make clear the difficulty of conserving adult animals based on their large-scale migrations (which often move through international waters, creating regulatory and management barriers) and their intermittent philopatric attachment to particular sites (Guttridge et al., 2017; Harry, Macbeth, Gutteridge, & Simpfendorfer, 2011; Techera & Klein, 2011).

Although there is stronger evidence for philopatric behaviors associated with residency and site fidelity than reproduction in great hammerheads, natal philopatry is well-known in some other shark species, and the quality of available nursery habitat can exert an important influence on juvenile survivorship (Chapman, Feldheim, Papastamatiou, & Hueter, 2015; Heupel & Simpfendorfer, 2011; Heupel et al. 2018). Size at birth for great hammerheads is reported to be between 66 and 71 cm TL with growth rates approaching 40 cm within the first year in the Western Atlantic and Gulf of Mexico (Harry et al., 2011; Piercy, Carlson, & Passerotti, 2010). A lack of neonates in nearshore habitats has been used to argue great hammerheads primarily use offshore habitats for pupping (Harry et al., 2011; Hueter & Tyminski, 2007), although pupping has never been witnessed. Evidence suggests that protecting not only neonates but also older juveniles can play an important role in population recovery for threatened shark species (Brewster-Geisz & Miller, 2000). The discovery of a highly urban-impacted, previously unidentified area of importance to young-of-the-year (YOY) and juvenile great hammerheads, with the potential to support neonates, may have significance for decisions about conservation and management of the threatened ecosystems of Biscayne Bay.

2 | METHODS

Biscayne Bay is a large, shallow, oligotrophic embayment, and marine estuary on the southeast coast of Florida, containing interconnected ecosystems including mangrove shoreline, seagrass beds, and coral reefs. These ecosystems support considerable biodiversity including more than 30 endangered species or species of special concern (Cantillo et al., 2000), and more than 100 species important to local recreational and commercial fisheries (Stoa, 2016). Rapid population growth, urbanization, and associated land-use change and anthropogenic pressure has resulted in eutrophication, pesticide and chemical accumulation, changes in salinity, habitat loss, direct damage from propellers and anchors, overfishing, and localized die-offs of seagrasses, mangroves, and corals (Cantillo et al., 2000). The fishing site discussed here encompasses an area of $\sim$2.5 km^2 in north-central Biscayne Bay, located less than 7 km from downtown Miami (Figure 1).

From June 2018 to January 2020, nine juvenile great hammerheads were captured via scientific longline in Biscayne Bay, Florida. Fishing took place as part of a research program deploying both longlines and drumlines, however, all juveniles were captured on longlines, on 13/0 or 15/0 circle hooks. Captured individuals were measured, sexed, tagged with mark-recapture tags, and sampled (<5 mm fin clip, <4 mm white muscle biopsy, <4 ml blood via caudal venipuncture) before release. Research effort over this period encompassed $\sim$80 total fishing days, distributed throughout the year with the greatest effort in the summer months.

Sampled individuals were carefully evaluated for species-specific characteristics, especially cephalofoil shape and relative size of the dorsal fin, to ensure identification due to the known risk of confusion with scalloped hammerhead *S. lewini*, especially at younger ages and smaller sizes (Barker, Frazier, Bethea, Gold, & Portnoy, 2017; Compagno, 2001).

3 | RESULTS

All great hammerheads captured at this site were < 200 cm in total length (TL), with a mean length of 133.4 cm TL and a median length of 131 cm TL (Table 1). Of five regularly sampled sites off the coast of Miami, this is the only site where great hammerheads <200 cm TL have been encountered. Larger subadult and adult individuals have been caught at other sites around Miami, and information on the reproductive status of mature individuals present in the area is currently under investigation. Individuals under 200 cm TL have been previously classified as sexually immature and under 5 years of age (Castro, 2010; Piercy et al., 2010). In addition to captured individuals, at least two additional hammerheads in this approximate size class have been observed

