An integrated approach to tackling wildlife crime: Impact and lessons learned from the world's largest targeted manta ray fishery

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Abstract
Manta rays (Mobula birostris and M. alfredi) are threatened by overexploitation for international trade. Indonesia was home to the world's largest documented manta fishery—Lamakera, in East Nusa Tenggara. However, in 2014, the Indonesian government declared manta rays a protected species. Here we describe an integrated intervention to reduce manta hunting and mortality in Lamakera, which combined community outreach and livelihood-focused incentives with targeted enforcement actions; and assess its impact over a five-year period (2013–2018) using a theory-based research design. Results show that the intervention is associated with a significant decline in manta hunting effort and mortality (p < .001), which is correlated and temporally-associated with conservation activities, and did not occur for modeled and natural experiment counterfactuals. Overall, total manta ray mortality declined by 86% by 2018, vs. the 2013 baseline. We conclude that a multifaceted, data-driven approach reduced illegal hunting and trade of manta rays from 2013 to 2018. However, this impact is not indefinite; new challenges are emerging, which highlight the importance of a long-term adaptive strategy. We make several recommendations for designing interventions to mitigate trade-driven over-exploitation of megafauna: (a) understand diverse drivers of human behavior; (b) adopt data-driven problem-oriented planning; (c) continuously document and share learning; (d) establish partnerships with diverse stakeholders to develop resilient institutions for enduring impact.

KEYWORDS
compliance management, conservation planning, elasmobranchs, evidence-based conservation, hunting, impact assessment, law enforcement, livelihoods, problem-oriented policing, wildlife crime
1 | INTRODUCTION

1.1 | Background

Mobulid rays (Mobula spp.) are a family of large, slow-growing cartilaginous fish (subclass elasmobranch), which consist of nine extant species of devil ray and two species of manta ray (reef: Mobula alfredi and oceanic: M. birostris) (Dulvy, Pardo, Simpfendorfer, & Carlson, 2014; Lawson et al., 2017). Mobulids are targeted and sold throughout their range, primarily to meet demand for their gills in Chinese medicine markets, however manta ray gills are the most highly-valued in commercial trade (Hau, Ho, & Shea, 2016; O’Malley et al., 2017; Ward-Paige, Davis, & Worm, 2013). Their high value and slow life-history makes manta rays particularly vulnerable to trade-driven extinction (McClenachan, Cooper, & Dulvy, 2016). With growing international concern regarding these threats, manta rays were listed on Appendix II of the Convention on the International Trade of Endangered Species (CITES) in 2013, which requires that Parties to CITES ensure any international trade in manta products is non-detrimental to their survival in the wild.

Within this international context, Indonesia is a global priority for manta ray conservation (Bräutigam et al., 2015; Dulvy et al., 2017). Indonesia is the world’s largest elasmobranch fishing nation, and has historically been a major catcher and supplier of manta gills to consumer markets (Dent & Clarke, 2014; O’Malley et al., 2017). Indonesia is also home to the world’s largest extant population of mobulid rays (reef: Mobula alfredi and oceanic: M. birostris) (Dulvy, Pardo, Simpfendorfer, & Carlson, 2014; Lawson et al., 2017). Indonesia’s multi-million-dollar manta tourism (O’Malley, Lee-Brooks, & Medd, 2013), motivated the Government of Indonesia (GoI) to declare manta rays a protected species in 2014 (Booth et al., 2020). This was implemented through a Ministerial Decree by the Ministry of Marine Affairs and Fisheries (MMAF), which prohibits capture, retention and trade of manta rays throughout Indonesia’s entire exclusive economic zone (MMAF No.4/KEPMEN-KP/2014, herein “the manta decree”).

In Lamakera, villagers have hunted marine megafauna for centuries (Barnes, 1996; Dewar, 2002). Historically, mobulid hunting was conducted in un-motorized artisanal vessels with harpoons, to provide meat for local subsistence. However, expansion and modernization of fleets and the emergence of a commercialized industry for gills drove intensification of mobulid hunting. It is estimated that 1,050–2,400 manta rays were killed annually in Lamakera in the early 2000’s, and these levels of exploitation have led to declines and extirpations of manta rays throughout their range (Dewar, 2002; Lewis et al., 2015). As a result, Lamakera began to attract international attention (e.g., Heinrichs, 2014, and the 2015 documentary “Racing Extinction”).

1.2 | An integrated conservation intervention

Since 2014, GoI and a coalition of stakeholders (government agencies, non-governmental organizations [NGOs] and community groups), have implemented a series of activities to address unsustainable manta hunting, and thus implement the manta decree, in Lamakera. Conservation efforts are primarily implemented through Indonesia’s fisheries, environment and law enforcement authorities. Agencies involved include MMAF, the water police (PolAir), the Directorate General of Environmental and Forestry Law Enforcement (Gakkum) (under the Ministry of Environment and Forestry [MoEF]), and the local and provincial government of East Flores (DKP Flotim) and East Nusa Tenggara (DKP NTT), respectively. These agencies are supported by a partnership between Misool Foundation and the Wildlife Conservation Society Indonesia Program (WCS-IP). Henceforth we refer to this group of governmental and non-governmental organizations as the project partners.

