Received: 1 October 2021 | Revised: 11 December 2021 | Accepted: 15 December 2021

DOI: 10.1111/csp2.12629

CONTRIBUTED PAPER

Conservation Science and Practice
A journal of the Society for Conservation Biology
Open Access

WILEY

The next generation of conservation research and policy priorities for threatened and exploited chondrichthyan fishes in the United States: An expert solicitation approach

David S. Shiffman[1] | **Jessica N. Elliott**[2] | **Catherine C. Macdonald**[2,3] | **Julia N. Wester**[3,4] | **Beth A. Polidoro**[1] | **Lara A. Ferry**[1]

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

[2]Masters of Professional Science Program, Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida, USA

[3]Field School, Miami, Florida, USA

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

Correspondence
David S. Shiffman, New College of Interdisciplinary Arts and Sciences, Arizona State University, 4701 W Thunderbird Rd, Glendale, AZ 85306, USA.
Email: david.shiffman@gmail.com

Abstract

Chondrichthyan fishes are ecologically and economically important, yet many are overfished or at elevated risk of extinction. Researchers report a desire to perform policy-relevant science that can generate data in support of effective conservation and management plans, but also report a lack of clarity about how to most effectively to do that. To address this gap, we created a list of research and policy priorities for chondrichthyan species of conservation concern in US waters using a modified expert solicitation horizon scan approach. Thirty-five policy-relevant research priorities and twenty-seven policy priorities are presented here, a list which can help to guide scientists and conservationists to maximize the effectiveness of their research and policy advocacy.

KEYWORDS

Chondrichthyan fishes, conservation priorities, fisheries marine protected areas, sustainable fisheries management

1 | INTRODUCTION

Chondrichthyan fishes (sharks, skates, rays, and chimeras) are a taxon of conservation concern. These animals serve a variety of important ecological roles (Heithaus et al., 2008) and are economically important to both fisheries and wildlife tourism (Macdonald et al., 2017; Simpfendorfer & Dulvy, 2017). However, many species are at elevated risk of extinction (Dulvy et al., 2014), and rapid and severe declines have been reported in some populations of some species (Pacoureau et al., 2021).

More (and more effective) conservation policies are needed to protect and promote recovery of threatened and overfished chondrichthyans, and in many cases additional scientific data are required to inform those policies (Shiffman & Hammerschlag, 2016a; Simpfendorfer et al., 2011). Many early career chondrichthyan researchers want to perform conservation-relevant work (Ferry & Shiffman, 2014) but report uncertainty about which specific research questions and methods are most helpful for conservation (Shiffman & Hammerschlag, 2016b).

Published lists of research priorities can help guide scientists hoping to maximize the conservation impact of their work. Lists of identified research priorities have previously been published for chondrichthyans in general (Simpfendorfer et al., 2011), and for regional groups of species including highly migratory species of sharks in the US Atlantic (NOAA, 2020). Research priorities have also been identified for specific species such as white sharks (Huveneers et al., 2018) and manta rays (Stewart

et al., 2018), and for specific research areas including the impact of recreational fisheries on sharks (Gallagher et al., 2017). To date, there have been no lists of research priorities for all threatened or overfished species of chondrichthyans in US waters, and few lists of ocean conservation research priorities that also incorporate expert-identified priorities for policy solutions to conservation threats.

Expert solicitation is an increasingly common method for eliciting future priorities for researchers, managers, and advocates to focus their attention on (e.g., Provencher et al., 2020; Sutherland & Burgman, 2015). By identifying and surveying a large group of individuals with relevant and distinct but overlapping areas of expertise, one can create an aggregate composite picture of expert perspectives on an environmental issue—in other words, a large group of experts knows more about a complex issue than any single expert. A similar approach known as horizon scanning (e.g., Sutherland et al., 2020) invites those experts to think about not only what is happening now, but about emerging issues.

US waters include many distinct ecosystems and ecoregions, with many associated species of chondrichthyan fishes. The United States is an active shark fishing nation that has some of the world's most sustainable shark and skate fisheries (Simpfendorfer & Dulvy, 2017), and US waters are home to several endangered species of chondrichthyans (e.g., smalltooth sawfish, Brame et al., 2019). The United States is also home to many of the world's shark researchers (Castro, 2016; Huveneers et al., 2015; Shiffman et al., 2020), some of the earliest (and currently some of the most advanced) shark research (Castro, 2016), and many of the world's shark conservation advocacy organizations (Shiffman et al., 2021). While many chondrichthyan species are highly migratory or widely distributed, studies in one location can provide template studies for research or directly inform management in other nations, though we note that many common research methods used in the United States would be less helpful for data-limited fisheries management, or in nations with limited basic research or fisheries management infrastructure. For example, studies about the ecological importance of sharks that were performed in the United States and Australia have been cited in conservation campaigns in the Global South (Shiffman et al., 2021). Additionally, some practices used by scientists based in the United States who study systems in the global south have been the subject of recent research ethics challenges (Trisos et al., 2021).

The goal of this study was to create an expert-solicited, expert-validated list of conservation-relevant research priorities for scientists studying chondrichthyan species of concern, and a complementary list of policy priorities for advocates and managers who work on managing these species. This study also aims to highlight other important perspectives of US-based experts in shark conservation and management, which can inform future stakeholder outreach, advocacy, and improved relations between researchers and managers.

2 | METHODS

This study had three phases: identifying focal species, identifying experts to survey, and distributing and analyzing a two-part survey to those experts willing to participate.

2.1 | Identifying focal species

This survey was intended to assist in the study and management of those species found in US waters which are at the greatest risk of extinction over overexploitation. To determine the focal species for this study which informed which experts to contact, we created a list (see Data S1) of chondrichthyan fishes found in US waters that meet at least one of the following criteria: (1) assessed as threatened (Vulnerable, Endangered, or Critically Endangered) or Near Threatened by the IUCN Red List; (2) highlighted in a recent IUCN Red List report on threatened chondrichthyan species of the Americas (Kyne et al., 2012); (3) listed as Endangered or Threatened under the United States Endangered Species Act; (4) listed as a prohibited species or species of concern by NOAA or any coastal state's natural resources management agency; (5) listed as overfished or experiencing overfishing in the 2019 NOAA SAFE (Stock Assessment and Fisheries Evaluation) report; or (6) are commercially fished in the United States. This comprehensive list includes both species that are of immediate conservation concern as well as those which may require attention in the near future (e.g., Near Threatened species, species that are fished but not currently experiencing overfishing). While a Critically Endangered species is likely to be in more immediate need of conservation intervention than a Near Threatened species, the goal of this exercise was to be comprehensive in identifying a broad range of research and policy priorities for chondrichthyans of conservation concern in US waters.

