Received: 10 July 2018 | Revised: 30 August 2018 | Accepted: 9 September 2018

DOI: 10.1111/conl.12610

POLICY PERSPECTIVE

WILEY Conservation Letters
A journal of the Society for Conservation Biology
Open Access

Leveraging satellite technology to create true shark sanctuaries

Darcy Bradley[1,2] | Juan Mayorga[1,3] | Douglas J. McCauley[2,4] | Reniel B. Cabral[1,2] | Patric Douglas[5] | Steven D. Gaines[1,2]

[1]Bren School of Environmental Science & Management, University of California, Santa Barbara, CA 93106, USA

[2]Marine Science Institute, University of California, Santa Barbara, CA 93106, USA

[3]Pristine Seas, National Geographic Society, Washington, DC 20036, USA

[4]Department of Ecology, Evolution, and Marine Biology, University of California, Santa Barbara, CA 93106, USA

[5]Reef Worlds, Los Angeles, CA 90120, USA

Correspondence
Darcy Bradley, Marine Science Institute, University of California, Santa Barbara, CA 93106.
Email: darcybradley@ucsb.edu

Abstract

Shark sanctuaries are an ambitious attempt to protect huge areas of ocean space to curtail overfishing of sharks. If shark sanctuaries are to succeed, effective surveillance and enforcement is urgently needed. We use a case study with a high level of illegal shark fishing within a shark sanctuary to help motivate three actionable opportunities to create truly effective shark sanctuaries by leveraging satellite technology: (1) require vessel tracking systems; (2) partner with international research organizations; and (3) ban vessels previously associated with illegal fishing from shark sanctuaries. Sustaining the level of fishing mortality observed in our case study would lead even a healthy shark population to collapse to <10% of its unfished state in fewer than five years. We outline implementations pathways and provide a roadmap to pair new and emerging satellite technologies with existing international agreements to offer new hope for shark conservation successes globally.

KEYWORDS

AIS, big data, fisheries, illegal fishing, protected areas, RFMO, shark conservation

1 | INTRODUCTION

With shark fishing efforts unrelenting and a quarter of shark species threatened with extinction (Dulvy et al., 2014), "shark sanctuaries" have arisen as an ambitious attempt to curtail further declines (Ward-Paige, 2017). Since 2009, sixteen countries have established sanctuaries that ban commercial fishing of sharks within entire exclusive economic zones (EEZs), covering >3% of the ocean (Ward-Paige & Worm, 2017). Almost immediately, the capacity for shark sanctuaries to effectively conserve and rebuild shark populations was questioned due to insufficient monitoring and enforcement (Davidson, 2012; Dulvy, 2013) – a position supported by indirect evidence that shark populations in the first sanctuary were still threatened by fishing (Vianna, Meekan, Ruppert, Bornovski, & Meeuwig, 2016). Still others urged skeptics to "give shark sanctuaries a chance," arguing that a moratorium on all shark products is easier and less resource-intensive to enforce than typical fisheries management strategies (Chapman et al., 2013). We use a case study that reveals evidence of a high level of illegal shark fishing within a shark sanctuary to motivate a framework for urgently needed surveillance and enforcement to ensure that the protections promised to sharks within sanctuary borders are realized.

Shark conservation is a complex and expensive enterprise (Dulvy et al., 2017), and overfishing continues to drive the decline of many shark populations globally (Davidson, Krawchuk, & Dulvy, 2016). The introduction of science-based fisheries management plans that include quotas, size limits, gear restrictions, and other regulations to address the overexploitation of sharks have seen successes in a handful of countries with well-funded and developed fisheries management systems (e.g., United States, Australia; Simpfendorfer & Dulvy, 2017). But enforcing shark management plans requires extensive monitoring for compliance and the regular collection of species-specific data to conduct stock assessments to track population trajectories and set future catch limits. For many nations with vast and remote ocean territories, often with limited human populations, developing economies with scarce resources for science, monitoring, and enforcement, and substantial industrial fishing by foreign fleets, overcoming the challenges of traditional fisheries species-specific management may simply be insurmountable (Ward-Paige, 2017). Instead, enacting blanket protection for sharks via sanctuaries could be a less complex and resource-intensive conservation solution to combat shark overfishing (Chapman et al., 2013), particularly when supported by legislation with high enforcement potential (e.g., prohibition of the possession of all shark products within a sanctuary; Cramp, Simpfendorfer, & Pressey, 2018). While complexity is reduced in terms of species-specific quota monitoring and the need for scientific assessments, enforcement of regulations – that is, a prohibition on shark fishing – requires effective surveillance that is currently lacking in many shark sanctuaries (Chapman et al., 2013; Davidson, 2012; Dulvy et al., 2017; Vianna et al., 2016; Ward-Paige, 2017; Ward-Paige & Worm, 2017).