The ultimate goal of manta ray conservation efforts in Lamakera is to change human behavior (i.e., stop manta hunting) through effective compliance management. Compliance to conservation regulations can be strengthened through enforcement; however enforcement also tends to be challenging, costly and can result in perverse consequences (Arias, 2015; Borroni et al., 2019; Challender, Harrop, & MacMillan, 2015; Keane et al., 2008). Context-specific social factors often determine the long-term success of marine conservation, with local institutions and positive incentives consistently recognized as important components of effective natural resource management (Arias et al., 2016; Brooks, Waylen, & Borgerhoff Mulder, 2012; Gutiérrez, Hilborn, & Defeo, 2011; Waylen et al., 2010). Efforts to instil pro-conservation behavior also need to consider the multiple and diverse drivers of human behavior, including extrinsic motivations (i.e., positive and negative incentives), intrinsic motivations (i.e., beliefs, social norms and cognitive biases) and complex interactions between the two (Ajzen, 1991; Bowles & Polania-Reyes, 2012; Cinner, 2018; St John, Edwards-Jones, & Jones, 2010; Wright et al., 2016). As such, a cross-disciplinary approach to compliance management was necessary to reduce manta hunting in Lamakera, combining lessons from...
criminology and social psychology (Borrion et al., 2019; Oyanedel, Gelcich, & Milner-Gulland, 2020; St John et al., 2010). Given the complex situation, a non-experimental mixed-methods research design was required to assess impact.

In this study we use a theory of change (ToC), supported by five-years of empirical data, to evaluate the impact of efforts to reduce manta ray hunting in Lamakera from 2014 to 2018. In doing so we:

1. Outline a case study of an integrated cross-disciplinary conservation intervention that has had a measurable impact on illegal and unsustainable exploitation of marine megafauna;
2. Provide an example of a rigorous, mixed-methods approach to assessing the impact of a conservation intervention in a complex, real-world situation, where an experimental research design was unfeasible;
3. Identify several management recommendations, since this case has broad application to other conservation interventions seeking to mitigate trade-driven exploitation of megafauna. This is particularly relevant in the context of increasing regulation of international shark and ray (elasmobranch) trade under CITES, and the need to provide models of successful implementation at national- and local-levels.

2 | METHODS

2.1 | Site

Lamakera is the collective name for two adjacent villages (Motonwutun and Wotobuku) in East Flores, East Nusa Tenggara (Figure 1). As of August 2014, approximately 2,500 people inhabited Lamakera in 661 households (Jaiteh, 2014a). In 2013, prior to the manta decree, the mobulid hunting fleet consisted of 40 boats, crewed by 5–8 people (approximately 350 people directly involved in hunting, representing ~50% of all households). Mobulids are targeted using harpoons, with “top hunters” leaping off the bow of the boat to capture mobulids aggregating at the surface (Lewis et al., 2015). Most manta mortality occurs within a spatio-temporal hotspot (Figure 1), during an eight-month season (March to October, peaking in July), and during 2–4 days per month, with en masse hunting events triggered by mantas aggregating at the sea surface around cleaning stations (Lewis et al., 2015). Aggregations typically take

**FIGURE 1** The location of Lamakera and the manta hunting hotspot (top left shows Indonesia and East Nusa Tenggara Province; bottom right shows East Flores Regency, and the specific locations of Watobuku and Motonwutun, which collectively comprise Lamakera)
place during the new moon, related to manta feeding and cleaning behavior, driven by oceanographic and environmental variables (Herwata, 2018; Herwata & Lewis, 2018). As well as hunters, four major gill traders were operating in Lamakera in 2013, acting as middlemen between hunters and exporters in Surabaya (Jaiteh, 2014b). Local women also make a living as Papalele: local processors and traders for of mobulid meat and gills. Gross annual revenue from manta hunting and trade was estimated at IDR 1 billion (~US$ 90,000) in 2014, providing an estimated monthly income of IDR 36,000 ($32) per household per month (Jaiteh, 2014b; Lewis et al., 2015).

### 2.2 Intervention design

Key events relating to protection of manta rays in Lamakera first began in 2013, when mantas were listed on CITES Appendix II (Booth et al., 2020) (Figure 2). From 2016, an adaptive management cycle was adopted for planning, implementing, analyzing, adapting and sharing, based the Conservation Measures Partnership (CMP) guidelines (CMP, 2020). In 2016, a robust theory of change (ToC) was developed through a joint planning process by project partners, which guides strategies and activities, and provides a hypothesis for theory-based impact evaluation (Figure 3).

Planning was grounded in criminology, social psychology and conservation science literature, and informed by empirical data on the ecological and socio-economic context in Lamakera. The ToC aimed to address several intrinsic and extrinsic motivators of hunter behavior, including: a lack of deterrents, a lack of alternative income sources, a high reward, and community norms and perceived legitimacy (Figure 3). To do so, two broad strategies were developed: (1) A community outreach and livelihood-focused incentives strategy aimed to reduce barriers and create positive intrinsic and extrinsic motivations for compliance. Design of this strategy was informed by social psychology, behavioral

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**FIGURE 2** Timeline of key events relating to implementation of the manta decree in Lamakera
economics and community-based conservation (Ajzen, 1991; Brooks et al., 2012; Cinner, 2018; St John et al., 2010; Waylen et al., 2010). Activities included awareness raising, collaborative research, community-based monitoring, and development of conditional non-manta livelihoods (Figure 3). (2) A species protection strategy aimed to create perceived net negative incentives for non-compliance. Strategy design drew from problem-oriented wildlife protection and situational crime prevention (Borrion et al., 2019; Cohen & Felson, 1979; Cornish & Clarke, 2003; Goldstein, 1979; Lemieux & Pickles, 2018; Petrossian, 2015), plus other examples of compliance management in conservation (Arias, 2015; Arias et al., 2016; Arias, Cinner, Jones, & Pressey, 2015; Keane et al., 2008; Travers, Archer, et al., 2019). Activities included overt site-based marine patrolling, community-based monitoring, covert monitoring of illegal trade, and arrest and prosecution of major illegal traders. Importantly, implementation was based on adaptive crime analysis, which drew on a range of data sources (mobulid habitat use models, observed hunting patterns and community-based monitoring), to target enforcement towards hotspots, peak times and priority offenders. These activities worked synergistically to: reduce the perceived rewards of manta hunting, increase the perceived risks, increase the perceived effort, remove excuses and reduce provocations (Table S1) (Cornish & Clarke, 2003).