2.2 | Identifying experts

Experts from a variety of fields including scientific research, conservation advocacy and environmental education, natural resource management, and industry were

identified and contacted via e-mail to assess willingness to participate in a two-part survey on emerging research and policy priorities for chondrichthyan species of concern. To identify academic researchers with relevant expertise, a literature review was conducted, focusing on studies from US waters in the past decade (2010–2019) on any identified focal species (Keyword searches can be found in supplementary materials.) Any author or coauthor from the identified studies who is based in the United States for whom we could find current contact information was approached for participation in this study. Any environmental activist based in the United States portfolio includes (broadly defined) conservation of or public education related to chondrichthyans (following Shiffman et al., 2021) was approached to participate in this survey. Representatives from the fishing industry who serve on Fisheries Management Councils or associated advisory panels for chondrichthyan fisheries were invited to participate in this study. Government natural resources management agency representatives who serve on Fisheries Management Councils, have coauthored fisheries management plans, or who have presented at SEDAR (Southeast Data Assessment and Review, a multi-stakeholder fishery science and management process) meetings were approached to participate. Contacted potential participants were also offered the opportunity to suggest people within their own organization or partner organizations that we should approach in addition to them. As the goal was determining the entire universe of US-based experts on these topics, identifying and contacting everyone with relevant expertise, this process did not focus on ensuring geographic, disciplinary, or demographic diversity, though questions related to these issues were included in the survey and are reported below. This process resulted in a total of 388 names.

2.3 | Survey Part 1

The first part of the survey asked participants to submit up to 15 proposed research priorities and up to 15 proposed policy priorities. Though the survey was anonymous, demographic information was also collected, including employer type (academia, environmental NGO, management, or industry), job type (researcher, manager, advocate, educator, fisher), region of focus, and past experience in science-based fisheries management. Other survey questions in Part 1 solicited respondent perspectives on a variety of background issues related to chondrichthyan conservation and management in the United States (see Data S1 for the exact wording of all survey questions). Respondents were also offered the opportunity to participate in Part 2 of the survey.

2.4 | Combining priorities from survey Part 1

All suggested priorities from Part 1 of the survey can be viewed in the Data S1. Similar suggested priorities were combined and rephrased for clarity. For example, "basic research on chondrichthyans that have not been well-studied such as catsharks" and "biological research aimed at understanding population dynamics of understudied sharks and skates in the North Pacific" were combined with other suggestions to "Improve knowledge of life history traits and reproductive potential of understudied species." Any priorities requiring elaboration or clarification are expanded upon in the results (e.g., North Pacific sharks and skates and catsharks were noted as specific species included in the initial priorities combined into the example above). Specific examples are not meant to be exhaustive and many priorities may be relevant for species of concern not listed by survey respondents.

2.5 | Survey Part 2

In Part 2, any respondent who participated in Part 1 was invited to comment on each priority identified in Part 1, and raise any concerns or suggestions they had. Priorities were grouped into broad categories, and both the categories and the priorities in each category were presented to respondents in randomized order. This survey component was included primarily as a quality control measure designed to allow expert respondents to confirm that the combined list of expert-generated priorities was reasonable and appropriate. Additionally, Part 2 respondents were offered the opportunity to rank priorities in their preferred order according to their professional opinion (e.g., if there were four priorities in a category, these were ranked from 1 to 4, if there were seven, they were ranked from 1 to 7, etc., and an average closer to one is a higher ranking). While the goal of this study was to determine a comprehensive list of research and policy priorities rather than identify "top priorities," we also report on relevant patterns in rankings.

3 | RESULTS

3.1 | Focal species

Based on the criteria described above, 85 focal species were identified (Data S1), including 1 chimera, 15 rays, 61 sharks, and 8 skates. Six species are assessed by the IUCN Red List as Critically Endangered, fifteen as Endangered, and eighteen as Vulnerable. Twenty-four species are assessed by the IUCN Red List as Near

Threatened and twelve as Least Concern (but are subject to local fishing pressure), and the remaining eleven species are assessed as Data Deficient. Four are listed as Threatened under the Endangered Species Act, and one as Endangered. Twenty-one species are protected from fishing in US waters or the waters of at least one state. Two species (great and scalloped hammerhead sharks) are protected in the waters of one state (Florida) but are commercially fished in adjacent Federal waters.

3.2 | Respondent demographics and expertise

Eighty-six identified experts participated in round 1 of the survey, and fifty-four participated in round 2. Any presented results that do not add up to 86 are because not every respondent answered every question, since not every question was relevant to everyone's background. Our respondents include multiple representatives from every identified category of expertise (e.g., industry, management, environmental conservation, and academic research) and every region within the contiguous United States (using the Fishery Management Council regions delineated by the Magnuson-Stevens Fishery Conservation and Management Act, Figure 1).

The most common employer type of respondents was academia, with 28 respondents including 19 faculty and eight graduate students. Eighteen respondents were government-employed scientists, including four state-level agency scientists. Eleven were government managers, including three state-level agency managers. Eight respondents were environmental NGO-employed scientists and seven were NGO-employed advocates or public educators. Four industry representatives responded, as did one classified as "other" (who reported working as a consultant across multiple fields). The most common regions of focus were the South Atlantic ($n = 15$), and the Gulf of Mexico and Pacific regions ($n = 13$ each). Three respondents identified their employer as "consultant/contractor," and two of those specified that they work primarily with industry groups and are therefore counted as industry here. One government manager who indicated that they worked in multiple regions noted that their regions of focus included New England, and one government scientist each who indicated that they worked in multiple regions noted that their regions of focus included the Caribbean and the Western Pacific, respectively. Two academics who indicated that they worked in multiple regions noted that their regions of focus included the Caribbean. The US Caribbean region, North Pacific region, and Western Pacific region are generally the subject of less management and research attention than other regions, so lower response numbers may be illustrative of issues the size of the professional community working in these regions rather than survey sample bias.