Shark sanctuaries were designed to allow existing natural resource management and customs personnel to enforce bans on the possession, sale, and trade of sharks and shark products without the need for additional resources, because identifying sharks among catch does not require special training or expertise (The Pew Charitable Trust, 2015). Although enforcement may be robust in some nearshore environments, onshore within fishing ports, and occasionally at fishing grounds via onboard observer programs, shark sanctuary nations generally lack a strategy to comprehensively enforce and monitor offshore and remote areas, which comprise the majority of ocean area protected by most shark sanctuaries. Yet, governments continue to draft shark sanctuary legislation without comprehensive compliance and enforcement mandates and without funding to support such efforts (Ward-Paige, 2017).

Here, we provide recommendations and suggest implementation pathways to improve sanctuary surveillance and enforcement via satellite technologies. Satellite technologies have created a new era of marine governance that, when combined with technical expertise from international organizations and academia, can monitor vessel activities in even our most remote ocean spaces (McCauley et al., 2016). Our recommendations are informed by a case study of suspected illegal shark fishing that we remotely observed occurring within the Republic of the Marshall Islands (RMI) shark sanctuary.

2 | A CASE STUDY: THE RMI SHARK SANCTUARY

The Republic of the Marshall Islands– a Pacific island nation consisting of 29 atolls and 5 islands – was an early leader in the adoption of sweeping protections for sharks. In 2011, the RMI parliament declared all ~2 million km^2 of its EEZ as a shark sanctuary, prohibiting the commercial fishing of sharks and retention of accidentally fished sharks from within the EEZ, sale of shark or shark products, and use of wire leaders responsible for high shark bycatch (MIMRA Act P.L. 2011-63). All fishing vessels operating in the RMI EEZ are required to land their catch at local RMI ports and at sea transfers (i.e., transshipments) are prohibited (with some exemptions). Non-compliance with these stipulations is punishable by fines up to US$200,000.

As part of an ecological study to track the movement of reef sharks within the RMI, 15 adult gray reef sharks (*Carcharhinus amblyrhynchos*) were tagged with pop-up satellite archival tags (Desert Star Systems) in October 2015 (Table S1). Within 6 days to 3 months from the date of tagging, at least 8 of the 15 satellite tagged sharks were suspected of being illegally fished from within the RMI shark sanctuary (Figure 1). Each of the 8 shark satellite tags was tracked moving 450-4,346 km from its deployment location at average cruising speeds of 18.8 ± 1.4 km/h (Table S2), roughly due west across the Pacific Ocean, until the end of the tag transmission period in March 2016 (Figure S1). Tags could not have been attached to freely swimming animals – gray reef sharks have an average sustained swim speed of 2.1 km/h (Watanabe, Goldman, Caselle, Chapman, & Papastamatiou, 2015). Tags were also not drifting at the surface – regional prevailing sea surface currents are southwest with a maximum reported speed of 0.3 km/h (Bonjean & Lagerloef, 2002). Two satellite tags ultimately transmitted from fishing ports in Guam and the Philippines (2,391 and 4,543 km from deployment locations, respectively; Figure S2). After tag 154257 arrived in the Port of Guam (March 10, 2016; 23:33), customs officials found that a single 16.2 m, 20 metric ton tuna longline vessel with authorization to transship on the high seas had recently arrived in port. The vessel was searched the following morning (March 11, 2016), but no shark or shark products were found. A final position was transmitted from the tag near the Guam airport (Figure 2).