2.3 | Impact assessment

2.3.1 | Research design

Given the context and complexity of this conservation intervention, it was not feasible to adopt an experimental research design. Rather, we adopt a theory-based method to assess impact, which is particularly useful when baseline data and sample sizes are limited, and can provide an in-depth understanding of how and why an intervention works (Margoluis et al., 2009; Salazar, Mills, &
The ToC (Figure 3) provides a testable conservation hypothesis to explain observed trends, with a null hypothesis that intervention activities did not cause any change in manta ray hunting and mortality. We verify the ToC and reject the null

### TABLE 1  Summary of available evidence for ToC (in bold) and associated data sources (in italics) used to assess project impact at each stage of the ToC. Numbers correspond to stages in the ToC in Figure 2

| Strategy                                      | Interim results                                                                 | Objectives                                                                 | Illegal hunting effort (2016–18)                                                                 | Impact                                                                 |
|-----------------------------------------------|--------------------------------------------------------------------------------|----------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|
| Outreach and livelihood-focused interventions  | R1. Number of business units developed for non-manta livelihoods (2014–18)       | O1. Number of community members benefiting from new non-manta livelihoods (2016–2018) | From WCS-IP SMART patrol data and Misool enumerators                                           | Number of manta rays killed (2013–18) From overt and covert observation of catch collected through WCS-IP and Misool enumerators |
|                                               | From official government cooperative records                                    |                                                                            | From Misool sign in sheets and cooperative records                                            |                                                                      |
|                                               | R2. Number of community members engaged in institutions for marine monitoring and management (2014–18) | O2. Number of (ex) manta ray hunters committed to complying to regulations (2014–18) | From signed community agreements                                                              |                                                                      |
|                                               | From Misool training records and meet meeting sign-in sheets                     |                                                                            | From WCS-IP online media monitoring records                                                    |                                                                      |
|                                               | R3. Number of socialization and training events, and estimated village coverage/attendance (2014–18) | O3. Frequency of marine monitoring reports from community (2016–2018)       | From reporting hotline records                                                                 |                                                                      |
|                                               | From Misool and WCS-IP project records and sign in sheets                       |                                                                            | From WCS-IP SMART patrol data                                                                 |                                                                      |
| Species protection                             | R4. Number of law enforcement trainings conducted (2014–18)                    | O4. Number of illegal fishers intercepted and punished (2016–18)           | From WCS-IP SMART patrol data                                                                 |                                                                      |
|                                               | From WCS-IP project reports and sign-in sheets                                  |                                                                            | From law enforcement records                                                                  |                                                                      |
|                                               | R5. Number of media articles published (2014–18)                                | O5. Number of illegal traders arrested and prosecuted (2014–18)           | From law enforcement records                                                                  |                                                                      |
|                                               | From WCS-IP online media monitoring records                                    |                                                                            | From law enforcement records                                                                  |                                                                      |
|                                               | R6. Days of marine patrols conducted (2016–18)                                  | O6. Amount of fines and prosecutions levied against illegal traders (2014–18) | From law enforcement records                                                                  |                                                                      |
|                                               | From WCS-IP SMART patrol data                                                  |                                                                            | From law enforcement records                                                                  |                                                                      |
|                                               | R7. Number of traders investigated (2014–18)                                   |                                                                            | From law enforcement records                                                                  |                                                                      |
|                                               | From WCS-IP intelligence database                                              |                                                                            | From law enforcement records                                                                  |                                                                      |
hypothesis through a mixed-methods approach, by analyzing and triangulating empirical evidence for each step of the hypothesized causal chain (Table 1) and testing three key assumptions: A1) The hypothesized ToC is an accurate representation of the world, A2) Observed trends in empirical data are reliable. A3) Observed trends are caused by the conservation intervention, as opposed to external confounding factors (Table S2).

2.3.2 | Data and analysis

Mixed-methods and triangulation are particularly important for this study, given the many potential biases (e.g., illegality and sensitivity) and confounding factors (e.g., environmental and market fluctuations) (Booth et al., 2020; Gavin, Solomon, & Blank, 2010).

Empirical evidence for the ToC was collected from a variety of data sources (Table 1, Annex S3). For data on interim results and objectives, we used NGO project reports and records from Misool and WCS-IP (evidenced by training records and sign-in sheets, signed community agreements, photographs and cooperative business records, see Annex S4); SMART patrol data; and government intelligence and law enforcement records (Table 1, Annex S3). For outcomes and impact (i.e., manta ray hunting effort and landings) we used SMART patrol data and landings monitoring data collected by WCS-IP and Misool Foundation enumerators (following survey methods from White et al. (2006), as well as historic published landings data from Dewar (2002) and Lewis et al. (2015) (Table 1, Annex S3).

