Optimizing enforcement and compliance in offshore marine protected areas: a case study from Cocos Island, Costa Rica

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Abstract Illegal exploitation of resources is a cause of environmental degradation worldwide. The effectiveness of conservation initiatives such as marine protected areas relies on users' compliance with regulations. Although compliance can be motivated by social norms (e.g. peer pressure and legitimacy), some enforcement is commonly necessary. Enforcement is expensive, particularly in areas far from land, but costs can be reduced by optimizing enforcement. We present a case study of how enforcement could be optimized at Cocos Island National Park, Costa Rica, an offshore protected area and World Heritage Site. By analysing patrol records we determined the spatial and temporal distribution of illegal fishing and its relationship to patrol effort. Illegal fishing was concentrated on a seamount within the Park and peaked during the third year-quarter, probably as a result of oceanographic conditions. The lunar cycle in conjunction with the time of year significantly influenced the occurrence of incursions. The predictability of illegal fishing in space and time facilitates the optimization of patrol effort. Repeat offenders are common in the Park and we suggest that unenforced regulations and weak governance are partly to blame. We provide recommendations for efficient distribution of patrol effort in space and time, establishing adequate governance and policy, and designing marine protected areas to improve compliance. Our methods and recommendations are applicable to other protected areas and managed natural resources.

Keywords Cocos Island, Costa Rica, illegal fishing, longlining, lunar phase, marine reserve, patrol, poaching

Introduction

Offshore marine protected areas are an emerging approach to marine conservation and fisheries management (Game et al., 2009; Graham & McClanahan, 2013). Their effectiveness, as for near-shore protected areas, relies heavily on compliance by fishermen (Campbell et al., 2012; Edgar et al., 2014). Even remote locations are not safeguarded from illegal fishing because fishermen will travel long distances to target commercially valuable species (Berkes et al., 2006); for example, in the Chagos Archipelago, a remote area in the Indian Ocean with few inhabitants, illegal fishing has resulted in a significant decline in sharks (Graham et al., 2010).

Ensuring compliance offshore is challenging. Patrolling large and distant tracts of ocean is logistically difficult and financially expensive, and therefore detection rates for illegal activity are low. Additionally, important factors for compliance, such as social norms (e.g. peer pressure and legitimacy) and legislation, may be absent or lack support offshore. Although voluntary compliance is desirable (Ostrom, 1990; Hønneland, 2000; Arias & Sutton, 2013), not all people comply voluntarily; typically some degree of enforcement is necessary (Tyler, 1990; Hønneland, 2000). However, enforcement is perhaps the most expensive management activity in both terrestrial and marine protected areas (Robinson et al., 2010; Ban et al., 2011). With limited funds for conservation, optimizing enforcement can make management more cost-effective.

There is a common misconception that enforcement involves only patrolling but it actually encompasses detection, arrest/citation, prosecution and conviction (Sutinen, 1987; Akella & Cannon, 2004); it can be described heuristically as a four-link chain. The first link, probability of detection, is mainly technical and field-based, relying on factors such as equipment, and number and skills of wardens. The remaining links (probabilities of arrest/citation, prosecution and conviction) tend to rely progressively more on legal and political constructs. The probability of arrest depends partly on field equipment (e.g. a boat's capacity to pursue) but also on what legally constitutes noncompliance and evidence. The probability of prosecution involves the capacity of the legal and institutional system to undertake proceedings against non-compliance, underlining the importance of strong institutions and coordination between them. Conviction, and its associated penalties, rests on the judiciary and its probability depends on the quality of evidence and the overall capacity of the enforcement system (Akella & Cannon, 2004). Ultimately