Forty-five respondents published (as lead or coauthor) at least one paper on a threatened or heavily fished species of US chondrichthyan, thirty-seven participated in at least one SEDAR workshop, and twenty-three served on a fisheries management council. Thirteen participated in at least one IUCN Red List shark specialist group workshop, and eight served in a formal capacity as part of the shark specialist group. Eighteen respondents answered "no" to each of these questions about their direct participation in the management process, five answered "yes" to all of these questions, and sixty-eight answered "yes" to at least one.

3.3 | Respondent perspectives on chondrichthyan conservation and management

The vast majority of respondents reported believing that the United States does a better or much better job than

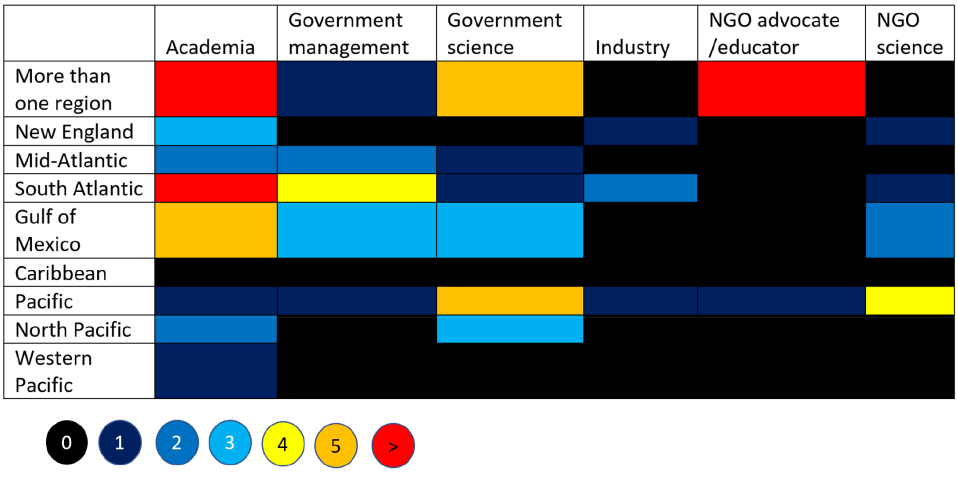

FIGURE 1 Heat map of employer class and region of expertise of Survey Part 1 respondents. Regions are following Fisheries Management Council regions as delineated by the Magnuson-Stevens Fishery Conservation and Management Act (see http://www.fisherycouncils.org/ for a map)

other countries at both protecting threatened species of chondrichthyans and managing chondrichthyan fisheries (Figure 2). All government employees (state and Federal, management and research), all NGO-employed scientists, and all graduate students believed that the United States does at least a comparable job relative to other countries on both questions. Most respondents answered similarly on both questions, but two NGO-employed advocates believe the United States does a much better job at protecting threatened species than other countries but does a much worse job at managing fisheries than other countries, and one industry representative believed the United States does a much worse job at protecting threatened species than other countries but does a much better job at managing fisheries. No respondents who have ever served on a fisheries management council, served as a member of the IUCN Red List Shark Specialist Group, or participated in a SEDAR workshop believed that the United States is generally doing worse at either action than other countries.

In response to the question "which of the following best describes your personal philosophy for shark conservation and management," 55 (71%) respondents indicated that "sustainable fisheries for sharks can and do exist, and therefore we should attempt to make shark fisheries more sustainable rather than attempt to ban shark fishing and trade in shark products whenever possible." Nine respondents indicated that "sustainable fisheries for sharks cannot and do not exist, and we should therefore attempt to ban shark fishing and trade in shark products," including three faculty members and two NGO advocates. This group of nine also included two past participants in SEDAR workshops and one respondent who had served on a fisheries management council. Ten respondents selected "other," of which seven responses consisted of support for sustainable fisheries in general while raising concerns about some specific fisheries or fishing practices. It should be noted that the presence of this question on the survey resulted in seven representatives from one environmental non-profit reporting that they would not take the survey.

Notably, during the second part of the survey when respondents were offered the opportunity to voice concerns about any suggested priority, no respondents raised major concerns about any proposed priority. Additionally, every individual priority was ranked first by at least one respondent and ranked last by at least one respondent. This suggests that our expert respondents were generally satisfied with the substance of the list of priorities generated by the group.

3.4 | Species of particular concern

Although the goal of this project was to generate a broad and thorough list of species facing variable levels of conservation challenges and not to identify the "top" species of concern, we did ask experts questions related to species that they feel are currently in the most need of conservation attention, as well as species they think will be in the most need of conservation attention over the next decade. The shortfin mako shark received by far the most mentions here ($n = 46$), followed by sawfish ($n = 30$), dusky sharks ($n = 23$), hammerhead sharks ($n = 19$), oceanic whitetip sharks ($n = 15$), cownose rays and thresher sharks (both with $n = 12$), and smooth hounds and dogfish ($n = 10$). Other species mentioned five or more times by expert respondents include blue sharks and great white sharks ($n = 9$), skates and rays, porbeagles, and sandbar sharks (each with $n = 6$), and sand tiger and blacknose sharks ($N = 5$). Several respondents explicitly noted that great white shark populations were increasing, and that their conservation concerns related to what increasing white shark populations meant for other species in the ecosystem, and that they were not especially concerned about the extinction of white sharks—the only case where a species mentioned in

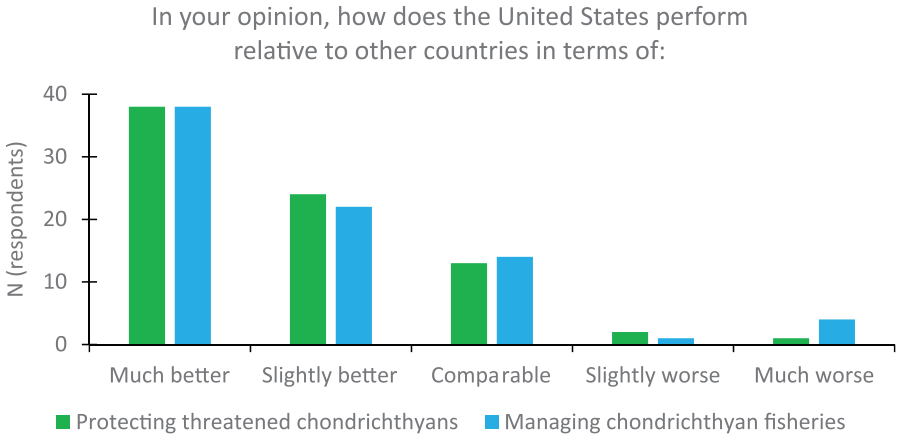

FIGURE 2 Responses to the questions "In your opinion, how does the United States Perform relative to other countries in terms of" both protecting threatened chondrichthyans (green) and managing chondrichthyan fisheries (blue)

