Copyright © 2013 by the author(s). Published here under license by the Resilience Alliance.
Arias, A., and S. G. Sutton. 2013. Understanding recreational fishers' compliance with no-take zones in the Great Barrier Reef Marine Park. *Ecology and Society* **18**(4): 18. http://dx.doi.org/10.5751/ES-05872-180418

Insight

Understanding Recreational Fishers' Compliance with No-take Zones in the Great Barrier Reef Marine Park

Adrian Arias [1,2] *and Stephen G. Sutton* [2,3]

ABSTRACT. Understanding fishers' compliance is essential for the successful management of marine protected areas. We used the random response technique (RRT) to assess recreational fishers' compliance with no-take zones in the Great Barrier Reef Marine Park (GBRMP). The RRT allowed the asking of a sensitive question, i.e., "Did you, knowingly, fish within in a Green Zone during the last 12 months?" while protecting respondents' confidentiality. Application of the RRT through a survey of recreational fishers indicated that the majority of recreational fishers, 90%, comply with no-take zones. Likewise, most fishers, 92%, reported not personally knowing anyone who had intentionally fished in a no-take zone, indicating that fishers' perceive high levels of compliance among their peers. Fishers were motivated to comply with no-take zones primarily by their beliefs about penalties for noncompliance, followed by beliefs about the fishery benefits of no-take zones. Results suggest that compliance-related communication efforts by the managing authority have partially succeeded in maintaining appropriate compliance levels and that future efforts should accentuate normative compliance drivers that will encourage voluntary compliance. We conclude that compliance monitoring should be integrated into the adaptive management of the GBRMP and other protected areas; in this case social surveys using the RRT are effective tools.

Key Words: *compliance; false consensus effect; Great Barrier Reef; illegal fishing; marine protected area; marine reserve; no-take zones; poaching; random response technique (RRT); recreational fishing*

INTRODUCTION

The Great Barrier Reef (GBR) is the largest coral reef system in the world and an environment of outstanding cultural and natural value. Most of the GBR is within the multiple use Great Barrier Reef Marine Park (GBRMP), which uses an extensive zoning system to manage human activities such as fishing, recreation, and tourism (GBRMPA 1994, Day 2002). In 2004, the Great Barrier Reef Marine Park Authority introduced a zoning plan that increased no-take zones, commonly known as Green Zones, from less than 5% to 33% of the park's area, with the remainder of the park open to multiple forms of fishing (GBRMPA 2004). The primary aim of the rezoning was to increase the level of protection afforded to the biodiversity of the GBR (Fernandes et al. 2005). Stakeholder responses to the 2004 zoning plan were mixed, with significant opposition coming from some segments of the recreational and commercial fishing communities (Sutton and Tobin 2009, McCook et al. 2010, Lédée et al. 2012).

The ecological effectiveness of the GBRMP is highly dependent on users' compliance (McCook et al. 2010). Available data postrezoning suggests that compliance with the 2004 GBR zoning plan is incomplete and that recreational fishing accounts for most of the offenses related to zoning within the park (McCook et al. 2010). Noncompliance with zoning by recreational fishers can potentially have a negative impact on protected ecosystems and reduce the likelihood of achieving conservation goals (Lester and Halpern 2008). Consequently, there is a strong need to better understand the level of zoning compliance among recreational fishers in the GBRMP and the factors that influence fishers' decisions to comply with zoning regulations. Reliable estimates of compliance can aid in determining the environmental impact of infractions, in understanding how enforcement affects compliance, and in distributing staff in the right numbers, times, and places (Cowles et al. 1979). A better understanding of compliance levels can also help gauge management effectiveness in the GBRMP and the level of acceptance of the zoning plan by local communities (Alder 1996, Ham 2009).

Estimating noncompliance of recreational fishers with spatial zoning in an area the size of the GBRMP is difficult. Currently used methods for monitoring recreational fishers' compliance in the GBRMP include aerial and vessel-based surveillance, indirect observation, e.g., discarded gear on reefs, and reports of illegal activity from GBRMP users (McCook et al. 2010). However, these methods can be logistically and economically inefficient and potentially misleading if reported or interpreted outside of the context in which the information was collected (Cowles et al. 1979, Gavin et al. 2010, McCook et al. 2010).