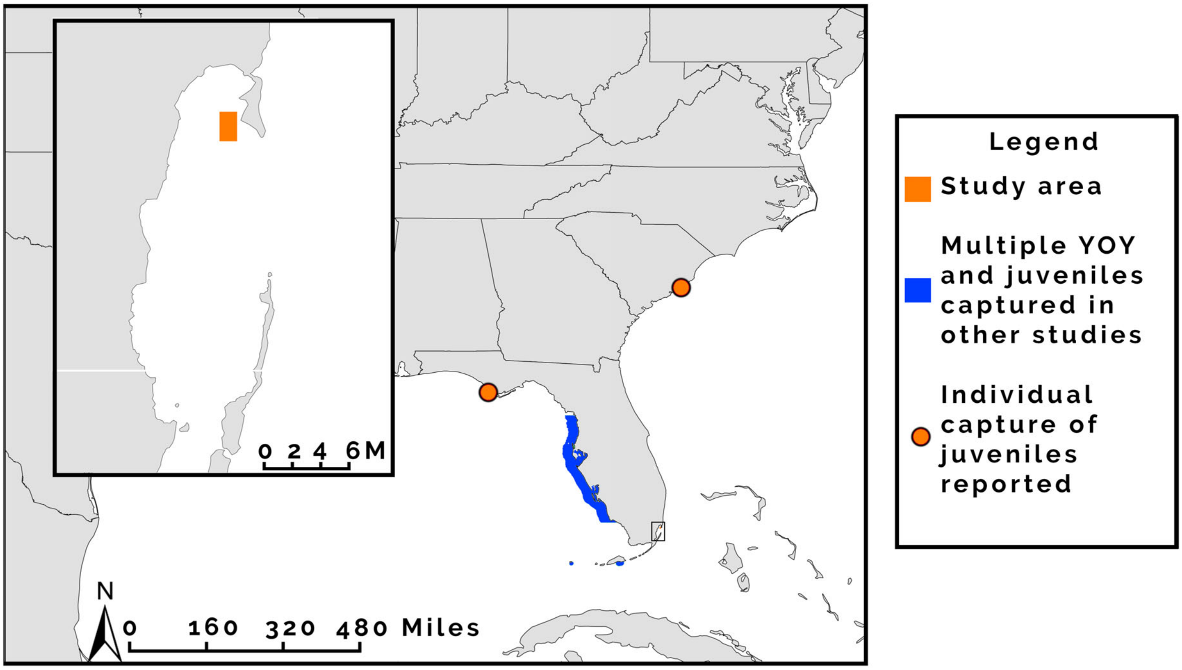

FIGURE 1 Map of the Southeastern United States and Eastern Gulf of Mexico showing identified locations where juvenile great hammerheads have been captured previously, with inset of the Biscayne Bay study area

TABLE 1 Capture date, size, and genetic confirmation for each individual captured

Date of capture (mm/dd/yyyy)	Fork length (cm)	Total length (cm)	Confirmed genetically as *Sphyrna mokarran*
June 30, 2018	103	131	X
November 11, 2018	101	131	X
January 16, 2019	72	92	X
February 13, 2019	72	94	X
April 19, 2019	125	166	X
April 19, 2019	149	197	X
June 17, 2019	152	199	X
August 17, 2019[a]	86	103	X
January 6, 2020	72	95	X

[a]Recaptured January 9, 2020. At recapture, FL was 100 cm and TL was 128 cm.

from the research vessel swimming around the longlines in shallow, clear water. Although not included in this analysis, three scalloped hammerheads (*S. lewini*) in the same size class were also captured at the study site, and all were successfully visually distinguished from juvenile great hammerheads.

Species identifications were confirmed with genetic analysis (see supplementary materials for methodological details). Nine fin clips were analyzed and yielded high-quality sequences for either COI or the control region. All BLAST searches to GenBank for samples identified in the field as great hammerheads found a 100% match to *S. mokarran*.

4 | DISCUSSION

While our findings remain preliminary, this data suggests we have identified a probable nursery site for great hammerhead sharks which demonstrably meets two of the three criteria for a nursery area, with the third supported by preliminary data and currently under investigation. Little is known about nursery areas for great hammerheads, although some have been tentatively identified on the Gulf coast of the state of Florida based on reported catches of juveniles, and larger juvenile individuals have been captured around the Florida Keys. Great hammerheads of this size (<200 cm) had never been confirmed in coastal Atlantic waters of the mainland United States until 2017, when one individual was identified in South Carolina as a result of genetic analysis (Barker et al., 2017; Hueter & Tyminski, 2007) (Figure 1).