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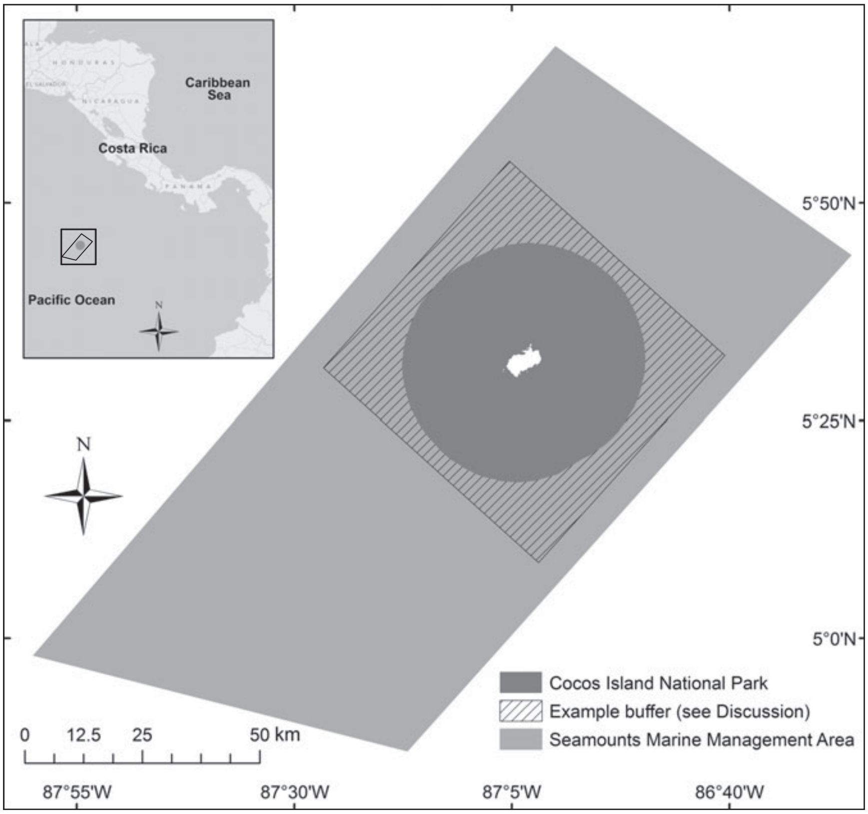

FIG. 1 Cocos Island National Park, Costa Rica, and the surrounding Seamounts Marine Management Area. The rectangle on the inset shows location of the main map in relation to mainland Costa Rica.

the effectiveness of all links is influenced by resources, legislation and political will.

Recognizing that all links in the chain must be strong for effective enforcement, here we focus on the probability of detection, which is a key, yet largely unstudied, aspect of natural resource management. To increase the probability of detection, patrol effort must be distributed efficiently; for this, authorities need reliable data on illegal use of resources. However, such illegal activity is typically clandestine, which poses methodological challenges for data collection (Gavin et al., 2010; Arias & Sutton, 2013). Few methods are suitable for studying illegal use of resources offshore. Sparse populations and the presence of foreign boats reduce the practicality of social-survey techniques. Modelling, forensics and remote surveillance are expensive and require appropriate technology and/or training, inhibiting their use in developing countries. Indirect observations of illegal activity, such as derelict gear, are challenged by currents, depth and extent. Enforcement in protected areas is typically based on patrols, and patrol records are one of the few means available for assessing illegal use of resources. This approach has been used in terrestrial protected areas to provide information on factors such as patrol allocation (Leader-Williams et al., 1990), funding of enforcement (Hilborn et al., 2006) and levels of poaching (Knapp et al., 2010), yet patrol records for marine protected areas remain largely unanalysed (but see Davis et al., 2004; Mangubhai et al., 2011).

Here we present a case study of Cocos Island National Park (hereafter Cocos), Costa Rica. We focus on the probability of detection and explore options for optimizing enforcement and compliance. Cocos shares key characteristics with other offshore marine protected areas, including remoteness, presence of illegal fishing and difficulty of enforcement. We analyse illegal fishing and patrol effort by using a multi-year dataset of patrol records, expert consultation and literature. We use the concept of the enforcement chain to address two research questions: (1) How can patrol effort be optimized to match the spatial and temporal distribution of illegal fishing? (2) What are the key constraints on the subsequent links of the enforcement chain: arrest/citation, prosecution and conviction? Our methodological developments and recommendations aim to contribute to the adaptive planning and management of Cocos and other offshore marine protected areas.