Surveys of recreational fishers have the potential to provide cost-effective information about compliance in the GBRMP. However, two major sources of bias arise in social surveys, especially if asking sensitive questions, e.g., noncompliance with regulations, when: (1) people refuse to participate, i.e., a nonresponse bias; and/or (2) those who participate provide false information, i.e., a response bias (Hansen et al. 1993). A

[1]Australian Research Council Centre of Excellence for Coral Reef Studies, James Cook University, [2]School of Earth and Environmental Sciences, James Cook University, [3]Centre for Sustainable Tropical Fisheries and Aquaculture, James Cook University

survey in which fishers feel comfortable sharing information about their compliance/noncompliance with GBRMP zoning would reduce bias and supply valuable data for estimating compliance rates and for designing strategies to improve compliance. The Random Response Technique (Warner 1965) is a promising survey methodology for asking sensitive questions that could potentially be employed to investigate compliance levels in the GBRMP.

The RRT has been successfully used to investigate areas such as sexual behaviors, abortion, gambling, drug use, cheating, and stealing (Fox and Tracy 1986). Despite its use in the social sciences, the method has not been fully exploited by natural resource managers. Nonetheless, it has been used to investigate noncompliance in freshwater recreational fishing (Schill and Kline 1995, St. John et al. 2010) and illegal use of terrestrial (Wright 1980, Solomon et al. 2007, St. John et al. 2012) and marine (Chaloupka 1985, Blank and Gavin 2009) resources. Lensvelt-Mulders et al. (2005) conducted a meta-analysis of RRT studies and concluded that the technique provides significantly more valid results compared to other methods, especially as the sensitivity of questions increases. We tested the utility of using RRT for estimating recreational fishers' level of noncompliance with GBRMP zoning, and to explore recreational fishers' attitudes and beliefs about compliance in the GBRMP.

METHODS

Random Response Technique allows survey participants to respond to a sensitive question while maintaining confidentiality, thereby increasing the probability of truthful answers (Fox and Tracy 1986). Typically, a randomizing device with known probabilities is used to determine whether the respondent is asked to answer the sensitive question, or whether the respondent is asked to give a predetermined answer, either 'yes' or 'no,' regardless of the true answer to the sensitive question (Horvitz et al. 1976). Confidentiality is maintained because the interviewer does not know whether the respondent was instructed to answer the sensitive question or instructed to give the predetermined answer. Because the probabilities of the randomization device are known, the proportion of the population with the sensitive attribute can be estimated through probabilistic logic. Fox and Tracy (1986) explained the method through the use of a die: the participant is instructed to say 'yes' if a one is rolled (P2), to say 'no' if a two or three is rolled (P3), and to respond to the sensitive question, 'yes' or 'no' answer, if a four, five, or six is rolled (P1). In this case, the ratio of the population with the nonsensitive attribute is 0.33, given by

$$P_2/(P_2+P_3) = P_2/(1-P_1) \quad (1)$$

The result of the die is unknown by the interviewer so the reason for the answer also remains unknown, but can be estimated. Researchers have developed randomizing devices that allow the probabilities to be varied and therefore increase the accuracy of estimates of the sensitive attribute (Abernathy et al. 1970). The RRT provides a simple and cost-effective tool for estimating compliance levels and facilitates further investigation of the factors that lead to compliance behaviors.

The study was conducted in Townsville, Australia, the most populated city along the Great Barrier Reef coast (Queensland Treasury and Trade 2012). The minor geographical variation in recreational fishers' characteristics within the GBR area (Sutton 2008, De Freitas et al. 2013) suggests that Townsville recreational fishers are representative of the wider population of recreational fishers in the GBR. Surveys of randomly selected recreational fishers were conducted at Townsville's main boat ramp every weekend and randomly selected weekdays during May and June 2009. When approaching potential interviewees, the interviewer identified himself as a university student conducting a short, i.e., 5-10 minute, anonymous survey on recreational fishing. Fishers who were encountered multiple times were not reinterviewed.

The questionnaire was designed to be administered on-site and collect information about recreational fishers' beliefs and attitudes about compliance and enforcement with zoning in the GBRMP (Table 1). A RRT section about compliance with no-take zones was asked at the end of the survey. Before the RRT section, fishers were told that the next part of the survey involved a question that some could deem as 'sensitive' and then were asked if they wished to proceed. Interviewees were unaware of the content of the sensitive question before deciding to participate. If the participant refused, they were thanked for participating and the survey ended. Respondents who agreed to proceed to the sensitive question were reminded that the interviewer was not a government employee, that their name was not requested, and that the survey was part of a university study. The interviewer then explained that a special method was being used to ensure confidentiality.