We used several impact evaluation techniques to establish causal inference and attribution, including statistical regression, pre/post comparison, counterfactual modeling, natural experiments, and process tracing to understand and explain observed trends (Bennett, 2010; Booth et al., 2020; Margoluis et al., 2009; Scriven, 2008). We conducted statistical analyses of trends using linear modeling, and tested for correlations between objectives, outcomes and impact to substantiate proposed causal links (where changes in numbers of manta rays killed is the impact indicator). More specifically: For law enforcement trainings (R4) and number of traders arrested and prosecuted (OS), we used a paired t-test to compare average fines and prosecutions before and after the onset of trainings (i.e., pre/post comparison). For hunting effort (outcome) and numbers of manta ray killed (impact), we used regression analysis, fitting negative-binomial models (Zuur et al., 2009) to assess the influence of daily and monthly species protection activities (i.e., patrols) on manta hunting and manta catch. Pre-decree daily landings data were not available, as such the models only included post-decree/pre-intervention data (May 2015-Dec 2015) and post-integrated intervention data (Jan 2016-Dec 2018) (see Annex S5 for detailed methods). We used counterfactual thinking to support inference and attribution, based on two types of counterfactuals: (a) devil rays as a natural experiment or quasi-counterfactual and, (b) a modeled counterfactual of predicted manta ray mortality in the absence of the intervention. We first conducted an events-based analysis of manta mortality, using linear modeling of daily landings (May 2015-Dec 2019) to assess whether there had been a significant decline in manta ray hunting events and total mortality over time, and if this decline was temporally associated with the intervention (i.e., pre/post comparison). Since devil rays are exploited for the same market as manta rays but are not a protected species, we used devil ray landings as a natural experiment to indicate external mobulid market fluctuations (C1) (Booth et al., 2020). We considered all meaningful models and used minimum AIC to determine the best-fit (Burnham & Anderson, 2003) (Annex S5). For models with multiple variable contrasts we applied a post-hoc generalized linear hypothesis test (GLHT), which enables multiple comparisons of factor means and confidence intervals simultaneously, to confirm which specific factor (or factor combinations) is significant (Annex S5). This ensures that the contrast relates to differences between the factors in the model that we are interested in (i.e., comparisons between manta pre- vs. manta post- and devil pre- vs. devil post-), and not the overall level of the response variable (Meier, 2020). Secondly, we used a General Additive Model (GAM) developed by Herwata and Lewis (2018) as a modeled counterfactual for estimated levels of targeted manta mortality in the absence of the intervention (C2). This model used pre-intervention data to predict trends for targeted manta catch per unit effort (CPUE), based on environmental variables (Annex S5). We then compared these predicted trends with empirical observations of actual post-intervention CPUE. We used RStudio software for all statistical analyses (RStudio Team, 2020), see Annex S5 for the list of packages. Finally, for comparison with pre-decree data, which could not be included in the statistical analysis due to different sampling methods (2002–2014, Dewar, 2002; Lewis et al., 2015) we provided a descriptive overview of trends in total annual landings over time, which we mapped against a timeline of events.

Quantitative data were supplemented with qualitative evidence on contextual factors, such as onset of activities, external market trends and the perceived reliability of available data. This enabled triangulation and verification of observed trends, and substantiation of assumptions through critical assessment of the inferential weight of available data and plausible alternative explanations.
| Strategy                                      | Results | Evidence | Objectives | Evidence | Outcome | Evidence | Impact | Evidence |
|-----------------------------------------------|---------|----------|------------|----------|---------|----------|--------|----------|
| Outreach and livelihood-focused interventions | R1. Number of business units developed for non-manta livelihoods (2017-2018) | 5 (total) | O1. Number of community members benefiting from new non-manta livelihoods (2017-2018) | 107 individuals/approx. 15% of households benefiting. Monthly salary equivalent to and more stable than estimated pre-decree income from mantas. | Illegal hunting effort (2015-18) | Frequency and intensity of hunting events significantly declined (p < 0.01). Temporally coincides with integrated intervention. Significantly correlates with increase in patrol effort. Significantly different from counterfactuals (C1 and C2). |
|                                               | R2. Number of community members engaged in marine monitoring and management (2014-2018) | 470 (total) | O2. Number of (ex) manta ray hunters committed to complying to manta ray regulation (2018) | 28 (approx. 8% of all mobulid hunters) | |
|                                               | R3. Number of socialisation and training events (2014-2018) | 11 (total formal events), Estimated that information on the decree has been communicated to at least one member of every household | O3. Frequency of marine monitoring reports from community (2018) | 20 per month by 2018 Number has increased over time. | |
| Species Protection                            | R4. Number of law enforcement trainings conducted (2014-2018) | 18 (total) | O4. Number of illegal fishers intercepted and punished (2016-18) | 10 (total) | |
|                                               | R5. Number of media articles published (2014-2018) | 1,013 (total) | |
|                                               | R6. Days of marine patrols conducted (2016-2018) | 170 (total); 6.5 days per month in 2018 peak season. | O5. Number of illegal traders arrested and | 25 (total), 6 operating in East Flores district. | |
RESULTS

3.1 Activities and objectives

3.1.1 Outreach, consultation and awareness raising

Between 2014 and 2018, 11 official socialization events relating to marine conservation and the manta decree were conducted in East Flores, based on WCS-IP and Misool Foundation project records. Of these, five were conducted in Lamakera. In particular, a high-level government event in April 2016 was jointly organized by MMAF, Misool Foundation, WCS-IP, the Islamic Council Indonesia (MUI) and the water police (PolAir), to reinforce and legitimize manta ray protection (Annex S4). This event was attended by roughly 1,000 villagers, representing almost all of Lamakera’s households. Informal meetings were regularly conducted across 50 villages in East Flores from 2016 onwards. These meetings were held 1–2 times per month in the 20 most actively engaged villages, and once every 2–3 months in the 30 remaining villages. Based on attendance records and other informal community engagement activities, Misool staff estimate that 100% of Lamakeran villagers were aware of the manta decree by 2016. This substantiates R3 in the ToC: community members are aware of the manta ray decree.