Study area

Cocos is located c. 500 km south-west of Costa Rica, in the Pacific Ocean (Fig. 1). The no-take marine protected area (1,989 km^2) was established in 1984 (Salas et al., 2012) and the only inhabitants of the Island are Park wardens and, occasionally, Coast Guard staff, researchers and volunteers. The Park is a World Heritage Site and a Ramsar site. Cocos has among the highest fish biomass in the tropics

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(7.8 tons ha^{-1}), notable endemism and globally threatened species (Friedlander et al., 2012) and is consequently recognized as a top international dive destination. However, it also attracts fishermen, mostly Costa Rican, who use surface longlines to target fish.

In 2011 a multiple-use marine protected area, Seamounts Marine Management Area (9,640 km^2), was created around Cocos (Fig. 1) with the primary objective of protecting seamounts. In the Seamounts Marine Management Area bottom trawling and purse seining are prohibited and longlining is regulated. Here we focus on Cocos but also provide recommendations that relate to the Seamounts Marine Management Area.

Methods

We used a 5-year dataset (December 2005–September 2010) of patrol records from Cocos, which were compiled by Park wardens, the Coast Guard and MarViva, an NGO that assisted with patrols. The dataset contained information on 1,501 patrols and was missing data for November 2007 and July and February 2008. Data were extracted from patrol logbooks detailing hours and nautical miles patrolled and, if applicable, the confiscation of longlines. We mapped only the initial location of confiscated longlines in the Park (hereafter incursions) because final locations were not commonly given. We did not estimate catch per unit effort because soak time, which is the time a baited hook is available and an integral component of catch per unit effort (Ward et al., 2004), was unknown and assumed to be highly variable.

To analyse whether and how patrols could be optimized we first examined illegal fishing in terms of catch, and the spatial and temporal distribution of incursions. We recorded (1) which fish species were commonly caught, (2) whether incursions were concentrated on specific bathymetric features and (3) whether incursions prevailed during specific months and lunar phases. Secondly, we examined the temporal distribution of patrol-days according to months and lunar phases. For these analyses we grouped all patrols for each day, giving a total of 1,078 patrol-days as input. These temporal analyses made it unnecessary to distinguish between multiple patrols on the same day. Thirdly, we tested for correlations (r_s) between (1) nautical miles and hours patrolled, (2) incursions and catch and (3) hours patrolled and incursions. For the correlations we used individual patrols, distinguishing between those occurring on the same day.

To explore bathymetry we used the *GEBCO_08 Grid v. 20100927* (GEBCO, 2014) and we created a three-dimensional chart using *Surfer v. 11* (Golden Software, Golden, USA). Incursions were mapped in *ArcMap v. 10.1* (ESRI, Redlands, USA) and analysed for spatial patterns with Moran's I spatial autocorrelation test. We used a 5 km threshold (mean distance between incursions) within which to consider the spatial relationship between neighbouring records.

We used a logistic regression to examine the effects of time of year (i.e. year-quarters) and lunar phases (i.e. lunar-quarters) and their influence on the probability of a patrol detecting an incursion. Patrol effort was not included in the model because once an illegal incursion was detected further search effort on that day was considerably reduced, and exploratory analyses revealed that including patrol effort did not change the model´s coefficients significantly. The regressions therefore examined variations between year- and lunar-quarters in the proportion of patrol-days on which incursions were detected. Because year-quarter and lunar-quarter were categorical variables, the model yielded a perfect fit to the data and was used to provide estimates of detection probabilities for each combination of year-quarter and lunar-quarter. Data analysis was carried out using *SPSS v. 20* (IBM, North Castle, USA) and *S-PLUS v. 8* (TIBCO Software, Palo Alto, USA).