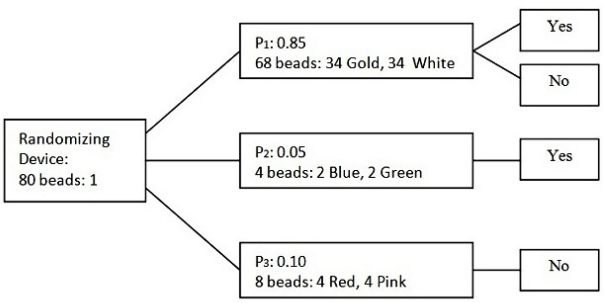
Similar to Abernathy et al. (1970), a plastic screw-top container filled with 80 beads of 6 colors was used as a randomizing device (Fig. 1). A trap mechanism exposed one bead to a clear window when the device was tipped. A list of instructions was attached to the lid. A red or pink bead required the respondent to answer with a 'no,' blue or green, a 'yes,' and gold or white led to the sensitive question: "Have you, knowingly, fished in a Green Zone in the Great Barrier Reef Marine Park during the last 12 months?"

The method and the reason it provides confidentiality was succinctly explained to participants. Further explanation was given to participants who appeared or admitted to being confused. During the explanation, the question was covered with dark adhesive tape to prevent the participant from reading it. Once the explanation was complete, the adhesive tape covering the question was removed and the device was handed to the participant. The participant was then instructed to tilt

Table 1. Questionnaire items, responses and comparison between 'yes' vs. 'no' respondents to the RRT question.

	Questions	Responses	P-value for comparison of 'yes' vs. 'no' respondents.
1	Townsville resident?	95% residents	0.933
2	Approximately how many times have you gone fishing during the last 12 months?	16.8 days (average)	0.312
3	Compared to other recreation activities that you do in the Great Barrier Reef Marine Park (such as boating, diving, swimming, etc.), would you say fishing is:	74% most important activity, 8% second most important activity, 2% third most important activity, 17% one of many	0.95
4	How knowledgeable are you about the location of Green Zones in the areas you like to fish?	54% very knowledgeable, 41% moderately knowledgeable, 5% not at all knowledgeable	0.516
5	What do you think would happen to a fisher who is caught by park/wildlife officers fishing in a Green Zone?	79% fines, 28% confiscation of property, 13% court hearing, 8% warning, 8% jail	0.686
6	How concerned would you feel if you saw a recreational fisher fishing a Green Zone near your favorite spot?	47% very concerned, 45% moderately concerned, 8% not at all concerned	0.643
7	How likely would you be to report such activity?	29% very, 45% moderately, 26% not at all	0.114
8	In general, how supportive of the 2004 Great Barrier Reef Zoning Plan are you today?	41% strongly supportive, 33% somewhat supportive, 17% neutral, 5% somewhat opposed, 4% strongly opposed	0.496
9	Degree of agreement: Limiting fishing grounds by the use of Green Zones can lead to a healthy Great Barrier Reef in the future.	67% agree, 24% neutral, 10% disagree	0.604
10	Degree of agreement: The Zoning Plan helps ensure sustainable recreational fisheries in the GBR.	76% agree, 15% neutral, 9% disagree	0.817
11	What do you think is the level of compliance with green zones in the Great Barrier Reef Marine Park by recreational fishers?	12% very high compliance, 48% high compliance, 35% moderate compliance, 2% low compliance, 3% very low compliance	0.058
12	In your opinion, which is the most important factor that would encourage people to comply with Green Zones? (rank)	Rank 1st: Fines Ranked 2nd: Fishery and other benefits Ranked 3rd: Disapproval by other people	0.345 0.803 0.118
13	In your opinion, which is the most important factor that would encourage people to not comply with Green Zones? (rank)	Ranked 1st:High fish numbers Ranked 2nd: Impact is not that big Ranked 3rd: Unlikely to get caught by authorities	0.386 0.935 0.371
14	How important do you think it is to measure compliance with green zones in the GBR?	59% very important, 40% moderately important, 1% not important	0.205
15	Do you personally know anybody who has intentionally fished a Green Zone?	92% no, 8% yes	0.032
	RRT		
16	How comfortable do you believe friends of yours would be in answering truthfully using this method?	72% very comfortable, 26% moderately comfortable, 1% not comfortable	0.295
17	Did you feel comfortable in answering truthfully using this method?	99.3% very comfortable, 0.7% uncomfortable	0.01
18	Did you understand why this method ensures your confidentiality?	92.6% yes, 7.4% no	0.01

Fig. 1. Decision tree (adapted from Chaloupka, 1985)



P_1: Probability obtaining the sensitive attribute (i.e., "Did you, knowingly, fish within a Green Zone during the last 12 months?")
P_2: Probability of obtaining the negative non-sensitive statement (i.e., answering "No")
P_3: Probability of obtaining the positive non-sensitive statement (i.e., answering "Yes")

the container to trap one bead and then answer only 'yes' or 'no,' without revealing to the interviewer the color of the bead, or whether they had been instructed by the device to answer the sensitive question. Finally, the respondent was asked to tilt or shake the device, which would remove the bead from the window, before returning it to the researcher.