To raise awareness beyond Lamakera, over 1,000 media articles were published in the national and international media during April 2015–December 2018, highlighting GoI’s efforts to combat marine wildlife crime (Annex S4, Table 3). Several of these publicized high-level cases of illegal manta trade, which emphasized GoI’s commitment to protect manta rays to, made information on prosecutions and punishments widely available, and gave national and international recognition to the officials involved in the cases. This provides evidence for R3 and R4 in the ToC, that both community members and government agencies are aware of and understand the manta ray decree. Public recognition for officials also supports R5: creating motivation for enforcement agencies to implement the manta decree.

3.1.2 Community surveillance

During 2017–2018 a network of community surveillance groups (referred to in Indonesia as POKMASWAS) was
established throughout East Flores to conduct community-based monitoring. A system was established for POKMASWAS to report incidents of illegal fishing and megafauna by-catch, via a reporting hotline. This was coupled with a rapid response team, led by MMAF and PolAir, to respond to reports. Based on Misool Foundation project records, the number of people engaged in POKMASWAS groups grew from 30 across 5 villages in 2017 to 470 across 50 villages in 2018. POKMASWAS reports increased from an average of 2.5 per month in 2017 to 20 per month by 2018, leading to the successful live release of 42 vulnerable marine animals during 2016–2018, including manta rays, whale sharks, sunfish and turtles (Annex S4). Participating community members received non-monetary awards (certificates) for reporting to the hotline and recognition in the local newsletter, every time a bycatch incident was reported. This substantiates R2 and O3 in the ToC, that institutions exist for community participation in marine resource management, and that community members actively participate and take pride in marine management, with positive attitudes towards marine conservation, and reduced provocations for non-compliance.

3.1.3 | Livelihood-focused incentives

Following extensive market research and community consultation, a sustainable fisheries cooperative was established in Lamakera in 2017 (Annex S4). Members benefit from access to resources and capital for developing non-manta livelihoods, which focus around five business units: a mini purse seine fishing vessel, ice supply, microfinance loans, fish drying and a mini-market offering basic provisions at a discounted rate. Cooperative membership is contingent on signing a “no megafauna hunting” agreement, ratified by the local government, which links benefits to pro-conservation behavior (Annex S4). Based on Misool Foundation project records, the cooperative recruited 107 members during 2017–2019, 28 of which are ex-manta ray hunters. Of this, the mini purse-seine crew comprises 14 ex-manta hunters, who each receive earnings of IDR...
500–750,000 ($35–$53) per month. This salary is equivalent to estimated monthly income from manta hunting during peak seasons, and more stable by comparison. A further five people are employed as full-time staff within the cooperative's business units. Microfinance loans were distributed to 59 people, including 23 Papalele. The loans supported development of non-manta small enterprises. This substantiates R1 and O1 in the ToC: the value of and access to non-manta livelihoods is improved, and communities engage in and benefit from non-manta livelihoods, with reduced barriers and positive incentives to comply to the manta decree.

### 3.1.4 Marine patrols and interception of illegal fishers

Marine patrols began in 2016, with an average of 2.9 patrol days per month. Initially, patrols were ad-hoc, but analysis of multi-source crime data supported a new patrolling strategy from 2017 onwards. Based on WCS-IP SMART patrol data, patrol effort increased significantly in 2017 and 2018 (Table 3, Figure 4, Annex S4). This was aided by the deployment of two new fast patrol boats, which reduced travel and response times, increased patrolling area per unit time, and boosted morale of patrol staff. Patrol focus also improved, with patrols directed towards known spatio-temporal hotspots (Figure 4). Patrol units operated using a dual strategy, with preventative routine patrols direct towards hotspots, and rapid-response patrols based on real-time reports of hunting or by-catch from project partners and POKMASWAS. This dual strategy, with continuous data collection and crime analysis, enabled patrols that were focused and adaptive. A total of 483 boat inspections were carried out from 2016 to 2018, leading to interceptions of 10 manta hunting vessels, as inferred by evidence of harpoons or manta body parts. Harpoons and manta parts were confiscated and administrative sanctions (i.e., warnings or confiscation letters) were given (Table 3). This substantiates R5, R6 and R7 in the ToC, as well as O4 and O5: enforcement agencies have capacity, resources and motivation to implement the manta decree, and species protection is effectively enforced at the site level, thus increasing the effort and risk to catch mantas.

### 3.1.5 Trader investigations and arrests

From April 2014 to December 2018 project partners collaboratively mapped data on illegal traders. 124 suspected illegal traders were identified, linked to nine geographically-clustered syndicates operating across 14 provinces (Table 3, Annex S4). This informed targeted enforcement actions by GoI, leading to 69 marine wildlife crime cases involving 86 offenders during 2014–2018, according to official enforcement records. Of these, 23 cases involved seizures of manta products, with the arrest of 25 suspects and an estimated 4,500 kg of manta products seized. 11 of these cases have led to successful fines and prosecutions, resulting in more than US$22,500 levied in fines and 24 months of jail time (Table 3, Annex S4). Six cases (in July 2015, September 2016 and October 2018) involved traders with known links to Lamakera, who were facilitating onward trade and trafficking to international markets. This substantiates R4-R7 in the ToC: enforcement agencies understand, and have capacity, resources and motivation to implement the manta decree; and O4-O6: the manta decree is effectively enforced throughout the trade chain, thus increasing the effort and risk of catching and trading mantas, and reducing the rewards of illegal trade, through enforcement disincentives.