A few important insights emerge from the RMI putative illegal shark fishing incidents. The level of fishing (>50% of the 15 tagged sharks within 3 months; Table S1) gives cause for concern and demands urgency for improved compliance. If captured sharks are assumed to have been killed, sustaining this level of fishing mortality would lead even a healthy population to collapse to <10% of its unfished state in less than 5 years (Figure S3). Our mortality estimates and modeled

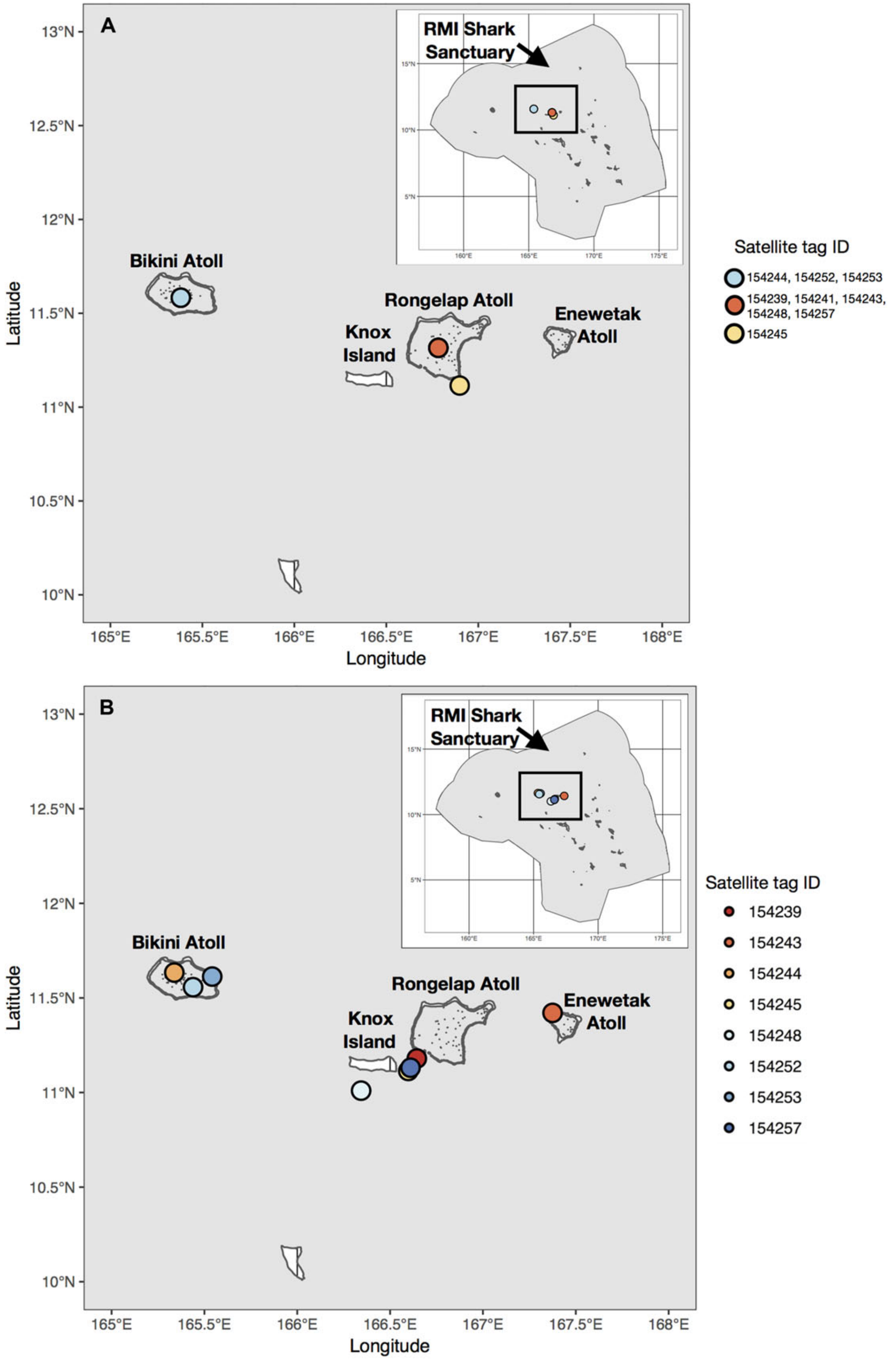

FIGURE 1 Tag deployment locations for sharks in the RMI shark sanctuary (only locations for sharks suspected of being illegally fished are shown) (A); and putative illegal shark fishing locations: (from west to east) Bikini atoll, between Rongelap atoll and Knox island, and on Enewetak atoll (B)

Note: Different colors indicate shark satellite tag IDs.