To analyse data according to the lunar cycle we counted the number of days after the new moon (day 0) when an incursion was detected, and we refer to these as lunar days. We used moon phase predictions by F. Espenak (NASA, 2012). We converted lunar days to angles by multiplying each lunar day by 360 and then dividing by 29.53 (number of days in a lunar month). We refer to the phase from new moon to first quarter as first quarter, first quarter to full moon as second quarter, full moon to third quarter as third quarter, and third quarter to new moon as last quarter. Circular histograms were created using *Oriana v. 4* (Kovach Computing Services, Anglesey, UK).

To analyse key constraints on arrests/citations, prosecutions and convictions related to incursions in Cocos we reviewed legislation, newspaper articles and grey literature, and interviewed five key informants, who had substantial legal and/or practical experience of enforcement in the Park. Interviews were conducted in Spanish and consisted of open-ended questions about patrols and the legal mechanisms to control illegal fishing.

Results

General characteristics of patrol effort and incursions

Three hundred incursions, with nearly 34,500 hooks, were recorded in the Park. Approximately 2,000 animals were hooked, of which 66% were tuna and 25% were sharks. The most commonly reported species were yellowfin tuna *Thunnus albacares* and silky shark *Carcharhinus falciformis*. Less common species included marlin (Istiophoridae), turtles (Chelonioidea), rays (Batoidea) and dolphins

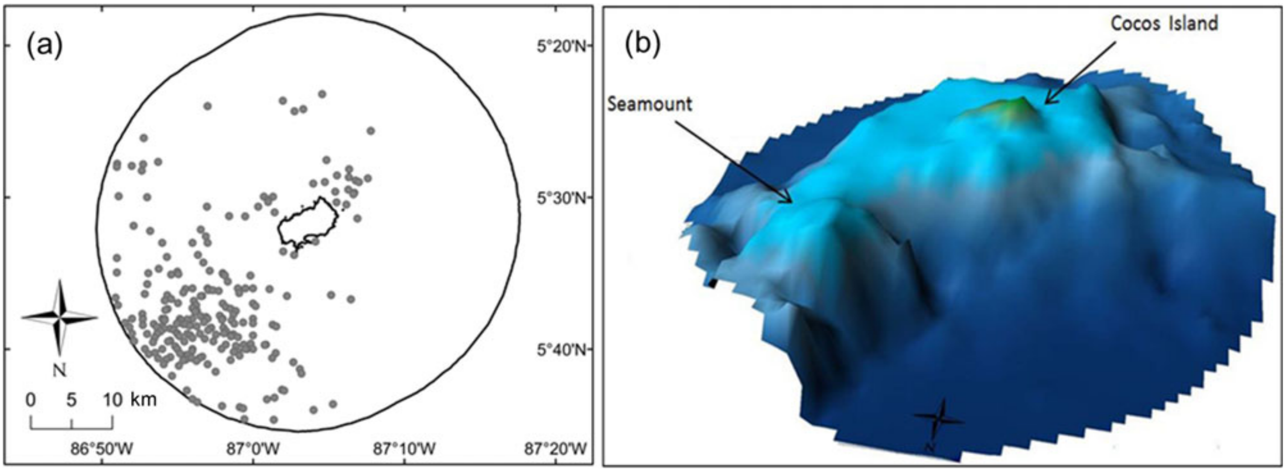

FIG. 2 (a) Locations of recorded incursions in Cocos Island National Park, Costa Rica. (b) Bathymetric profile of the Park. The black circle in (a) and the 3D area in (b) represent the Park. Note that north–south orientation has been inverted in both (a) and (b) to show the steep walls of the seamount in (b).

TABLE 1 Analysis of deviance for the binary logistic regression. Year and lunar quarters and their interactions were tested as predictors of illegal incursions into Cocos Island National Park (Fig. 1).

	df	Deviance	Residual df	Residual deviance	P (χ)
Null			1,077	1,068.8	
Year quarter	3	20.9	1,074	1,047.8	0.0001
Lunar quarter	3	5.4	1,071	1,042.4	0.1416
Year quarter x lunar quarter	9	18.4	1,062	1,023.9	0.0305

(Delphinidae). Incursions were clustered non-randomly ($I = 0.301$, $z = 75.18$, $P < 0.0005$) north-east of the Park, in the vicinity of a seamount (Fig. 2). The seamount has a steep wall and lies c. 15 km from the island (Fig. 2b; Lizano, 2012).