### 3.1.6 Enforcement training and sanctions

From August 2015 to December 2018 a series of 18 training workshops were conducted on marine wildlife law enforcement, and in-house training modules for public prosecutors and environmental judges were established (Annex S4). A total of 645 fisheries and law enforcement officers including MMAF, police, customs, aviation security, the National Agency of Drug and Food Control (NADFC), judges and public prosecutors were trained (Table 3). Onset of the training series coincides with an observed increase in average punishments for traders of protected marine species, with a statistically significant increase in average fines before vs. after the onset of trainings (paired t test, \( p < .05 \) [Annex S4]). This provides evidence for causal links between R4-R7 and O5-O6, indicating that training improved capacity and motivation of enforcement agencies, leading to increasing punishments (and thus reduced rewards) for illegal trade.

### 3.2 Outcomes and impact

#### 3.2.1 Observed trends

Overall, targeted manta ray mortality (i.e., mantas killed using spears) reduced by over 90%, and total mortality (i.e., including mantas killed using spears, and mantas captured in gill nets) reduced by 86% by 2018, in comparison to the 2013 (pre-decree) baseline (Figure 5). This equates to an estimated 400 manta rays saved since 2014,
assuming constant fishing mortality would have occurred in the absence of the decree and intervention.

Observed trends in daily landings data (2015–2018) indicated that en masse hunting events declined significantly following onset of the integrated intervention. There was a significant negative relationship between year and likelihood of a hunting event (coefficient = −0.26, \( p < .01 \)), and significant declines in hunting events in 2017 (coefficient = −1.17, \( p < .001 \)) and 2018 (coefficient = −0.53, \( p < .05 \)) vs. 2015 (Table 3, Annex S4 and S5). En masse hunting events appeared to halt by 2017 and 2018, and hunting patterns shifted to become less frequent, less severe (in terms of number of mantas killed) and generally more one-off or opportunistic (Annex S4 and S5). Linear models of recorded mortality over time indicated a significant negative relationship between year and number of manta rays killed (coefficient = −0.72, \( p < .001 \), Annex S4). Mortality in all post-intervention years (2016, 2017, and 2018) were significantly lower than 2015 (Table 3, Figure 5, Annex S4 and S5). This substantiates the outcome (illegal hunting declines) and impact (fewer manta rays killed) in the ToC.

### 3.2.2 Attribution and assumptions

Negative binomial models of manta landings indicate significant negative relationships between the number of mantas killed and implementation of site-based patrolling activities. In particular, the introduction of patrols by government enforcement agencies, improved patrol focus (i.e., a data-driven patrol strategy, targeting patrols towards hotspots) and the interaction between the two are all significant in explaining declines in landings (\( p < .05 \)) (Annex S5).

Linear models indicate a step-change in the number of mantas killed occurred in 2017 (Figure 5, Annex S5). This step-change temporally coincides with the onset of an integrated strategy with focused patrols and arrests of Lamakera-linked traders. A similar decline was not observed for devil rays; 2017 and 2018 saw increases in devil ray catches (Figure 5, Annex S5). This suggests the declines in manta landings cannot be attributed to fishers moving out of the mobulid fishery due to external factors (e.g., declines in demand for mobulid products). This is also supported by market surveys showing continued sales of mobulid gills in China and Hong Kong during this period (Hau et al., 2016; O’Malley et al., 2017). Modeled predictions of Catch Per Unit Effort (CPUE) based on environmental variables shows there is a significant difference between predicted and empirically observed CPUE (Figure 5, Annex S5). This suggests trends cannot be attributed to environmental variables alone.

Data on contextual considerations indicates several sources of bias and external factors that could be influencing observed trends in manta hunting and mortality: (a) Manta hunting has been displaced to other locations with no monitoring or enforcement; (b) Manta hunting and landings have become clandestine, due adoption of offenders in response to enforcement; (c) Manta catch has declined due to environmental variables, natural population stochasticity or a population collapse; (d) Manta hunting effort has declined due to reduced consumer demand. However, we can largely discount these alternative explanations. Manta hunters are part of a small and highly localized community. Hunting occurs in near-shore waters, using small boats which are ill-equipped to travel long distances to other waters. Manta hunting also uses specialized equipment (harpoons) and occurs en masse during manta aggregations, which makes the behavior relatively conspicuous and predictable. News of illegal hunting is usually relayed to POKMASWAS and other reliable sources. Although there is no robust data on the status of the manta population, there are still regular sightings of mantas, as well as accidental by-catch of mantas in gill nets, which is evidence that the population is extant (though may well be reduced). Finally, the increased targeting of devil rays, and reported rises in consumption of mobulid gill plates (Hau et al., 2016; O’Malley et al., 2017) indicate that the international market persists.

### 4 DISCUSSION

This study presents an example of an integrated conservation intervention, designed to combine species protection and livelihood-focused incentives to deliver measurable conservation impact. The planning process and management recommendations offer insights for the design, implementation and evaluation of other similar conservation interventions, particularly those focusing on reducing illegal or unsustainable behavior, or exploitation of marine megafauna. The impact assessment also provides an example of a robust nonexperimental research design, using a theory-based mixed-methods approach, which could be applied to similar interventions where experimental designs are unfeasible.