After using the randomizing device and ensuring that all participants had read and understood the nature of the sensitive question, the researcher restated why the method was being used and how it ensured confidentiality. Subsequently, three nonsensitive questions were asked to elicit the participant's comfort with and his/her understanding of the RRT. The estimated proportion of participants who had knowingly fished within a no-take zone in the GBRMP over the previous 12 months and the variance for the estimate were calculated using formulas provided by Horvitz et al. (1976; Appendix 1). To explore differences between compliers and noncompliers with GBR zoning, Mann-Whitney tests were used to test for

differences between participants who answered ‘yes’ and those who answered ‘no’ in the RRT exercise. Group differences were tested for variables regarding knowledge, attitudes, and beliefs about compliance in the GBRMP and level of comfort with and understanding of the RRT. Because of the exploratory nature of the study and because the RRT introduces additional variability into the data, statistical significance was set at alpha = 0.1. Statistical software used was SPSS Version 20.

RESULTS

Of the 144 fishers who participated in the survey (response rate = 78%), 88% of respondents were male, and 95% were residents of Townsville. The average number of days fished in the last 12 months by respondents was 16.8 (range 1 to 60 days; median = 12 days). Approximately 75% of respondents rated fishing as their most important GBR activity. Fishers reported being ‘very’ (54%) to ‘moderately’ (41%) knowledgeable of the location of no-take zones in the areas they likes to fish. Of the respondents, 74% reported being supportive of the GBRMP zoning plan, whereas 9% were opposed. Most fishers reported believing that there was a positive effect on fisheries and sustainability associated with no-take zones (76% agree) and the zoning plan in general (67% agree).

Fishers were asked an open-ended question to gauge their beliefs about the legal implications of getting caught by authorities while fishing in a no-take zone. The most commonly cited implications were: fines, cited by 79% of respondents; confiscation of property, e.g., gear, boat, trailer, 28%; court hearing, 13%; warning, 8%; and jail, 8%. Fishers were presented with a list of three potential drivers for compliance and noncompliance with no-take zones and asked to rank them in order of importance. The possibility of being fined was the highest ranked compliance driver (mean rank = 1.44), followed by the belief that no-take zones have benefits to the fishery and the wider ecosystem (mean rank = 2.01), and finally, the belief that others would disapprove of fishing in no-take zones (mean rank = 2.55). The perception that there are more fish in no-take zones was the highest ranked noncompliance driver (mean rank = 1.76), followed by the belief that the impact of recreational fishing in no-take zones is not significant (mean rank = 2.07), and finally, the low perceived likelihood of being caught (mean rank = 2.17). When asked if there were any other important factors affecting compliance, 5% of fishers mentioned education as an additional factor fostering compliance; conversely, 17% mentioned ignorance of zoning regulations as a noncompliance driver.

Most fishers reported that they would be ‘very’ (47%) or ‘moderately’ (45%) concerned if they saw a recreational fisher fishing in a no-take zone near their favorite fishing spot. Fishers also reported that they would be ‘very’ (29%) or ‘moderately’ (45%) likely to report observed noncompliance within no-take zones to the authorities. Fishers believed that compliance with the GBRMP zoning plan by recreational fishers is ‘very high’ (30%), ‘high’ (30%), or ‘moderate’ (35%). Recreational fishers reported that it is ‘very’ (59%) to ‘moderately’ (40%) important to measure compliance with no-take zones in the GBRMP. When directly asked “Do you personally know anybody who has intentionally fished in a Green Zone?” 8% of recreational fishers responded affirmatively.

The RRT section of the survey was answered by 136 interviewees (94%). Of those who participated in the RRT question to estimate the compliance rate with no-take zones, 118 (87%) respondents answered ‘no’ and 18 (13%) respondents answered ‘yes.’ Using the RRT estimators, which adjust for the probability of a respondent being directed by the device to answer ‘yes’ or ‘no’, resulted in an estimated proportion of the population who knowingly fished in no-take zones over the past 12 months of 9.70% (95% CI = 9.64 to 9.76). When asked if they felt comfortable answering truthfully using the RRT, 99% of respondents said ‘yes’, and 93% claimed to understand why the method ensured their confidentiality. Of the respondents, 72% believed that other recreational fishers would feel ‘very comfortable’ in answering truthfully by using the RRT.