TABLE 1 Research priorities identified by this study, organized by category

1. Category: Population status, stock assessments, and fisheries-independent population monitoring
Regular stock assessments of species impacted by fisheries (2.59)
Better assessments of population size, stock delineation, and connectivity, including expanded use of genetic tools (2.92)
Continue and expand fisheries-independent population surveys (3.41)
Regular population assessments of species facing threats (including but not limited to fisheries) (3.51)
Better understand the effects of different management strategies on sustainability and population recovery (3.87)
Develop population baselines for currently unexploited chondrichthyan species (4.69).
2. Category: Migration, habitat usage, and critical habitat identification
Identify important habitat, including nursery areas, mating grounds, foraging sites, and migratory pathways (1.92)
Study the impacts of climate change on chondrichthyan migration, home range, and habitat usage (3.03)
Expand acoustic monitoring arrays and acoustic telemetry research (3.26)
Focus telemetry efforts on conservation-relevant applied research (3.32)
Develop new tools for studying habitat use and migration (3.37)
3. Category: Fisheries interactions (including bycatch mitigation and post-release mortality) and data
Improve quality of data and reporting from commercial fisheries including non-target catch and discards (2.25)
Improve quality of data and reporting from recreational fisheries (2.53)
Assess effects of interventions on bycatch rates and post-release survival (2.92)
Assess rates of post-release mortality across gear types including variation based on environmental conditions (3.14)
Assess effects of interventions on quality and abundance of fisheries data (3.17)
4. Category: Ecological interactions and ecosystem role (3.92)
Understand the ecosystem role of chondrichthyans and the ecological effects of changing chondrichthyan populations (1.54)
Study the effects of climate change on chondrichthyan ecological interactions (2.22)
Study the effects of altered environmental conditions on chondrichthyans (2.24)
5. Category: Life history (3.85)
Improve knowledge of life history traits and reproductive potential of understudied species (2.31)
Assess potential fisheries-induced evolutionary impacts of chondrichthyan fishing, and how life history relates to fisheries sustainability (2.37)
Develop improved methods for studying age and growth, especially for species where vertebral ring counts are ineffective. (2.57)
Improve assessments of natural mortality rates in exploited chondrichthyan species across life history stages (2.74)
6. Category: Social science and interdisciplinary research
Develop and assess strategies for communicating scientifically accurate information to stakeholders and the public (2.27)
Assess the knowledge, attitudes, and practices of key stakeholder groups that interact with chondrichthyans, and how these groups interact (2.62)
Assess the cultural importance of sharks and how this influences public support for management options (3.14)
Better understand the motivations, attitudes, and practices of recreational anglers (3.43)
Increase research attention to markets for and conservation issues surrounding less-studied chondrichthyan products (3.54)
7. Category: Research priorities that did not fit into other categories
Develop and assess tools for managing data-limited and data-poor fisheries (2.63)
Increase available research and data on understudied chondrichthyan species (3.0)
Increase available research and data on understudied areas of the United States (3.32)
Better understand the causes of increased depredation rates, the effects of depredation, and interventions which could reduce or eliminate it (3.87)
Better understand the effects of pollutants on chondrichthyan species (4.97)
Identify and describe new species so they can be conserved and managed appropriately (5.03)
Develop and shift to non-lethal/minimally invasive research techniques (5.18)

Note: Priorities are presented by mean rank order from the second round of the study (e.g., if there are four priorities in a category, respondents ranked them from 1 to 4, and a lower mean value closer to one means that they were ranked more highly). While we present these priorities in the order they were ranked by respondents, this does not imply that any are a higher priority than others, anything on this list should be considered a priority.

response to this question included caveats like this. There were no significant patterns concerning a respondent's geographic area of focus and the species they suggested as species of particular concern (e.g., several respondents based in the Pacific suggested sawfish in Florida and cownose rays in the Chesapeake), suggesting that while experts have their area of focus, many are generally aware of broader issues in the field.

3.5 | Research priorities for focal chondrichthyan species

Two hundred and five suggested research priorities (Data S1) were combined into 35 consolidated research priorities in seven broader thematically grouped categories (Table 1). Priorities are presented in order as ranked in Part 2 of the survey, with mean rankings presented in parenthesis. The order of presentation is not meant to imply the relative importance of these proposed priorities or categories of priorities, anything on this list is considered a priority.

3.5.1 | Research priorities: Population status, stock assessments, and fisheries-independent population monitoring

Six population status priorities were identified (Table 1-1). Several respondents expressed support of the US fisheries management system, but encouraged more regular stock assessments and population tracking of fished species, specifically mentioning thresher and blue sharks. A genetic tool that several respondents felt would assist abundance estimates was close kin mark recapture (CKMR). Respondents noted that several currently underexploited or lightly exploited species may face expanded threats from shifting fisheries pressure in the future, including small skates and rays, Greenland sharks, and species found in the North Pacific.

3.5.2 | Research priorities: Migration, habitat usage, and critical habitat identification

Five research priorities related to migration and habitat usage were identified (Table 1-2). The climate change impacts priority here is distinct from those within the ecosystem role category. Here we are focusing on understanding climate change induced range shifts and changes in habitat usage; the ecosystem role category (below) focused on understanding the wider ecological effects of those changes. While respondents suggested that identifying critical habitat is important for all species, specific species mentioned here included hammerhead sharks, sawfish, and manta rays. Expert respondents expressed support for telemetry tools to answer vital questions related to migration and habitat usage, but expressed some concern that not all research in this field was driven by hypothesis-driven questions (see Hammerschlag et al., 2011, which notes that these tools are often used for exploratory "see where sharks go" studies not driven by research questions). New research tools suggested by respondents for increased use in studies of migration include AUVs and gliders, stable isotope and trace element analysis, and eDNA, and while respondents did not note this, it seems appropriate to stress that like telemetry tools, studies using these other tools should also be hypothesis-driven.