#### 4.1 Conservation impact

Our results show that there were significant observed declines in the frequency and severity of manta ray hunting from 2013 to 2018, with up to 400 manta rays saved by 2018 in comparison to the 2013 baseline. Given that an
individual manta ray is estimated to be worth up to US$ 1-million to marine tourism over its lifetime, this also equates to up to US$ 400-million saved in tourism value (O’Malley et al., 2013). Evidence substantiating the steps in the ToC, and associated assumptions, suggests that these observed declines are at least in part due to a real reduction in hunting and manta mortality, as opposed to monitoring bias and external factors. Significant differences between observed trends and counterfactuals (i.e., modeled predictions and devil ray landings) and temporal coincidence and correlation of observed trends with intervention activities (i.e., trainings and marine patrols) show it is reasonable to attribute these trends to the conservation intervention. This suggests that we can reject the null hypothesis, that intervention activities did not cause any change in manta ray hunting and mortality. However, the extent to which these declines can be attributed to the intervention is difficult to quantify, particularly in the absence of robust data on the status of the manta ray population, hunting in unmonitored seascapes, and comprehensive market demand data from consumer countries, which could still be influencing trends to some degree.

We also acknowledge that these findings focus on a specific site (Lamakera in East Flores, Indonesia). While this does provide an example of a successful site-based conservation intervention in Indonesia’s largest known manta fishery, we should be cautious in assuming that the manta ray regulation has led to effective conservation outcomes throughout Indonesia. There could be displacement of hunting and trading effort to other sites that lack monitoring and implementation effort.

In addition, the observed increase in manta ray mortality in 2018, and the significant increase in devil ray mortality in 2017 and 2018, highlights the complex and evolving nature of threats facing mobulids. Enforcing natural resource regulations can lead to “arms races” with offenders continually responding to enforcement tactics, and the need for enforcement to continually adapt (Anderson et al., 2011; Jenkins, 2006). The 2018 increase in manta mortality is predominantly attributed to “by-catch” in gill nets as opposed to targeted spear hunting, which may represent perceived loopholes or adapted tactics, or may be the result of genuine increases in accidental catch due a small recovery in the manta ray population. Preliminary information from project partners in 2019 suggests this trend is continuing, as offenders adapt their tactics in response to enforcement. This highlights the need for long-term investments, with continuous learning and adaptation to emerging challenges.

Increases in devil ray catch is also cause for concern, since these species are currently unprotected in Indonesia, and may now be the focus of unsustainable targeted fisheries. This also highlights how protection of some species or sites can lead to displacement of threats towards other vulnerable species or sites (Agardy, di Sciaara, & Christie, 2011; Suuronen, Jouanela, & Tschnernij, 2010). These substitution effects may be particularly acute in the absence of other legal, sustainable, comparable alternatives to manta hunting. In Lamakera it is unsurprising that effort has shifted towards devil rays, since this represents a familiar and similarly socially-desirable and economically-profitable activity. The transition is therefore much less frictionless than turning to entirely new fishing gears or target species. These findings reinforce previous work on the importance of understanding the function of environmentally-damaging behavior, and ensuring that livelihood-focused interventions are suited to people’s capacities and aspirations, and have real market appeal (IMM, 2008; Wright et al., 2016). In this case, devil rays hunting may represent a natural substitute activity, with unintended consequences for these species if management is not strengthened in the future.

4.2 Management implications

This case study highlights the importance of adopting multi-faceted, adaptive interventions when attempting to reduce illegal and unsustainable behavior. Significant declines in illegal hunting and landings were only observed when focused marine patrols were launched and a fully integrated strategy was adopted. Prior to this, national regulations and trade enforcement alone did not appear to significantly reduce the number of manta rays killed at the site-level in Lamakera (Figure 5) (Booth et al., 2020). It is well known that a diversity of drivers and barriers influence individual and group compliance to conservation regulations, and that these are often heterogeneous within a given community (Cinner & McClanahan, 2006; Keane et al., 2016; Oldekop et al., 2010; Wright et al., 2016). In Lamakera, most community members were willing to comply with the manta decree, while a small number of highly invested individuals were less willing to comply and continued to offend. As such, it was important to acknowledge heterogeneity in attitudes and behaviors, and address different drivers and barriers to compliance. By combining efforts to promote positive attitudes and norms for proconservation behavior, motivate compliance through incentives, and reduce barriers to compliance, these different strategies worked synergistically to deliver impact at scale. This also supports the utility of combining individual and situational approaches to wildlife crime prevention, in which multiple techniques are adopted to simultaneously address individual motivations, as well as the immediate environment/situation (Oyanedel et al., 2020).
In terms of enforcement, the significance of focused marine patrols in influencing the number of manta rays killed, and the interaction between patrol frequency and focus (Figures 4 and 5, Annex S4), highlights that both patrol quality and quantity are needed to effectively enforce species protection laws. This is consistent with previous studies showing that efficient distribution of patrol effort in space and time is important for optimizing enforcement and compliance in a marine conservation context (Arias et al., 2016), particularly when patrols areas are large and detection probabilities can be low. This also supports the utility of problem-oriented approaches to wildlife protection (Borrion et al., 2019; Lemieux & Pickles, 2018) in which enforcement resources target specific spatio-temporal hotspots and key offenders, in order to address a specific problem or cluster of incidents (Goldstein, 1990). Adoption of overt and covert approaches also enabled disruption of illegal activity at multiple levels of the trade chain, from choking supply at the site-level to blocking onward trade and export within the broader trade network. Coupling this with support of judicial processes to strengthen criminal sanctions created a strong, credible deterrent against noncompliance. Crucially, success was facilitated by a clear pre-existing legal framework for manta ray protection, and a national-level mandate to act. Species protection actions would not have been possible without commitment and buy-in from key agencies and institutions at multiple levels within GoI.