We detected several differences between ‘yes’ and ‘no’ respondents in the RRT question (Table 1). Respondents who answered ‘no’ were more likely to understand why the RRT ensured their confidentiality than those who answered ‘yes’ (95% vs. 78%, respectively; $p = 0.01$). Likewise, respondents who answered ‘no’ were more likely to report being comfortable answering truthfully using the RRT method than were respondents who answered ‘yes’ (100% vs. 94 %, respectively; $p = 0.01$). ‘Yes’ respondents were more likely to report knowing somebody who had intentionally fished a no-take zone than were ‘no’ respondents (22% vs. 7%, respectively; $p = 0.032$). ‘No’ respondents were more likely to perceive higher compliance levels than ‘yes’ respondents (66% vs. 33%, respectively; $p = 0.058$).

DISCUSSION

Using a customized Random Response Technique, we were able to provide an estimate of the percentage (~10%) of recreational fishers in the Townsville region of the GBRMP who knowingly did not comply with no-take zones in the preceding 12 month period. The time and financial costs of providing this estimate were very low compared to other potential methods of estimating compliance in the GBRMP, e.g., on-water monitoring and aerial surveillance. Moreover, results suggest that most recreational fishers surveyed understood how the RRT protected their confidentiality and felt comfortable answering compliance related questions with this method. Although compliance levels estimated through

social surveys, including surveys employing RRT, are prone to overestimation because of response bias, it is likely that the RRT-derived estimate we derived is less biased than if the estimate had been derived from direct questioning (Lensvelt-Mulders et al. 2005). Overall, the results suggest that the RRT is an appropriate tool for measuring recreational fishers' compliance with no-take zones and potentially with other fishing regulations, e.g., size and bag limits, in the GBRMP.

Results suggest that only a small minority (< 10%) of recreational fishers in the Townsville region knowingly fished in GBRMP no-take zones. Previous studies using direct observations have also suggested that "measurable but low levels of illegal recreational fishing occur within no-take zones" in the GBRMP (Davis et al. 2004:373). It should be noted, however, that even low levels of illegal fishing can degrade marine protected areas' effectiveness (Little et al. 2005), hence illegal fishing effort is an important variable to consider. For example, in just four weeks and using hook and line, Harrison et al. (2012) captured, tagged, and released a quarter of the coral trout (*Plectropomus maculatus*) and a third of stripey snapper (*Lutjanus carponotatus*) adult populations within three no-take zones in the GBR; this underlines how localized and intensive fishing effort can quickly erode reserve benefits (Roberts 2012). Indeed, a small number of noncompliers fishing at high effort levels can account for considerable environmental damage, particularly if vulnerable species, e.g., sharks (Graham et al. 2010), or vulnerable individuals, e.g., fish spawning aggregations (Sadovy and Domeier 2005), are targeted. Our compliance estimate does not provide an indication of recreational fishing effort within no-take zones. However, RRT can be modified to estimate illegal fishing efforts and to analyze factors such as compliance with fishery regulations such as quotas and legal sizes (Blank and Gavin 2009). We emphasize that to inform adaptive management in the GBRMP, and other protected areas, a systematic application of compliance studies is required for estimating and understanding compliance levels, illegal fishing efforts, and their variability through space and time. Recent social and economic monitoring projects in the GBR (see projects 8.1 and 10.2 in NERP 2011) may present opportunities to integrate and further develop compliance studies.

We found that concern about receiving a penalty was the most important driver of compliance in no-take zones. Nevertheless, compliance levels mostly dependent on enforcement require a strong authority presence, which translates into high operation costs (Keane et al. 2008, Ban et al. 2011). The high awareness level related to fines may be caused by government efforts to educate for compliance, which at the time of this study emphasized the illegality of fishing in no-take zones. However, despite awareness about fines, fishers' perceptions of the legal implications of fishing in no-take zones were inaccurate. Nearly 30% of respondents believed, erroneously, that property confiscation would result if they were caught fishing in no-take zones. This lack of awareness of actual sanctions is not surprising given the diversity of agencies and regulations involved in management and enforcement in the GBRMP (GBRMPA 2009, Kenchington and Day 2011). Although the perception that sanctions are more severe than they actually are appears to be having a positive effect on compliance levels, reliance on misperceptions to promote compliance may not be a viable strategy for two reasons. First, complex management arrangements can generate confusion among users and even managers, potentially undermining compliance and enforcement (Akella and Cannon 2004). Second, one must question whether the motivation for compliance would remain should misinformed fishers eventually learn that the penalties for noncompliance are not as severe as they believed. We believe that compliance based on penalties and/or misperceptions is not compatible with ongoing efforts to strengthen compliance in the GBRMP.