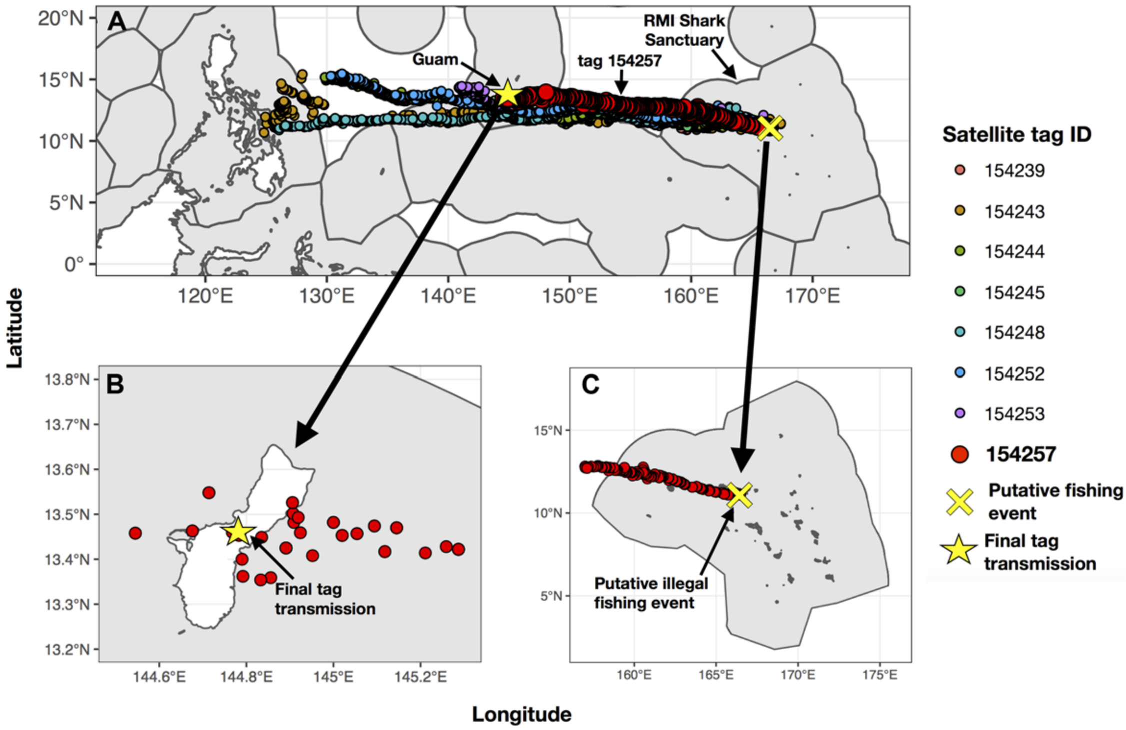

FIGURE 2 Suspicious transit of a shark tag from a shark sanctuary to the Port of Guam. The transit of tags associated with all sharks suspected of being illegally fished from the RMI Shark Sanctuary across the western Pacific Ocean are shown (A), with shark satellite tag 154257 shown in red. The shark associated with tag 154257 was suspected of being illegally fished from within the RMI Shark Sanctuary (C); the tag then transited 2,391 km to the Port of Guam (the scatter of points shows the approach to port), with a final position transmitted near the Guam airport (B) Note: The yellow "x" indicates the location of putative illegal fishing and yellow stars indicate the location of the final tag transmission. Uniquely colored circles show the transit path of individual shark satellite tag IDs suspected of being illegally fished.