Alongside enforcement, the role of community outreach and engagement should not be overlooked. There is both a moral and practical impetus for paying attention to the socioeconomic dimensions of illegal behavior (Arias, 2015; Keane et al., 2008; St John et al., 2010). In Lamakera, community engagement played a role in gathering information, building awareness and goodwill, improving relationships between different stakeholders, and incentivizing compliance. These activities can also help to “capture hearts and minds” for longer-term intrinsic motivations to take shape (Blomley et al., 2010; Bowles & Polania-Reyes, 2012; Gneezy, Meier, & Rey-Biel, 2011).

The amount of information available to direct species protection activities was also important, with scavenging activities prior to 2016 helping to build a robust evidence-base for designing intervention actions. As demonstrated, this enabled data-driven conservation planning, as well as timely feedback on the success or otherwise of those actions, and continuous adaptive management. By investing in many forms of monitoring project partners had an on-going “pulse check,” and could quickly react to emerging threats to ensure the strategy remained preventative and resilient. This also provides benefits for impact assessment, as it creates multiple datasets which can be triangulated. This is particularly important for illicit, sensitive behavior such as wildlife trade, which may be clandestine, such that monitoring data is subject to bias. Combining multiple methods and datasets can help to identify and circumvent the biases associated with monitoring illegal behavior (Booth et al., 2020; Gavin et al., 2010; Nuno & St. John, 2014).

Although this project benefitted from monitoring data, regular analysis, learning and adaption is required for data to be useful for adaptive management. The seasonality of manta hunting gave project partners a period of inaction and review each year, creating time for the “Analyze and Adapt,” and the “Share” steps of the project management cycle (CMP, 2020), and for new operations and tactics to be planned for the upcoming season. Not many conservation sites benefit from seasonality, but learnings from this case study underlines the value of regular review and learning.

Finally, from an ethics perspective, when implementing an integrated intervention, it is also important to maintain separation between enforcement teams, outreach and livelihood teams, and research teams. This helps to maintain the safety, integrity and reputation of project team members; ensure that trust and relationships within the community are not abused and undermined; and guarantee that any social research remains confidential, ethical, and does not cause harm to human subjects (Brittain et al., 2020).

4.3 | Research implications

This study also provides lessons for assessing the impact of conservation regulations in cases where experimental research designs are unfeasible. Measuring the impact of complex interventions can benefit from a comprehensive theory of change, with collection and analysis of empirical data at each step to demonstrate change, and clear causal links between project activities and desired conservation outcomes (Salazar et al., 2019; Woodhouse et al., 2016). Where factors influencing compliance to regulations are multiple and dynamic, it is important to gain a comprehensive understanding of the broader socioecological system beyond the site of project implementation, and trends in distant drivers. Modeled counterfactuals or natural experiments can aid this process. Where behavior is illicit or sensitive, it can be useful to triangulate multiple datasets, and supplement empirical observations with qualitative information on data collection processes and physical and social context. Rather than taking observed trends at face value, this mixed-methods approach leads to improved understanding of the systems and contexts that create observed trends,
and thus better acknowledge uncertainties, bias and confounding variables; and strengthen causal inference and attribution (Booth et al., 2020; Burn, Underwood, & Blanc, 2011).

5 CONCLUDING REMARKS

Overall, this study has shown that data-driven and cross-disciplinary approaches to conservation can reduce illegal and unsustainable exploitation of megafauna, through addressing the multiple and diverse drivers of human behavior. Our study supports previous research on the value of: understanding context, robust project design, working with and building capacity of local institutions, and on-going adaptive management (Brooks et al., 2012; Lejano & Ingram, 2010; Travers, Selinske, et al., 2019; Waylen et al., 2010). However, with new emerging challenges, we also emphasize the need for long-term commitments, strong partnerships with diverse local stakeholders, and commitments to capturing and sharing learning. Together, these approaches can build resilient and adaptive institutions for enduring impact.

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CONFLICT OF INTEREST

The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

Hollie Booth conceptualized and designed the paper and methods, conducted parts of the analysis, and coordinated writing of the manuscript, with substantial inputs/revisions involving critically important intellectual content from all co-authors. In particular: Jonathan Hunter provided substantial inputs on crime science components of the paper; Jo Marlow provided substantial inputs on the livelihoods components of the paper; Ulfah Mardhiah, Hanifah Siregar, Mochamad Iqbal Herwata Putra, Andi Cahyana, and Irfan Yulianto provided substantial inputs on spatial and statistical analysis; Hanifah Siregar, Giyanto Giyanto, Mochamad Iqbal Herwata Putra, Jo Marlow, Boysandi Boysandi, Apolinardus Yosef Lia Demoor, Sarah Lewis, Dwi Adhiasto collated data used in the study; Luky Adrianto, Dwi Adhiasto, and Irfan Yulianto provided oversight for the intervention design and project monitoring.

ETHICS STATEMENT

H. B. has undergone comprehensive research integrity and ethics training as per the University of Oxford Central University Research Ethics Committee (CUREC) procedures and the Social Research Association Ethical Guidelines. The Wildlife Conservation Society has training and internal review board (IRB) procedures for research involving human subjects. No specific ethical clearance was sought for this study, since it is based on analysis of secondary data, and did not therefore directly involve any human or animal subjects.

DATA AVAILABILITY STATEMENT

Many of the data sources used herein—including patrol data, intelligence data, law enforcement data and landings data—include sensitive information, which cannot be shared in a public repository. Some information can be made available on request. For more information, a detailed description of all data sources and their respective custodians is available in Table S3.

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