Parturition for great hammerheads is thought to occur during the summer months (Piercy et al., 2010). In the present study, three individuals captured in January or February were < 100 cm TL. Given estimated sizes at birth (66–71 cm) and growth rates (40 cm in the first

FIGURE 2 The recaptured *Sphyrna mokarran* during the scientific work-up

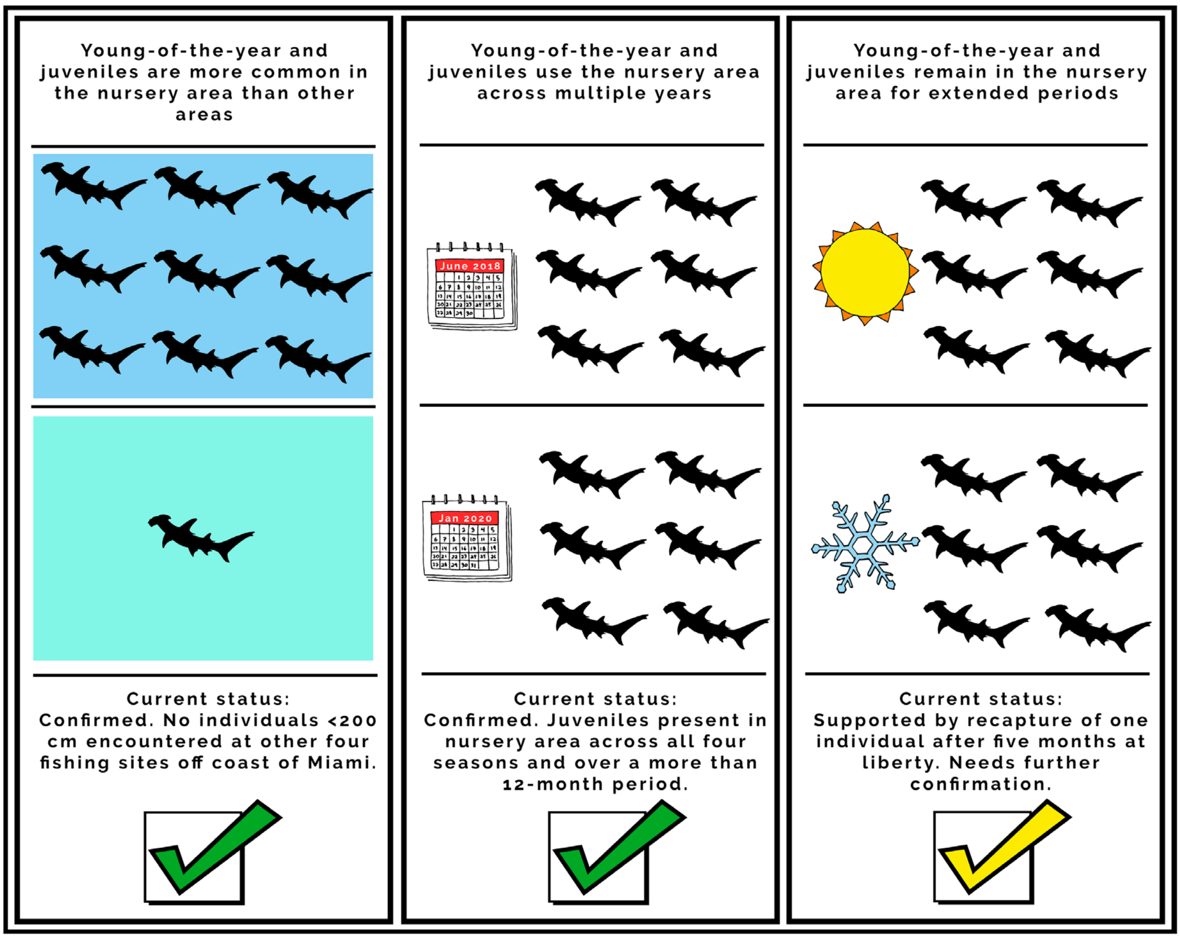

FIGURE 3 Criteria for determining if an area represents critical nursery habitat (Heupel et al., 2007) and progress toward meeting criteria reported in this study

year) for great hammerheads, we infer that these individuals were likely YOY. A recaptured individual grew 25 cm (103 to 128 cm) in less than 5 months (146 days) at liberty between August 2019 and January 2020, suggesting the possibility that published growth rates may underestimate growth potential in this habitat (Figure 2).