population collapse are based on a small sample size in a fairly localized region of the RMI sanctuary (Figure 1), and may therefore not be representative of illegal fishing activity throughout the sanctuary. However, declines in the presence of shark species and the illegal catch and sale of shark has been reported for a number of sites in the RMI, and historical shark catch comprised nearly 14% of all catch reported for the RMI EEZ, an order of magnitude higher than any other shark sanctuary (Ward-Paige & Worm, 2017). Each shark in this study was also fished in nearshore waters (Figure 1) then transported up to thousands of kilometers (Figure S1). The location of the suspected fishing incidents followed by this long-distance transit suggests that targeted shark fishing by commercial vessels, as opposed to subsistence shark fishing for local consumption (which is permitted under RMI law), is likely. Alternatively, it is also possible that local fishers caught and illegally sold captured sharks to commercial fishing vessels, such as tuna boats, which has been reported in the region (Ward-Paige & Worm, 2017). Additionally, the incident in the Port of Guam indicates that relatively small vessels, particularly those with authorization for transshipment, may be characteristic of vessels likely to engage in targeted reef shark fishing within shark sanctuaries and therefore may demand a heightened level of monitoring, including monitoring of refrigerated cargo vessels (i.e., transshipment vessels). Finally, despite monitoring satellite tag tracks in near real-time and cross-checking position information with available vessel monitoring data and information about transshipment vessels operating in the vicinity of the RMI EEZ (Figure S4), we were unable to identify the vessels responsible for the illegal fishing activity in the RMI (see Supporting Methods), highlighting the need to rethink an effective monitoring strategy for shark sanctuaries.

2.1 | Recommendations: The power of satellite technology

We identify three actionable opportunities for shark sanctuary nations to expand their enforcement capacity and improve the efficacy of sanctuary regulations. First, a robust marine monitoring program that permits the viewing of all vessel activity within shark sanctuary borders is urgently needed. Shark sanctuary nations should therefore mandate satellite vessel tracking systems (VTS) – that is, automatic identification system (AIS), vessel monitoring systems (VMS), or other emerging VTS – for all vessels operating in their EEZs. The use of anticollision signals from AIS has revolutionized the way we monitor ocean uses, including the