Few studies compare methods for estimating compliance levels (Gavin et al. 2010). We compared perceived compliance, i.e., fishers' beliefs about their peers' compliance levels, and if they personally knew someone who intentionally fished in a no-take zone, and compliance estimated by RRT. We found that fishers' perceptions of compliance levels were similar to our estimate of compliance derived from RRT. Other authors have recently gauged perceived compliance in marine protected areas, finding correlations with ecological health (Pollnac et al. 2010) and management arrangements, such as graduated sanctions (Cinner et al. 2012). Collectively, these results suggest that recreational fishers' perceptions of compliance levels could be a valuable source of information that could easily be incorporated in socioeconomic monitoring programs. It should be noted, however, that our measures of perceived compliance were not measured on a temporal scale, unlike our RRT measure, which estimated compliance for the previous 12 months; therefore, we recommend more research to determine the accuracy and effectiveness of this measure.

We found a difference between the levels of perceived compliance among 'yes' and 'no' respondents, suggesting that respondents who engage in noncompliance are more likely to believe that other recreational fishers also fish illegally in no-take zones. These results may be attributable to the false consensus effect, i.e., a person's tendency to overestimate the normality of their own behavior (Ross et al. 1977, Mullen and Hu 1988). An important implication of this finding is that fishers who believe that many others fish illegally could feel less pressure to comply (Dawes et al. 1977).

We suggest that normative drivers, e.g., peer pressure, legitimacy, and awareness, could be further exploited to increase voluntary compliance in the GBRMP (Alder 1996). For example, we found that peer pressure is present and can

be bolstered: 92% of participants reported they would feel 'very' to 'moderately' concerned if they saw someone fishing a no-take zone near their favorite fishing spot, and 74% were 'very' to 'moderately' likely to report such behavior to authorities. Communication campaigns could potentiate the effect of peer pressure on compliance by underlining the ecological benefits of fishers' compliance with zoning regulations and encouraging reporting of noncompliance through the existing 'Eyes and Ears' incident reporting program. Such campaigns could increase awareness, stewardship, and the probability of detection for those who do not comply. Additionally, the public shame as well as the private guilt of being reputed as a noncompliant free-rider can pose a strong dissuasive effect, that could, and should, be offset with the public and private pride of being compliant (Whatley et al. 1999, Cialdini and Goldstein 2004).

CONCLUSION

We present a set of useful tools and possible directions for future compliance studies in the GBRMP and other marine protected areas. The RRT is a robust tool for analyzing fishers' compliance through social surveys. Our results indicate that adequate compliance levels are possible even if they are based mostly on rational compliance drivers, e.g., fines and enforcement. To achieve a higher degree of voluntary compliance, we advise additional use of normative drivers, i.e., managers should aim for resource users to comply because it is 'the right thing to do,' not to avoid penalties. In this case, erroneous beliefs about the consequences of being caught fishing in a no-take zone seem to play a role in influencing compliance levels; the relationship between erroneous beliefs and compliance presents an interesting venue for future research in natural resource management. The observed relationship between fishers' perceived compliance and RRT results should be further investigated to test the potential of perceived compliance as a proxy for compliance levels. Fishers' compliance will influence conservation outcomes; the extent of this influence and whether positive or negative, depends greatly on management decisions. We aim to encourage the expansion of compliance studies and the recognition of users' compliance as an underpinning factor in natural resource management.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/5872

Acknowledgments:

A.A. acknowledges support from the Australian Research Council and the Australian people through AusAID. S.S. was supported by MTSRF Project 4.8.5. We thank Sam Ham, James Aumend, Mick Bishop, Simon Woodley, Natalie Ban, and all the interviewees for their valuable input. We also thank the constructive feedback of the reviewers who improved this paper.

LITERATURE CITED

Abernathy, J. R., B. G. Greenberg, and D. G. Horvitz. 1970. Estimates of induced abortion in urban North Carolina. *Demography* 7:19-29.