At this time, this site demonstrably meets two of the three criteria for a nursery area described by Heupel et al. (2007) which requires that (a) sharks be more commonly encountered there than elsewhere, (b) sharks remain in the area for extended periods, and (c) the area is used repeatedly across years (Figure 3). In reference to Criteria 1, we have caught no hammerheads in this size class (<200 cm TL) at any other fishing sites, exclusively encountering them at this site. Criteria 2 is supported by our recapture of one individual, but will be further explored in future passive acoustic tagging studies providing improved spatial use data at far higher resolution. This site definitively meets Criteria 3, as juveniles have been encountered there across all four seasons and over a more than 12-month period, from June 2018 to January 2020.

The discovery of probable great hammerhead nursery habitat in a highly anthropogenically impacted environment only miles from downtown Miami, Florida, suggests both the ability of this physiologically delicate species to adapt to survive human impacts and the potential for management improvement. The capture of three similarly sized juvenile scalloped hammerheads further supports arguments that this habitat may represent an important nursery for multiple shark species of conservation concern. Both commercial and recreational fishing are allowed in this area, and within the boundaries of nearby Biscayne National Park. Two of the juveniles captured in this study had hooks from previous recreational capture still embedded in their jaws, and researchers regularly encounter illegally unmarked trap lines at this site. Despite the controversy around limits on marine resource extraction (a 2015 effort to designate 6% of the park area a no-fishing zone failed), there is precedent for species-specific regulations associated with critical habitat in this region. For instance, spiny lobsters are protected from harvest pressure within the park-bounded Biscayne Bay/Card Sound Lobster Sanctuary.

Nursery area designation or identification of important habitat for juvenile sharks has occasionally driven conservation action, including designation critical habitat or establishment of marine protected areas (see Heupel et al. 2018). For threatened hammerhead species, state regulations outlawing harvest may not offer adequate protection from harmful sub-lethal effects or mortality associated with recreational fishing capture given their relative intolerance to capture stress. This suggests the establishment of habitat protections or reduction of fishing pressures for hammerheads or their vital prey species within nursery habitats may lead to improved conservation of great hammerheads.

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CONFLICT OF INTEREST

The authors have no competing interests.

AUTHOR CONTRIBUTIONS

Catherine Macdonald conceived the study with contributions from all other authors. Jacob Jerome, Christian Pankow, Nicholas Perni, Julia Wester, and Catherine Macdonald collected all biological and ecological samples. Kristina Black conducted the genetic analysis. All authors discussed and interpreted results. Catherine Macdonald and Jacob Jerome drafted the manuscript with contributions from all other authors.

DATA AVAILABILITY STATEMENT

Relevant data are available in the main text or the supplementary materials. Additional data available upon request to the corresponding author.

ETHICS STATEMENT

Research followed protocols approved by the University of Miami's Institutional Animal Care and Use Committee (#20–044) and Florida state permits (#SAL-1798).

ORCID

Catherine Macdonald https://orcid.org/0000-0003-2146-4966
Jacob Jerome https://orcid.org/0000-0002-8380-9854
David Shiffman https://orcid.org/0000-0002-6093-5559

REFERENCES

Barker, A. M., Frazier, B. S., Bethea, D. M., Gold, J. R., & Portnoy, D. S. (2017). Identification of young-of-the-year great hammerhead shark *Sphyrna mokarran* in northern Florida and South Carolina. *Journal of Fish Biology*, *91*(2), 664–668.

Beck, M. W., Heck, K. L., Able, K. W., Childers, D. L., Eggleston, D. B., Gillanders, B. M., … Orth, R. J. (2001). The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates: A better understanding of the habitats that serve as nurseries for marine species and the factors that create site-specific variability in nursery quality will improve conservation and management of these areas. *Bioscience*, *51*(8), 633–641.

Brewster-Geisz, K. K., & Miller, T. J. (2000). Management of the sandbar shark, *Carcharhinus plumbeus*: Implications of a stage-based model. *Fishery Bulletin*, *98*(2), 236–249.

Cantillo, A. Y., Pikula, L., Hale, K. K., Collins, E. V., & Caballero, R. (2000). *Biscayne Bay environmental history and annotated bibliography*, NOAA Technical Memorandum NOS NCCOSCCMA, Maryland: Department of Commerce.

Castro, J. I. (2010). *The sharks of North America*. Oxford, UK: Oxford University Press.