3.5.3 | Research priorities: Fisheries interactions (including bycatch mitigation and post-release mortality) and data

There were five priorities from the fisheries interactions category suggested by respondents (Table 1-3) Proposed priorities related to bycatch mortality mostly focused on fishing gear modifications and changes in handling practices, while interventions to improve the quality and abundance of data included improved training for fishermen and the addition of electronic fisheries monitoring. Respondents concerned about data and reporting wanted to ensure both accuracy (not missing anything) and specificity, requesting species-level data rather than merely recording, for example, "skate bycatch," as skate species vary widely in their conservation status.

3.5.4 | Research priorities: Ecological interactions and ecosystem role

Three research priorities related to ecological interactions and ecosystem role were identified (Table 1-4). Respondents stressed that changes in chondrichthyan populations could include decreases due to overexploitation, as well as population increases due to stock recovery. Local changes in population from range shifts due to climate change were also mentioned as a possible source of changes in population in a given ecosystem. When respondents referred to the effects of climate change on ecological interactions, these included studying the impacts of climate change induced range shifts on both the source and sink ecosystems (i.e., where chondrichthyans leave and where they newly arrive). While altered environmental conditions from many sources could potentially impact chondrichthyans, respondents specifically mentioned

bottom habitat loss due to trawling, overfishing of prey populations, and construction associated with offshore energy production and coastal development.

3.5.5 | Research priorities: Life history

Four life history research priorities were identified (Table 1-5), and mean rankings were all very similar (the total range was 0.4 out of a scale of 1–4). For understudied species, respondents specifically mentioned North Pacific species, deep sea species, and rays.

3.5.6 | Research priorities: Social science and interdisciplinary research

Five priorities from the social science and interdisciplinary research category were proposed (Table 1-6). Some less-studied chondrichthyan products suggested by respondents included stingray leather and shark liver oil.

3.5.7 | Research priorities that did not fit into other categories

Seven research priorities that did not fit into other categories were suggested by respondents (Table 1-7). Understudied areas of the United States suggested by respondents include US territories in the Caribbean, and while not noted by any respondents, we note here that the United States also has territories in the Pacific with threatened and understudied chondrichthyan fauna.

3.6 | Policy priorities for focal chondrichthyan species

Ninety-one suggested policy priorities (Data S1) were combined into twenty-seven consolidated priorities (Table 2). Each priority was also sorted into one of six categories, and presented in rank order from Part 2 of the survey with mean ranking in parenthesis.

3.6.1 | Policy priorities: Quotas/TAC

There were five policy priorities related to quotas and total allowable catches suggested by survey respondents (Table 2-1). The respondent suggested a take limit for bycatch of threatened chondrichthyans that automatically triggers fishery closure if exceeded, this respondent referenced a similar example in sea turtle conservation. Species-specific management plans were suggested as an alternative to the current US shark fisheries management system which manages related species together as complexes (e.g., the "large coastal shark complex" includes several species of sharks managed together).

3.6.2 | Policy priorities: Habitat/area-based protections

Five policy priorities related to habitat or area-based protections were suggested (Table 2-2). These included creating new protected areas, improving existing protected areas, using new technologies for monitoring and enforcement.

3.6.3 | Policy priorities: Data and monitoring requirements

Four policy priorities related to data and monitoring requirements were proposed (Table 2-3). Concerns about species-level data are related to the coarse nature of some bycatch data (e.g., recording bycatch as "skate" but not which species).

3.6.4 | Policy priorities: Market and trade measures

Five policy priorities related to markets and trade were proposed by respondents (Table 2-4). These focused on issues like traceability and transparency, restricting markets for illegal or poorly managed fisheries, and promoting markets for well-managed fisheries.

3.6.5 | Policy priorities: International policy issues

Four policy priorities related to international solutions were proposed (Table 2-5). While the focus of this study was on US-based species, many of these species are wide-ranging or highly migratory and face threats when they leave US waters. The United States also plays a role in international conservation and management policy negotiations (e.g., Levesque, 2008).

3.6.6 | Policy priorities that do not fit into other categories

Three policy priorities that do not fit into other categories were proposed (Table 2-6). The respondent who

TABLE 2 Policy priorities identified by this study, organized by category

1. Category: Quotas/total allowable catch
Bycatch/take limits that trigger automatic fishery closure when exceeded (2.5)
Use of ecosystem-based fisheries management plans (2.71)
Use of the precautionary principle to manage emerging fisheries (2.92)
Increased management attention for skate fisheries (3.39)
Use of species-specific fisheries management plans (3.47)
2. Category: Habitat/area-based protections
More and stronger spatial or temporal protections of important habitats including time-area closures and MPAs (2.41)
Improve management for species with multi-jurisdictional ranges (2.59)
Real-time monitoring and management of hotspots for threatened species (2.86)
Prioritize improvement of management and habitat protection in US territories (3.46)
Consider future habitat needs when planning for population recovery or climate change (3.68)
3. Category: Data and monitoring requirements
Require species-level data on bycatch (both landings and discards) from commercial fisheries (1.74)
Incorporate new technology (e.g., electronic monitoring) into data gathering from fishing vessels (2.41)
Improve the monitoring of recreational fishery landings and discards (2.44)
Promote greater transparency of data used to generated CITES non-detriment findings (3.41)
4. Category: Market and trade measures
Restrict the importation of overfished or threatened chondrichthyans, or seafood with high chondrichthyan bycatch (2.81)
Restrict the illegal trade in shark fins, including transshipment through US ports (2.89)
Limit domestic markets for chondrichthyan products from poorly managed unsustainable fisheries, or from species of conservation concern (2.95)
Promote domestic markets for chondrichthyan products from well-managed, sustainable fisheries (3.16)
Improve the import/export transparency and traceability of chondrichthyan products, or products from fisheries with high chondrichthyan bycatch (3.19)
5. Category: International Policy Issues
Encourage trading partners to improve the sustainability of their fisheries (2.06)
Encourage trading partners to improve the protection of their threatened chondrichthyan species (2.2)
Factor international catch of shared stocks into domestic fishery management plans (2.49)
Provide international aid including funding, equipment, and expertise to support improved sustainability of international chondrichthyan fisheries and protected of threatened species abroad (3.26)
6. Category: Policy priorities that do not fit into other categories
Prioritize improving management (catch limits, gear/handling regulations) and data collection from recreational fisheries (1.69)
Adjust gear or fishing practices to reduce bycatch rates and/or increase post-release survival (1.72)
Develop clearer guidance for addressing negative interactions between protected chondrichthyans and other protected species (2.59)

Note: Priorities are presented by mean rank order from the second round of the study (e.g., if there are four priorities in a category, respondents ranked them from 1–4, and a lower mean value closer to one means that they were ranked more highly). While we present these priorities in the order they were ranked by respondents, this does not imply that any are a higher priority than others, anything on this list should be considered a priority.

suggested improving policies concerning interactions between protected chondrichthyans and other protected species was referencing recent reports of how great white shark populations off the Pacific coast of the United States are recovering, and that recovery is resulting in increased predation pressure on protected sea otters.