The percentage of patrol-days on which incursions were detected was 20%. The mean duration of patrols was 6.9 hours, covering 40.3 nautical miles. There was a positive correlation between total nautical miles and hours patrolled ($r_s(1{,}407) = 0.629$, $P < 0.0005$) and between total incursions and total number of animals hooked ($r_s(1{,}474) = 0.782$, $P < 0.0005$). Although statistically significant, there was only a weak correlation between total hours patrolled and total incursions ($r_s(1{,}421) = 0.204$, $P < 0.0005$).

Records revealed that illegal fishers used plastic containers and old tyres as buoys. Some boats were seen breaching the Park's boundaries repeatedly, and this persisted until more recently (SINAC-MINAET, 2012; Salas, 2013). Using the patrol boat's radar, wardens detected multiple fishing boats frequently, some within the Park and others close to the boundary; those within the Park would flee on seeing the patrol boat. Commonly, boats failed to stop when requested, with insults and threats occasionally directed at wardens by radio. Threats have also been reported more recently (Rojas, 2013). Illegal fishers have reportedly been trolling (Salas, 2013), using currents to drift their gear in and out of Cocos, fishing under cover of darkness and painting buoys in low-contrasting colours (SINAC-MINAET, 2012).

Temporal distribution of patrol effort and incursions

Time of year and lunar phase together significantly influenced the probability of encountering incursions (Table 1), which increased during the third year-quarter, with higher probabilities during the first and last lunar-quarters at this time of year (Fig. 3).

Incursions peaked during the third year-quarter (Figs 3 & 4a), reaching a maximum in August (Fig. 4a). Patrol hours were more evenly distributed throughout the year than incursions (Fig. 4b). Incursions peaked during the first lunar-quarter (Fig. 4c). Patrol hours were higher during the second and third lunar-quarters (Fig. 4d).

Key constraints on the probabilities of arrest/citation, prosecution and conviction

The management and conservation of marine resources in Costa Rica rely on the fisheries authority and the Environment Ministry. In 2011 the President created a commission to 'diagnose, assess and recommend the necessary

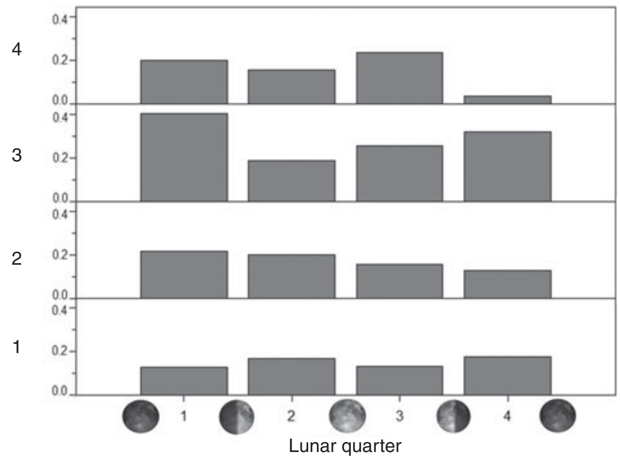

FIG. 3 Predictions of probability of encountering incursions within Cocos Island National Park (Fig. 1). Predictors are year-quarters (rows) and lunar-quarters (columns). Probabilities are given on the vertical axis.

adjustments for good marine governance in Costa Rica' (Casa Presidencial, 2011). The Commission recommended a review and restructuring of the fisheries authority (Comisión Presidencial para la Gobernanza Marina, 2012) and this was backed by environmental groups (Frente por Nuestros Mares, 2013) and the Comptroller General (CGR, 2012). There is a conflict of interests within the fisheries authority: most of the board members are representatives of the fishing industry (Quesada-Alpízar, 2006).