Akella, A. S., and J. B. Cannon. 2004. *Strengthening the weakest links: strategies for improving the enforcement of environmental laws globally*. Conservation International, Arlington, Virginia, USA.

Alder, J. 1996. Costs and effectiveness of education and enforcement, Cairns Section of the Great Barrier Reef Marine Park. *Environmental Management* 20:541-551. http://dx.doi.org/10.1007/BF01474654

Ban, N. C., V. Adams, R. L. Pressey, and J. Hicks. 2011. Promise and problems for estimating management costs of marine protected areas. *Conservation Letters* 4:241-252. http://dx.doi.org/10.1111/j.1755-263X.2011.00171.x

Blank, S. G., and M. C. Gavin. 2009. The randomized response technique as a tool for estimating non-compliance rates in fisheries: a case study of illegal red abalone (*Haliotis rufescens*) fishing in Northern California. *Environmental Conservation* 36:112-119. http://dx.doi.org/10.1017/S037689290999004X

Chaloupka, M. Y. 1985. Application of the randomized response technique to marine park management: an assessment of permit compliance. *Environmental Management* 9:393-398. http://dx.doi.org/10.1007/BF01866338

Cialdini, R. B., and N. J. Goldstein. 2004. Social influence: compliance and conformity. *Annual Review of Psychology* 55:591-621. http://dx.doi.org/10.1146/annurev.psych.55.090902.142015

Cinner, J. E., T. R. McClanahan, M. A. MacNeil, N. A. J. Graham, T. M. Daw, A. Mukminin, D. A. Feary, A. L. Rabearisoa, A. Wamukota, N. Jiddawi, S. J. Campbell, A. H. Baird, F. A. Januchowski-Hartley, S. Hamed, R. Lahari, T. Morove, and J. Kuange. 2012. Comanagement of coral reef social-ecological systems. *Proceedings of the National Academy of Sciences* 109:5219-5222. http://dx.doi.org/10.1073/pnas.1121215109

Cowles, C. J., K. H. Beattie, and R. H. Giles. 1979. Limitations of wildlife law compliance estimators. *Wildlife Society Bulletin* 7:188-191.

Davis, K. L. F., G. R. Russ, D. H. Williamson, and R. D. Evans. 2004. Surveillance and poaching on inshore reefs of the Great Barrier Reef Marine Park. *Coastal Management* 32:373-387. http://dx.doi.org/10.1080/08920750490487223

Dawes, R. M., J. McTavish, and H. Shaklee. 1977. Behavior, communication, and assumptions about other people's behavior in a commons dilemma situation. *Journal of Personality and Social Psychology* 35:1-11. http://dx.doi.org/10.1037/0022-3514.35.1.1

Day, J. C. 2002. Zoning: lessons from the Great Barrier Reef Marine Park. *Ocean and Coastal Management* 45:139-156. http://dx.doi.org/10.1016/S0964-5691(02)00052-2

De Freitas, D. M., S. G. Sutton, J. M. Moloney, E. J. I. Lédée and R. C. Tobin. 2013. Spatial substitution strategies of recreational fishers in response to zoning changes in the Great Barrier Reef Marine Park. *Marine Policy* 40:145-153. http://dx.doi.org/10.1016/j.marpol.2012.12.038

Fernandes, L., J. Day, A. Lewis, S. Slegers, B. Kerrigan, D. Breen, D. Cameron, B. Jago, J. Hall, D. Lowe, J. Innes, J. Tanzer, V. Chadwick, L. Thompson, K. Gorman, M. Simmons, B. Barnett, K. Sampson, G. De'Ath, B. Mapstone, H. Marsh, H. Possingham, I. Ball, T. Ward, K. Dobbs, J. Aumend, D. Slater, and K. Stapleton. 2005. Establishing representative no-take areas in the Great Barrier Reef: large-scale implementation of theory on marine protected areas. *Conservation Biology* 19:1733-1744. http://dx.doi.org/10.1111/j.1523-1739.2005.00302.x

Fox, J. A., and P. E. Tracy. 1986. *Randomized response: a method for sensitive surveys*. Sage, Thousand Oaks, California, USA.