4 | DISCUSSION

Many US-based chondrichthyan researchers report wanting to perform practical applied science with the goal of generating data useful for conserving threatened species; however, they have also expressed uncertainty concerning where and how to most usefully focus this effort

(Ferry & Shiffman, 2014; Shiffman & Hammerschlag, 2016b). Additionally, many conservation advocates and practitioners have expressed frustration that academics are not focusing their work on the most appropriate study species or research questions if the goal is assisting with conservation, expressing concern that some species are already quite well-studied and some methods are already quite widely used (Shiffman et al., 2021), though we acknowledge that study species selection is often based on logistical ease of access. This expert-solicited list of research priorities, which includes perspectives from academics, managers, environmental advocates, and industry can help US-based researchers to focus on the most pressing research needs of their study species or even to select new study species and systems.

Experts participating in this study overwhelmingly believed that the United States does as well or better than other nations at managing chondrichthyan fisheries. This perception is supported by comparative global-scale analyses of the sustainability of shark fisheries (Shiffman & Hueter, 2017; Simpfendorfer & Dulvy, 2017). While this is heartening news for those who have dedicated their lives to using this system to protect threatened species, this result does not imply that the US system is perfect or beyond reproach. Even the most sustainable fisheries have room for improvement, especially as new data are published and new techniques are made available, and concerns remain about some aspects of US shark fisheries management.

Additionally, the expert respondents who were more involved in US fisheries management were more likely to believe that US fisheries management is working well than those who have not participated in these processes. To some extent this result may be because people who are more aware of the details and nuances of management decisions and processes are simply better informed about these complex issues. Indeed, environmental advocates who report being more familiar with the technical scientific literature generally have a higher opinion of the state of shark fisheries management (Shiffman et al., 2021). This finding also aligns with social science research on the importance of stakeholder engagement, "buy in," and understanding of management data and processes as factors shaping perceptions of the ease or effectiveness of management (e.g., Crosman et al., 2020).

However, this result may also reflect a lack of objective perspective on the part of those heavily involved in management decision-making. Numerous studies about stakeholder buy-in show that people who participate in a regulatory process are more likely to support the decisions made during that process and are more likely to believe that the process is effective, independent of how objectively effective those decisions are (Deith et al., 2021). Additionally, if the same people are the only experts present for many management discussions and decisions, it is less likely that any possible errors will be caught. And while it may make sense to involve strong supporters of science-based fisheries management in decisions surrounding science-based fisheries management, input from experts who have not participated in these discussions before (or are even publicly skeptical of them) may reveal issues or perspectives that otherwise may not have been noticed, or may result in former critics becoming supporters as they engage more deeply with fisheries management processes. Fisheries management discussions in the United States are open, transparent, and participatory, but opportunities for engagement are not widely advertised outside of fisheries management professional circles—indeed, several experts from academia and the environmental non-profit sector surveyed in this study reported that they have never participated in such discussions. We do not mean to imply that NOAA is intentionally excluding perspectives (or the individuals or organizations that hold those perspectives) just that individuals who represent certain perspectives report that they haven't gotten involved in management discussions, and in some cases that they do not know how to do so.

Relatedly, there is an ongoing debate over whether the most effective solutions to shark conservation crises are sustainable fisheries management tools or bans on fishing and trade in chondrichthyan products (Shiffman et al., 2021; Shiffman & Hammerschlag, 2016a). This debate seems largely absent from our results here, with suggested priorities overwhelmingly related to sustainable fisheries management tools, and 71% of respondents in this study indicating that their personal philosophy leans more towards sustainable shark fisheries than towards bans on shark trade and shark fishing. This is likely because of our focus on the United States, which generally has the most sustainably managed chondrichthyan fisheries in the world (Shiffman & Hueter, 2017; Simpfendorfer & Dulvy, 2017). However, some of the non-profits who work towards bans are based in the United States (Shiffman et al., 2021), so this result may also reflect that certain voices and perspectives were not captured by our survey methodology. Representatives of organizations which promote bans rather than sustainable fisheries (as well as organizations that work towards both kinds of policies) were contacted in this study, and had previously agreed to participate in past studies by this research team (Shiffman et al., 2021). A few representatives of an environmental non-profit organization working on bans declined to participate in this survey because of the presence of the question on experts' personal philosophies about shark conservation and

management, so the responses to this question and related questions should be interpreted with some caution. Additionally, there are some types of relevant expertise that might not have been captured by our method of expert identification.

The research priorities identified by this exercise encompass a wide spectrum of disciplines, species, and study systems, further demonstrating that science-based management is a complex endeavor that requires support from many sectors. No one researcher or lab can reasonably gather data on all of these priorities or species, and we must work in concert with each other to generate data that can help conserve and protect chondrichthyans. Additionally, cross-disciplinary collaborations between labs are becoming increasingly important because answering complex questions often requires multiple areas of expertise (Huveneers et al., 2018).

The species of particular concern identified by expert respondents here largely match recent management resolutions issued by the Elasmobranch Society's conservation committee (https://elasmo.org/resolved), which in the last 5 years have focused on Atlantic shortfin mako sharks, sawfishes, skates, dusky sharks, and hammerhead sharks. Sawfishes have long been some of the most threatened marine fishes in the world (Simpfendorfer, 2002), and dusky sharks are a longstanding conservation issue along the Atlantic seaboard (Bangley et al., 2020). The inclusion of oceanic whitetip sharks here suggests a possible new area of focus for the near future, as NOAA begins holding workshops associated with their recent Endangered Species Act listing (Young & Carlson, 2020). Atlantic shortfin mako sharks being overwhelmingly the most mentioned species of concern here should further encourage rapid and dramatic conservation actions to protect this heavily fished species recently re-assessed as Endangered by the IUCN Red List. These findings suggest that our sample does accurately reflect broader existing expert consensus, as the priorities identified here are largely those which experts have recently attempted to publicly identify as urgent policy and management concerns. However, despite the fact that many of the most threatened species of chondrichthyans are rays, most species of concern mentioned here were sharks. This perhaps reflects the relatively large public focus on sharks compared to their relatives which face similar threats.