Probabilities of arrest or citation are low. Although only authorized vessels are allowed to enter the Park (Poder Ejecutivo, 2012), this rule is commonly flouted and is difficult to enforce. When illegal fishermen detect a patrol boat while setting or retrieving gear they cut the line and flee to avoid charges of illegal fishing (Costa Rica does not mandate gear identification). Unless wardens can intercept fleeing boats, arrests/citations are impossible. Wardens must then remove the abandoned fishing gear from the Park. If a boat is intercepted it is given a written and verbal notification stating the illegality of entering the Park. If the same boat is intercepted again within the Park it is processed for 'disobedience to authority', for which the captain could face a jail sentence.

Even after arrest or citation the probability of prosecution is limited. Most illegal fishing boats found in the Park lack the legal autonomy to travel further than 40 nautical miles (c. 74 km) from the coast but non-compliance with this regulation goes unsanctioned. There are reported cases of illegal fishing boats receiving fuel subsidies from the fisheries authority (Delgado, 2012), allowing them to reach distant waters at a lower cost. To circumvent the limitations of administrative sanctions by the fisheries authority, the Park's management goes through the judicial system. However, inefficiencies in this system can result in prosecutions being delayed by > 8 years.

At the end of the enforcement chain, convictions are rare. No longline boat or captain has been convicted with severe sanctions (e.g. jail sentences or boat confiscations) for fishing illegally or entering the Park, although one boat has been the subject of > 10 lawsuits for disobedience to authority. Of six prosecutions concluded during December 2010–March 2013 three cases were dismissed and three ended in conviction. However, in all three convictions the captains received probation.

Discussion

Increasing the probability of detection

In Cocos illegal fishing is a considerable threat to some marine species. Illegal activity takes place at targeted locations and times, and repeat offenders usually go unpunished.

Illegal fishing is focused on a seamount within the Park (Fig. 2), which is consistent with the expectation of aggregations and increased presence of predators around seamounts (Morato et al., 2010). Studies have reported derelict fishing gear and low densities of groupers at seamounts outside the Park (Starr et al., 2012) and declines in shark abundance inside the Park (Friedlander et al., 2012). Fishing pressure is significant around and within Cocos and detracts from the Park's ecological integrity.

The higher incidence of illegal fishing during the third year-quarter (Figs 3 & 4a) could be attributable to oceanographic variables. For example, seasonal variations in mixed-layer depth (Fiedler & Talley, 2006) can affect the distribution and catchability of yellowfin tuna (Song et al., 2008), potentially luring fishermen further from the coast and closer to Cocos. Fishermen commonly use remote sensing technology to find oceanographic features such as upwellings (SPC, 2011), so enforcement authorities could also exploit these tools to improve the probability of detection. However, using remotely sensed data increases the technical difficulty of analyses, possibly constraining their usage where expertise and/or funding are limited. The lunar and bathymetric data we used are freely accessible and relatively easy to explore and analyse compared to remotely sensed data on dynamic oceanographic features. Simple and effective methods for analysing patrol records can foster replication.

Fishermen have long been aware of an effect of lunar cycles on fish behaviour and catchability (Parrish, 1999), and the concentration of illegal fishing activity around certain lunar phases observed here is in line with the findings of other studies. Lowry et al. (2007) reported peak catch of several predators, including yellowfin tuna, during the first lunar-quarter. Reduced light around the new moon could drive both prey and predators closer to the surface (Blaxter,