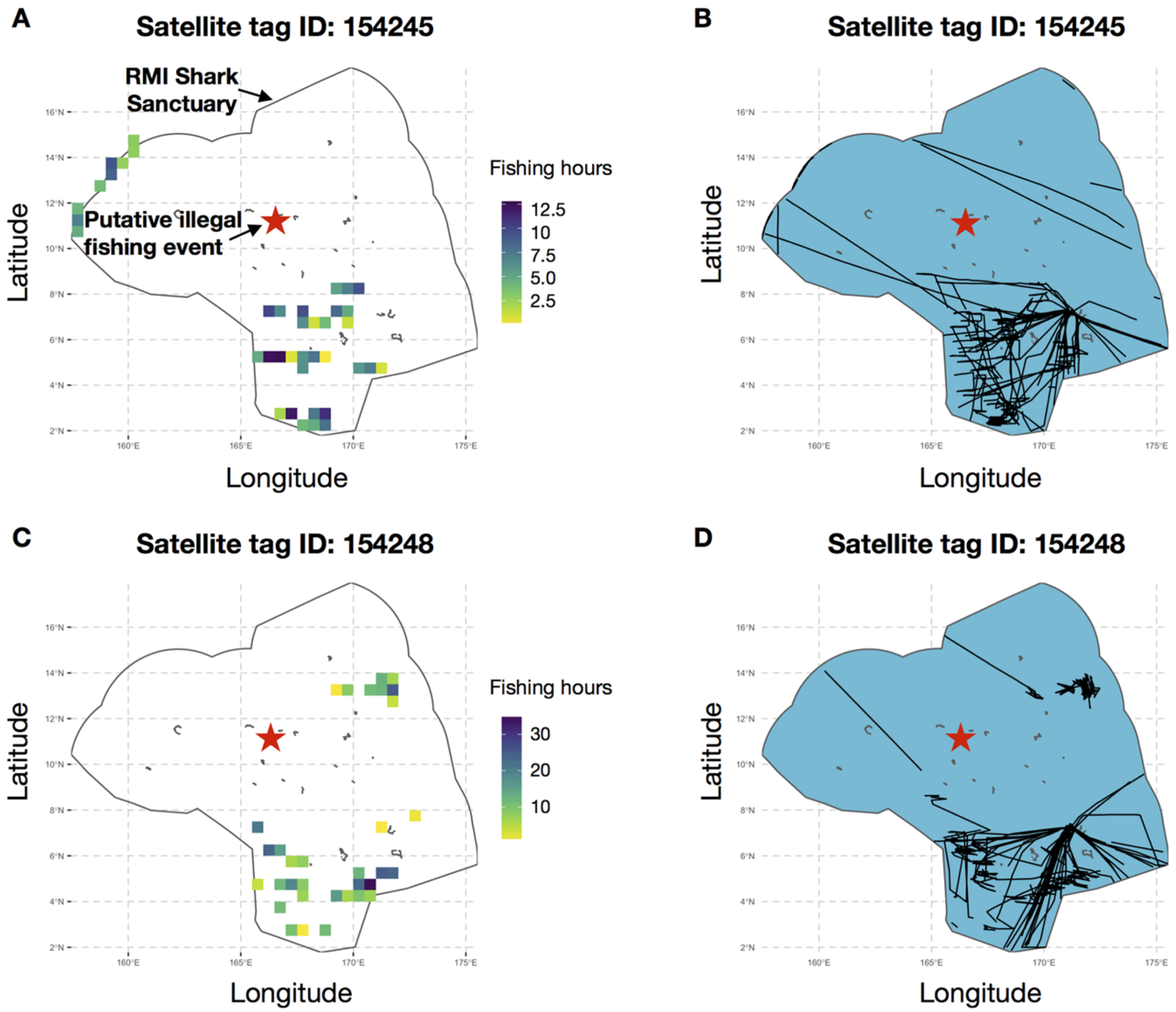

FIGURE 3 Fishing vessel activity concurrent with putative illegal fishing events in the RMI shark sanctuary. Fishing effort (hours) for vessels with AIS transmissions actively engaged in fishing activity in the RMI EEZ by location on the day of the putative illegal fishing event (A, C); and tracks of all fishing vessels with AIS transmissions in the 2 days ± the putative illegal fishing event (B, D) are shown for two sharks suspected of being illegally fished from the RMI shark sanctuary (satellite tag IDs 154245 and 154248)
Note: Fishing effort and all fishing vessel tracks are shown for days concurrent with all 8 illegal fishing events in Figure S6.

identification of fishing vessels involved in illegal fishing activities (McCauley et al., 2016). AIS is an open-sourced system with global coverage and information for >70,000 fishing vessels and 50%-70% of global offshore fishing effort is now available through the Global Fishing Watch (GFW) online platform (Kroodsma et al., 2018). However, the vast majority of small- and medium-sized vessels operating in the ocean are not presently required to use AIS (Figure S5). It is perhaps then unsurprising that there were no AIS equipped vessels transmitting in the immediate vicinity of the suspected illegal shark fishing locations in the RMI (Figure 3 and Figure S6), where AIS-equipped vessels are generally >20 m in length (Figure S5). Mandating AIS use will therefore substantially improve monitoring and enforcement within shark sanctuaries at relatively low cost compared to traditional surveillance on-the-water, from-the-air, or via the construction of land-based infrastructure (McCauley et al., 2016). The acquisition, installation, and training costs for AIS systems are roughly \$1,000 (Class B transmitter) to \$4,200 (Class A transmitter) per vessel, with an additional \$250 per unit each year for operation and maintenance (Arroyo, Lewald & Tetreault, 2015). The total cost of outfitting the 254 industrial vessels licensed to fish in the RMI will not be insignificant (although many already carry AIS); but in most contexts, individual vessels are responsible for installing tracking devices when mandated, and there are just 12 domestic industrial fishing vessels operating in the RMI (MIMRA, 2016).

Alternatively, requiring all vessels operating within shark sanctuaries to carry VMS can provide a valuable layer of information that will improve monitoring and enforcement given current AIS coverage. For example, Indonesian VMS contains information about an additional 5,000 commercial fishing vessels that do not carry AIS (Global Fishing Watch, 2017), providing a means to track previously untraceable vessels. VMS also has the added benefit that it is less vulnerable to data manipulation than AIS, which can be turned off and generally tampered with (McCauley et al., 2016). In addition to helping to protect a country's shark population, VMS programs can also provide benefits to fisheries management in general that can significantly outweigh the implementation costs (Cabral et al., 2018; Suhendar, 2013).