Several identified priorities from this study are similar to those identified by past research priority surveys. Indeed, some of the most-studied areas of chondrichthyan research like basic life history, reproductive biology, and habitat use studies (Huveneers et al., 2015; Shiffman et al., 2020) are still listed here as outstanding research priorities. This suggests that several long-established research avenues remain useful over time, and that the geographic scope and biological diversity of chondrichthyan populations ensures that many areas of "basic" research continue to be relevant and urgent. However, the expert scientists surveyed here were selected in part because they perform research like this, and this may be a case of people arguing for the importance of the work they perform rather than an objective assessment of the relative importance of different types of work.

However, the results presented here also include several research priorities not identified by previous exercises, including studying more aspects of the impacts of climate change on biology, behavior, and habitat usage of chondrichthyans, new concerns about the effects of offshore energy infrastructure construction, more emphasis on recreational fisheries, concerns about understudied species and markets, suggestions to more regularly run existing stock assessments and perform new stock assessments for populations not yet exploited by fisheries, and new priorities related to public science engagement and public education. These novel results demonstrate the utility of repeating similar priority-setting exercises across different geographic regions and study systems, and repeating these exercises over time. Additionally, this priority-setting exercise is distinct from past similar studies due to the inclusion of environmental advocates and representatives from the fishing industry, as well as the inclusion of policy priorities in addition to research priorities.

It is noteworthy that some research priorities highlighted in past studies were not suggested here, such as those related to shark wildlife tourism (Huveneers et al., 2018), economic valuation of chondrichthyan fisheries and economic valuation of non-extractive uses of chondrichthyans (Simpfendorfer et al., 2011), and studying the socioeconomic implications of shark fin trade bans or public safety concerns associated with shark population rebuilding (NOAA, 2020). This is more likely a result of distinct areas of focus between these surveys rather than past priorities no longer being relevant (e.g., wildlife tourism was stressed by Huveneers et al., 2018's focus on white sharks globally, and limited white shark tourism exists in the United States where this study is focused). This suggests that in addition to there being value in repeating similar priority setting exercises for different study systems, it is important for prospective researchers in search of research priority areas to select the list of priorities most relevant to their study system.

Many non-profit advocates may have limited ability to choose the policy issues they work on, but it is our goal for this expert-produced list of emerging policy priorities to assist their important work by highlighting areas that a broad cross-section of experts believe are not currently receiving enough attention. Many advocacy groups report basing their policy priorities on scientific evidence and

scientists' expert opinions (Shiffman et al., 2021), so these results may be a useful resource for identifying new and emerging areas of advocacy.

Although many of the species identified in this study are widely distributed (i.e., found in the waters of many nations) or highly migratory (i.e., individuals moving between the territorial waters of many nations) and many threats are global in nature, this study focused on the United States. This was done for logistical simplicity because much of the world's shark research and conservation infrastructure is based in the United States (Shiffman et al., 2020; 2021) and because the United States' research and policymaking system is the one most familiar to the authors. However, although some of the marine science and management infrastructure in the United States is distinct from that of other nations, many of the outstanding research priority questions identified here could be useful to researchers studying these species in other locations, and studies performed on US populations of these species can be useful to managers elsewhere, though we certainly acknowledge that not all US-derived data will be useful to managers in other nations with other management systems in place. Additionally, following Trisos et al. (2021) we feel it is inappropriate for a team of US-based researchers to determine global priorities, but suggest that this study itself could be a template for follow-up priority-setting exercises in other nations, led by locally based experts familiar with their regions.

It is our goal to have these findings aid the next generation of US-based chondrichthyan researchers who want to conduct conservation-relevant research to devote their studies to gathering data that will support the improved conservation and management of chondrichthyan species of concern.

ACKNOWLEDGMENTS

The authors would like to thank the many scientists, managers, conservationists, and fishers who took the time to complete our survey. We would like to thank Dr. Jennifer Provencher for her assistance in shaping the methodology.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

This project was conceived by author David S. Shiffman under the postdoctoral supervision of author Lara A. Ferry. This work served as the Masters of Professional Science conservation internship for coauthor Jessica N. Elliott, whose work included data mining, literature reviews, and some preliminary data analysis. Authors Catherine C. Macdonald and Julia N. Wester provided social science advice throughout, and author Beth A. Polidoro provided fisheries management and marine conservation advice throughout. All authors contributed to writing the manuscript.

DATA AVAILABILITY STATEMENT

In keeping with the terms of our IRB approval, an anonymized version of the data used in this study is available upon request.

ETHICS STATEMENT

This survey was covered under Arizona State University Institutional Review Board permit #00011976.

ORCID

David S. Shiffman https://orcid.org/0000-0002-6093-5559

Catherine C. Macdonald https://orcid.org/0000-0003-2146-4966

REFERENCES

Bangley, C. W., Curtis, T. H., Secor, D. H., Latour, R. J., & Ogburn, M. B. (2020). Identifying important juvenile dusky shark habitat in the Northwest Atlantic Ocean using acoustic telemetry and spatial modeling. *Marine and Coastal Fisheries*, *12*(5), 348–363.

Brame, A. B., Wiley, T. R., Carlson, J. K., Fordham, S. V., Grubbs, R. D., Osborne, J., … Poulakis, G. R. (2019). Biology, ecology, and status of the smalltooth sawfish Pristis pectinata in the USA. *Endangered Species Research*, *39*, 9–23.

Castro, J. I. (2016). The origins and rise of shark biology in the 20th century. *Marine Fisheries Review*, *78*(1–2), 14–33.

Crosman, K. M., Dowling, N. A., & Bostrom, A. (2020). The effects of Fishpath, a multi-stakeholder decision-support tool, on stakeholder buy-in to management in data-limited fisheries. *Marine Policy*, *122*, 104215.

Deith, M. C., Skerritt, D. J., Licandeo, R., Duplisea, D. E., Senay, C., Varkey, D. A., & McAllister, M. K. (2021). Lessons learned for collaborative approaches to management when faced with diverse stakeholder groups in a rebuilding fishery. *Marine Policy*, *130*, 104555.