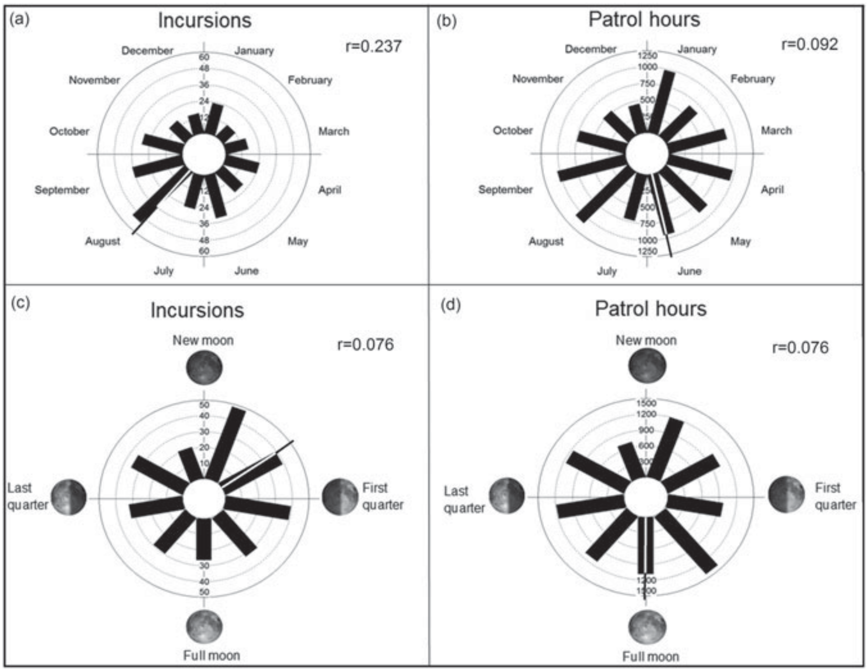

FIG. 4 Temporal distribution of incursions and patrol effort in Cocos Island National Park. (a) Incursions by month; (b) patrol hours by month; (c) incursions by lunar cycle; (d) patrol hours by lunar cycle. Bars indicate frequencies. Labels on vertical lines represent number of recorded incursions or hours of enforcement. The radial line on each graph shows the location of the mean value. The length of the mean vector (*r*), a measure of variance (range 0–1), is given in the top right of each graph; larger values indicate that observations are grouped closer to the mean.

1974), potentially increasing their catchability with surface longlines. Reduced light may also favour illegal boats by lowering the probability of detection. The observed temporal patterns of incursions are therefore not unexpected.

Our analysis of monthly trends and the lunar cycle suggests that patrols can be optimized by matching incursions more closely (Fig. 4), thereby increasing deterrence when most needed and reducing management costs by cutting unnecessary effort. However, although natural variables can explain inter- and intra-monthly fluctuations in incursions, fluctuations can also be influenced by patrol effort. If fishers became aware that detection was unlikely at a given time, their motivation for non-compliance could increase at that time and vice versa. Managers can adapt to such variations by monitoring patrol records periodically and systematically to develop approaches that maximize the probability of detection.

The role of marine protected area design in compliance

The spatial design of marine protected areas plays an important role in compliance. An example of this is the Great Barrier Reef Marine Park, Australia, where simple and easily identifiable boundaries provide clarity for users and wardens (Day et al., 2012). In contrast, the boundary at Cocos is defined by a radius of 12 nautical miles (Fig. 1), represented by the territorial sea, which poses problems for compliance and enforcement. The boundary is somewhat irregular because of the shape of the island and is therefore difficult to identify accurately in the field, which can cause confusion for fishermen and wardens. Modifying the Park's boundary would be difficult politically but a feasible alternative would be to zone the Seamounts Marine Management Area to create a simple polygonal buffer zone around the Park (Fig. 1), which could serve three purposes: (1) to facilitate navigation, (2) exclude longlining further from the Park, and (3) reduce the boundary effect. Fishing effort could be concentrated on the boundary areas (Kellner et al., 2007) and illegal fishing would be likely to occur near boundaries because of accidental incursions or deliberate ones facilitated by easier entry and exit (Gribble & Robertson, 1998). For a given shape the boundary effect is amplified in smaller marine protected areas because of larger perimeter : area ratios (Kritzer, 2004), but buffers reduce this effect by reducing the perimeter per unit area. The perimeter : area ratio of the hypothetical buffer in Fig. 1 is c. 0.066 : 1, compared to 0.079 : 1 for the almost circular Park.