Currently, extant international agreements, including regional fisheries management organizations (RFMOs), do not require the use of AIS. However, if shark sanctuary nations are able to establish national policy that mandates AIS, RFMOs could be forced to reify and act as an implementation mechanism for a fleet-wide AIS policy to maintain access to fishing grounds located within the sanctuary. All Pacific shark sanctuary nations are members of the Western and Central Pacific Fisheries Commission (WCPFC), which acts as a centralized governance body for the conservation and management of tuna and other highly migratory fish stocks, the fisheries of which pose a significant threat to many shark species caught unintentionally as bycatch (Worm et al., 2013). Like other RFMOs, the WCPFC maintains vessel registries and manages VMS, but only requires that vessels use VMS when operating in the high seas, while operation within EEZs is generally up to the discretion of individual countries. By extending this VMS requirement to EEZs, shark sanctuary nations can utilize existing hardware and leverage the expertise of WCPFC data analysts to improve surveillance through a single, standardized VMS program at virtually no additional cost. There is a significant amount of fishing by mostly foreign fishing fleets in many shark sanctuaries (Figure S7; Ward-Paige, 2017); extant international agreements including RFMOs that govern and regulate these vessels present an opportunity for sanctuary nations to actualize policy requiring use of AIS and/or VMS within their EEZs.

Second, shark sanctuary nations cannot act alone – the transboundary nature of shark fishing requires international collaboration to assist with enforcement. A recent effort to unlock previously proprietary VMS data through a public-private partnership is already proving to be a game changer in the global fight against illegal fishing. In June 2017, the Republic of Indonesia worked with GFW to become the first country to make all VMS data for their flagged fishing vessels publicly available. These VMS data, together with AIS and night light satellite imaging data, revealed that Indonesia's aggressive anti-illegal fishing policies have been successful, resulting in at least a 25% reduction in fishing effort within their EEZ (Cabral et al., 2018). By adding analytical capacity through partnerships, Indonesia was better able to monitor their EEZ and identify and target suspicious illegal fishing activities, while also uniquely demonstrating that their stance against illegal fishing was working and could result in significant benefits to the Indonesian fishery (Cabral et al., 2018).

Shark sanctuary nations are often limited in their capacity for effective on-the-ground monitoring (Ward-Paige, 2017), thereby highlighting the imperative for information sharing, technological transfer, and improved agreements between sanctuary nations and regional fisheries management bodies and other partners. Although vessel-tracking satellite technology is relatively low-cost to implement and acquire, there is a steep learning curve in terms of translating data into something usable for enforcement. Partnerships with non-profit organizations such as GFW, private companies, and academic collaborators can serve to empower enforcement capacity by allowing shark sanctuary nations to become stewards of vessel monitoring data, with implications well beyond regulating shark catches within sanctuaries (Cabral et al., 2018). There is also a growing trend for open data sharing across marine industries (Cabral et al., 2018; Kroodsma et al., 2018). Member states and constituent citizens of RFMOs have a lot to gain through standardized and open data sharing. Sharing data could increase the capacity for different RFMOs to meet joint commitments for curtailing illegal, unreported, and unregulated (IUU) fishing. At the same time, open data would improve transparency for an industry that is the primary shaper of regional food security patterns and trajectories of sustainable development. Critically, failure of RFMOs to embrace new open technologies for data sharing compromises their commitments to protect safety and life at sea for fishers active in these RFMOs and to other mariners that operate in waters under RFMO oversight.

In addition to AIS and VMS, other remote sensing technologies can also be layered and leveraged to fill in one another's blind spots. For example, a coordinated effort between Planet's microsatellite imaging fleet and DigitalGlobe's higher-resolution satellites is actively improving automated methods to identify suspicious transshipment events in near real-time (Tarr & Marshall, 2017). However, the challenge with near real-time photographic surveillance is knowing which area of the ocean to target. If sanctuary nations and RFMOs were to require AIS, then partnerships with satellite imaging operators could leverage the technology to find bad actors by searching specifically for vessels failing to comply with AIS regulations. In the not too distant future, satellite imaging will likely have better marine coverage, lower costs, and semiautomated workflows to perform directed searches to identify a variety of illegal fishing events, including the illegal fishing of sharks, across our global ocean.