Chapman, D. D., Feldheim, K. A., Papastamatiou, Y. P., & Hueter, R. E. (2015). There and back again: A review of residency and return migrations in sharks, with implications for population structure and management. *Annual Review of Marine Science*, *7*, 547–570.

Compagno, L. J. (2001). *Sharks of the world: Bullhead, mackerel, and carpet sharks (Heterodontiformes, Lamniformes, and Orectolobiformes)* (Vol. 2). Rome: Food & Agriculture Organization.

Gallagher, A. J., & Klimley, A. P. (2018). The biology and conservation status of the large hammerhead shark complex: The great, scalloped, and smooth hammerheads. *Reviews in Fish Biology and Fisheries*, *28*(4), 777–794.

Giles, J. L., Ovenden, J. R., AlMojil, D., Garvilles, E., Khampetch, K. O., Manjebrayakath, H., & Riginos, C. (2014). Extensive genetic population structure in the indo–West Pacific spot-tail shark, *Carcharhinus sorrah*. *Bulletin of Marine Science*, *90*(1), 427–454.

Guttridge, T. L., Van Zinnicq Bergmann, M. P., Bolte, C., Howey, L. A., Finger, J. S., Kessel, S. T., … Cashman, R. C. (2017). Philopatry and regional connectivity of the great hammerhead shark, *Sphyrna mokarran* in the US and Bahamas. *Frontiers in Marine Science*, *4*, 3.

Harry, A. V., Macbeth, W. G., Gutteridge, A. N., & Simpfendorfer, C. A. (2011). The life histories of endangered hammerhead sharks (Carcharhiniformes, Sphyrnidae) from the east coast of Australia. *Journal of Fish Biology*, *78*(7), 2026–2051.

Heupel, M. R., Carlson, J. K., & Simpfendorfer, C. A. (2007). Shark nursery areas: Concepts, definition, characterization and assumptions. *Marine Ecology Progress Series*, *337*, 287–297.

Heupel, M. R., Kanno, S., Martins, A. P., & Simpfendorfer, C. A. (2018). Advances in understanding the roles and benefits of nursery areas for elasmobranch populations. *Marine and Freshwater Research*, *70*(7), 897–907.

Heupel, M. R., & Simpfendorfer, C. A. (2011). Estuarine nursery areas provide a low-mortality environment for young bull sharks *Carcharhinus leucas*. *Marine Ecology Progress Series*, *433*, 237–244.

Hueter, R. E., & Tyminski, J. P. (2007). Species-specific distribution and habitat characteristics of shark nurseries in Gulf of Mexico waters off peninsular Florida and Texas. In C. T. McCandless, H. L. Pratt, Jr., & N. E. Kohler (Eds.), *American Fisheries Society Symposium* (Vol. 50, p. 193). Bethesa, MD: American Fisheries Society.

Miller, M. H., Carlson, J. K., Hogan, L., & Kobayashi, D. (2014). Status review report: Great hammerhead shark (*Sphyrna mokarran*). *National Marine Fisheries Service*. https://repository.library.noaa.gov/view/noaa/16286.

Piercy, A. N., Carlson, J. K., & Passerotti, M. S. (2010). Age and growth of the great hammerhead shark, *Sphyrna mokarran*, in the north-western Atlantic Ocean and Gulf of Mexico. *Marine and Freshwater Research*, *61*(9), 992–998.

Rigby, C.L., Barreto, R., Carlson, J., Fernando, D., Fordham, S., Francis, M.P., Herman, K., Jabado, R.W., Liu, K.M., Marshall, A., Pacoureau, N., Romanov, E., Sherley, R.B. & Winker, H. (2019). *Sphyrna mokarran*. The IUCN Red List of Threatened Species. T39386A2920499.

Shiffman, D. S., Macdonald, C., Ganz, H. Y., & Hammerschlag, N. (2017). Fishing practices and representations of shark conservation issues among users of a land-based shark angling online forum. *Fisheries Research*, *196*, 13–26.

Shiffman, D. S. (2020). Recreational shark fishing in Florida: How research and strategic science communication helped to change policy. *Conservation Science and Practice*, *2*(4), e174.

Stoa, R. B. (2016). Cooperative Federalism in Biscayne National Park. *Natural Resources Journal*, *56*(1), 81–115.

Techera, E. J., & Klein, N. (2011). Fragmented governance: Reconciling legal strategies for shark conservation and management. *Marine Policy*, *35*(1), 73–78.

SUPPORTING INFORMATION

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

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