Constraints in subsequent links of the enforcement chain

For Cocos the probability of detection, although needing improvement, is apparently stronger than the subsequent links of the enforcement chain. The main reason for weaknesses in the three subsequent parts of the chain is an ineffective legal and governance base. Boats enter the Park continually, sometimes employing techniques to avoid detection. This suggests that some illegal fishing goes undetected and the thousands of illegal hooks that we report are probably underestimates. When illegal fishers lose their gear to wardens their economic losses are potentially offset by the high market prices for tuna and shark fins (finning has been reported in Cocos; Delgado, 2012). They can further minimize their losses by selecting cheap gear. Apparently in Cocos the potential gains from illegal fishing

Table 2 Cumulative probability of illegal fishers in Cocos Island National Park (Fig. 1) being penalized, given various hypothetical probabilities for each of the four links of the enforcement chain.

	Probability of detection (%)	Probability of arrest/citation (%)	Probability of prosecution (%)	Probability of conviction (%)	Cumulative probability of penalization (%)
Case 1	50	50	50	50	6.25
Case 2	90	90	5	90	3.65
Case 3	90	50	50	50	11.25

surpass the potential costs of getting caught. This also applies internationally, particularly in relation to high-valued catch (Sumaila et al., 2006).

Assuming that the probabilities of detection, arrest, prosecution and conviction were each 50% the cumulative probability of being penalized would be 6.25% (Table 2, Case 1). However, at Cocos and other offshore marine protected areas these probabilities are likely to be < 50%. With 20% of patrol-days resulting in detection of incursions in Cocos it can be assumed that the overall probability of detecting incursions is lower. Some incursions are not detected because they go unseen during patrols and others occur on days with no patrols. Importantly, as the value for any one link approaches zero, overall enforcement becomes practically ineffectual (Table 2, Case 2), and weak links undermine investments in and success of stronger ones (Table 2, Cases 2 & 3). Obtaining accurate probabilities for such analysis requires systematic record keeping for each link, and/or values estimated through social surveys (Akella & Cannon, 2004).

Perhaps the main gain from enforcement at Cocos has been avoiding rampant illegal fishing through the partial deterrence offered by patrols. Nevertheless, this is a limited approach that is failing to achieve strong compliance. Technology (e.g. vessel monitoring systems and radar) can increase the probability of detection and reduce management costs by directing patrols but deterrence remains low if other links are weak. Offshore marine protected areas require clear and enforceable regulations, applicable at sea and in ports (e.g. inspections, vessel blacklists). Field staff, prosecutors and judges must be trained in environmental and marine law (Akella & Cannon, 2004). The institutions managing compliance must collaborate and adapt to change (Hauck & Kroese, 2006). Penalties must counter the illegal gains from highly valued catch and include loss of privileges (Robinson et al., 2010), such as loss of access to the Seamounts Marine Management Area (Fig. 1). Graduated sanctions are a useful system in which to nest penalties (Ostrom, 1990), varying sanctions according to the number and/or severity of violations (Russell, 1990).

Although the enforcement system in place at Cocos has deficiencies it deters widespread non-compliance. However, this may not be the case in other marine protected areas. A systematic and periodic analysis of patrol records, such as that presented here, can help optimize enforcement. Our case study highlights how clear and enforceable regulations coupled with strong institutions can also help optimize enforcement. This also applies for areas beyond national jurisdiction (high seas) where, because of legal and governance weaknesses, additional national, regional and international efforts are needed to ensure adequate enforcement (Gjerde et al., 2013). Enforcement is a tool to encourage compliance, a means to an end; other tools such as social norms should also be exploited. In the process of achieving international objectives for marine conservation (e.g. effectively conserving ≥ 10% of coastal and marine areas by 2020; CBD, 2010), and with increasing pressure on global marine resources, compliance is vital. Failing to maintain compliance undermines the conservation benefits expected from effective marine protected areas and leads to metrics, such as the extent of marine protected areas, not reflecting actual outcomes for marine conservation.

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