Third, all vessels identified as having engaged in IUU fishing of protected species anywhere in the world should be banned from shark sanctuaries. The “Combined IUU Vessel List” (https://iuu-vessels.org/iuu) contains information about all vessels associated with IUU fishing activities identified by nine RFMOs and INTERPOL. However, listed vessels are likely to change their identification (e.g., name, flag) once they have been flagged as associated with IUU fishing, and accurately tracking changes to vessel identification information is a monumental challenge. A solution may be possible through satellite vessel monitoring. Specifically, by requiring fishing and transshipping vessels to obtain International Maritime Organization (IMO) identification numbers – unique hull identifiers that do not change with vessel name, flag, or ownership – vessel identification anomalies will no longer plague the reliability of the IUU vessel registry. If a requirement to obtain an IMO was combined with a policy that mandated AIS, AIS identifiers could be updated with IMOs and vessel identity could be reliably tracked through time and space, thereby providing a means to increase compliance in perpetuity. A policy that permanently bans vessels involved in IUU fishing from operating in shark sanctuaries will also likely reduce the market value of IUU vessels and may serve as a deterrent for illegal fishing activity (Cabral et al., 2018).

Ratifying the Port State Measures Agreement (PSMA) – which aims to eliminate illegal fishing through port and landings bans for vessels that have engaged in IUU fishing – is a logical first step toward actualizing an IUU vessel ban while simultaneously strengthening the international impact of shark sanctuaries. The combination of PSMA ratification and an AIS/VMS requirement would enable sanctuary nations to monitor compliance with existing regulations, such as the RMI requirement that all industrial vessels fishing within the EEZ land their catch in the RMI as well as the prohibition of industrial shark fishing. Specifically, satellite technologies can be used to monitor vessels' postfishing activity, thereby “watching” to ensure vessels return to port, do not perform transshipments, etc., while the PSMA requires foreign fishing vessels to request permission before entering port, sets minimum standards for vessel inspections, and requires nations to share information about IUU fishing such that illegal shark fishing within a shark sanctuary could have international repercussions.

2.2 | Moving toward successful shark sanctuaries

Improving vessel monitoring and enforcement capacity bolsters the efficacy of shark sanctuary regulations by ratcheting up the cost of engaging in illegal fishing given often stringent sanctuary penalties (e.g., fines, imprisonment). To address current weaknesses with the shark sanctuary model, we suggest the following roadmap to stakeholder nations to actualize the recommendations above and move toward successful shark sanctuaries:

1. Convene a common forum on improving the management of shark sanctuaries.
2. Develop shared commitments to adopt strategies (e.g., mandate AIS/VMS use for vessels operating within the sanctuary) for which there is consensus of impact and tractability for implementation.
3. Work with nonprofit and private sector tech partners to begin to implement local-level partnerships to bolster the utility of vessel tracking data (e.g., the Indonesia GFW partnership).
4. Advance consolidated efforts to reform national-level policies (e.g., mandated AIS/VMS use) and the ratification of international agreements (e.g., PSMA) based on shared global shark sanctuary standards.
5. Work with international groups (e.g., RFMOs) to lead or reinforce national-level policies with parallel international policy.

While comprehensive monitoring of fishing activities has historically not been possible, satellite technology and public-private partnerships are rapidly changing the landscape of possibility in ocean enforcement, providing cost-effective solutions to remotely monitor vessel activity in our ocean's most faraway locations. The future success and scaling of the shark sanctuary model requires a more aggressive monitoring and enforcement strategy that can capitalize on these new monitoring tools. The adoption of new and emerging satellite technologies as policy mandates by sanctuary nations is an important first step toward ensuring more shark conservation successes globally.

ACKNOWLEDGMENTS

Support for this work was provided by The Waitt Foundation. We thank Minister Tony de Brum for permitting and facilitating the work in the Republic of the Marshall Islands. Earlier versions of the project were improved by input from T. Clavelle and G. McDermott.

ORCID

Darcy Bradley http://orcid.org/0000-0003-2581-8768

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SUPPORTING INFORMATION

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

How to cite this article: Bradley D, Mayorga J, McCauley DJ, Cabral RB, Douglas P, Gaines SD. Leveraging satellite technology to create true shark sanctuaries. *Conservation Letters*. 2018;e12610. https://doi.org/10.1111/conl.12610