Dulvy, N. K., Fowler, S. L., Musick, J. A., Cavanagh, R. D., Kyne, P. M., Harrison, L. R., … White, W. T. (2014). Extinction risk and conservation of the world's sharks and rays. *elife*, *3*, e00590.

Ferry, L. A., & Shiffman, D. S. (2014). The value of taxon-focused science: 30 years of elasmobranchs in biological research and outreach. *Copeia*, *2014*(4), 743–746.

Gallagher, A. J., Hammerschlag, N., Danylchuk, A. J., & Cooke, S. J. (2017). Shark recreational fisheries: Status, challenges, and research needs. *Ambio*, *46*(4), 385–398.

Hammerschlag, N., Gallagher, A. J., & Lazarre, D. M. (2011). A review of shark satellite tagging studies. *Journal of Experimental Marine Biology and Ecology*, *398*(1–2), 1–8.

author>Heithaus, M. R., Frid, A., Wirsing, A. J., & Worm, B. (2008). Predicting ecological consequences of marine top predator declines. *Trends in Ecology & Evolution*, *23*(4), 202–210.

Huveneers, C., Apps, K., Becerril-García, E. E., Bruce, B., Butcher, P. A., Carlisle, A. B., ... Werry, J. M. (2018). Future research directions on the "elusive" white shark. *Frontiers in Marine Science*, *5*, 455.

Huveneers, C., Ebert, D. A., & Dudley, S. F. J. (2015). The evolution of chondrichthyan research through a metadata analysis of dedicated international conferences between 1991 and 2014. *African Journal of Marine Science*, *37*(2), 129–139.

Kyne, P. M., Carlson, J. K., Ebert, D. A., Fordham, S. V., Bizzarro, J. J., Graham, R. T., Kulka, D. W., ... Dulvy, N. K. (2012). In P. M. Kyne (Ed.), *The Conservation Status of North American, Central American, and Caribbean Chondrichthyans*. IUCN Species Survival Commission Shark Specialist Group.

Levesque, J. C. (2008). International fisheries agreement: Review of the International Commission for the Conservation of Atlantic Tunas: Case study—Shark management. *Marine Policy*, *32*(3), 528–533.

Macdonald, C., Gallagher, A. J., Barnett, A., Brunnschweiler, J., Shiffman, D. S., & Hammerschlag, N. (2017). Conservation potential of apex predator tourism. *Biological Conservation*, *215*, 132–141.

NOAA Fisheries (2020). Atlantic Highly Migratory Species Management-Based Research Needs and Priorities

Pacoureau, N., Rigby, C. L., Kyne, P. M., Sherley, R. B., Winker, H., Carlson, J. K., ... Dulvy, N. K. (2021). Half a century of global decline in oceanic sharks and rays. *Nature*, *589*(7843), 567–571.

Provencher, J. F., Liboiron, M., Borrelle, S. B., Bond, A. L., Rochman, C., Lavers, J. L., ... Mallory, M. L. (2020). A Horizon Scan of research priorities to inform policies aimed at reducing the harm of plastic pollution to biota. *Science of the Total Environment*, *733*, 139381.

Shiffman, D. S., Ajemian, M. J., Carrier, J. C., Daly-Engel, T. S., Davis, M. M., Dulvy, N. K., Grubbs, R. D., Hinojosa, N. A., Imhoff, J., Kolmann, M. A., Nash, C. S., Paig-Tran, E. W. M., Peele, E. E., Skubel, R. A., Wetherbee, B. M., Whitenack, L. B., & Wyffels, J. T. (2020). Trends in chondrichthyan research: An analysis of three decades of conference abstracts. *Copeia*, *108*(1), 122–131.

Shiffman, D. S., & Hammerschlag, N. (2016a). Shark conservation and management policy: A review and primer for non-specialists. *Animal Conservation*, *19*(5), 401–412.

Shiffman, D. S., & Hammerschlag, N. (2016b). Preferred conservation policies of shark researchers. *Conservation Biology*, *30*(4), 805–815.

Shiffman, D. S., & Hueter, R. E. (2017). A United States shark fin ban would undermine sustainable shark fisheries. *Marine Policy*, *85*, 138–140.

Shiffman, D. S., Macdonald, C. C., Wallace, S. S., & Dulvy, N. K. (2021). The role and value of science in shark conservation advocacy. *Scientific Reports*, *11*(1), 1–12.

Simpfendorfer, C. A. (2002). Smalltooth sawfish: The USA's first endangered elasmobranch? (Marine Matters). *Endangered Species Update*, *19*(3), 53–58.

Simpfendorfer, C. A., & Dulvy, N. K. (2017). Bright spots of sustainable shark fishing. *Current Biology*, *27*(3), R97–R98.

Simpfendorfer, C. A., Heupel, M. R., White, W. T., & Dulvy, N. K. (2011). The importance of research and public opinion to conservation management of sharks and rays: A synthesis. *Marine and Freshwater Research*, *62*(6), 518–527.

Stewart, J. D., Jaine, F. R., Armstrong, A. J., Armstrong, A. O., Bennett, M. B., Burgess, K. B., ... Stevens, G. M. (2018). Research priorities to support effective manta and devil ray conservation. *Frontiers in Marine Science*, *5*, 314.

Sutherland, W. J., & Burgman, M. (2015). Policy advice: Use experts wisely. *Nature News*, *526*(7573), 317–318.

Sutherland, W. J., Dias, M. P., Dicks, L. V., Doran, H., Entwistle, A. C., Fleishman, E., ... Thornton, A. (2020). A horizon scan of emerging global biological conservation issues for 2020. *Trends in Ecology & Evolution*, *35*(1), 81–90.

Trisos, C. H., Auerbach, J., & Katti, M. (2021). Decoloniality and anti-oppressive practices for a more ethical ecology. *Nature Ecology & Evolution*, *5*, 1–8.

Young, C. N., & Carlson, J. K. (2020). The biology and conservation status of the oceanic whitetip shark (Carcharhinus longimanus) and future directions for recovery. *Reviews in Fish Biology and Fisheries*, *30*(2), 293–312.

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: Shiffman, D. S., Elliott, J. N., Macdonald, C. C., Wester, J. N., Polidoro, B. A., & Ferry, L. A. (2022). The next generation of conservation research and policy priorities for threatened and exploited chondrichthyan fishes in the United States: An expert solicitation approach. *Conservation Science and Practice*, *4*(3), e12629. https://doi.org/10.1111/csp2.12629