Gavin, M. C., J. N. Solomon, and S. G. Blank. 2010. Measuring and monitoring illegal use of natural resources. *Conservation Biology* 24:89-100. http://dx.doi.org/10.1111/j.1523-1739.2009.01387.x

Graham, N. A. J., M. D. Spalding, and C. R. C. Sheppard. 2010. Reef shark declines in remote atolls highlight the need for multi-faceted conservation action. *Aquatic Conservation: Marine and Freshwater Ecosystems* 20:543-548. http://dx.doi.org/10.1002/aqc.1116

Great Barrier Reef Marine Park Authority (GBRMPA). 1994. *The Great Barrier Reef: keeping it great. A 25 year strategic plan for the Great Barrier Reef World Heritage Area: 1994-2019*. Great Barrier Reef Marine Park Authority, Townsville, Queensland, Australia. [online] URL: http://elibrary.gbrmpa.gov.au/jspui/handle/11017/238

Great Barrier Reef Marine Park Authority (GBRMPA). 2004. *Great Barrier Reef Marine Park zoning plan 2003*. Great Barrier Reef Marine Park Authority, Townsville, Queensland, Australia. [online] URL: http://www.gbrmpa.gov.au/__data/assets/pdf_file/0015/3390/GBRMPA-zoning-plan-2003.pdf

Great Barrier Reef Marine Park Authority (GBRMPA). 2009. *Great Barrier Reef outlook report 2009*. Great Barrier Reef Marine Park Authority, Townsville, Queensland, Australia. [online] URL: http://www.gbrmpa.gov.au/outlook-for-the-reef/great-barrier-reef-outlook-report

Ham, S. H. 2009. From interpretation to protection: is there a theoretical basis. *Journal of Interpretation Research* 14:49-57. [online] URL: http://www.thefreelibrary.com/From interpretation to protection: is there a theoretical basis?-a0219824506

Hansen, M. H., W. N. Hurwitz, and W. G. Madow. 1993. *Sample survey methods and theory*. Wiley-Interscience, Hoboken, New Jersey, USA.

Harrison, H. B., D. H. Williamson, R. D. Evans, G. R. Almany, S. R. Thorrold, G. R. Russ, K. A. Feldheim, L. van Herwerden, S. Planes, M. Srinivasan, M. L. Berumen, and G. P. Jones. 2012. Larval export from marine reserves and the recruitment benefit for fish and fisheries. *Current Biology* 22:1023-1028. http://dx.doi.org/10.1016/j.cub.2012.04.008

Horvitz, D. G., B. G. Greenberg, and J. R. Abernathy. 1976. Randomized response: a data-gathering device for sensitive questions. *International Statistical Review* 44:181-196. http://dx.doi.org/10.2307/1403276

Keane, A., J. P. G. Jones, G. Edwards-Jones, and E. J. Milner-Gulland. 2008. The sleeping policeman: understanding issues of enforcement and compliance in conservation. *Animal Conservation* 11:75-82. http://dx.doi.org/10.1111/j.1469-1795.2008.00170.x

Kenchington, R. A., and J. C. Day. 2011. Zoning, a fundamental cornerstone of effective marine spatial planning: lessons learnt from the Great Barrier Reef, Australia. *Journal of Coastal Conservation* 15:271-278. http://dx.doi.org/10.1007/s11852-011-0147-2

Lédée, E. J. I., S. G. Sutton, R. C. Tobin, and D. M. De Freitas. 2012. Responses and adaptation strategies of commercial and charter fishers to zoning changes in the Great Barrier Reef Marine Park. *Marine Policy* 36:226-234. http://dx.doi.org/10.1016/j.marpol.2011.05.009

Lensvelt-Mulders, G. J. L. M., J. J. Hox, P. G. M. Van der Heijden, and C. J. M. Maas. 2005. Meta-analysis of randomized response research: thirty-five years of validation. *Sociological Methods and Research* 33:319-348. http://dx.doi.org/10.1177/0049124104268664

Lester, S. E., and B. S. Halpern. 2008. Biological responses in marine no-take reserves versus partially protected areas. *Marine Ecology Progress Series* 367:49-56. http://dx.doi.org/10.3354/meps07599

Little, L. R., A. D. M. Smith, A. D. McDonald, A. E. Punt, B. D. Mapstone, F. Pantus, and C. R. Davies. 2005. Effects of size and fragmentation of marine reserves and fisher

infringement on the catch and biomass of coral trout, *Plectropomus leopardus*, on the Great Barrier Reef, Australia. *Fisheries Management and Ecology* 12:177-188. http://dx.doi.org/10.1111/j.1365-2400.2005.00440.x

McCook, L. J., T. Ayling, M. Cappo, J. H. Choat, R. D. Evans, D. M. De Freitas, M. Heupel, T. P. Hughes, G. P. Jones, B. Mapstone, H. Marsh, M. Mills, F. J. Molloy, C. R. Pitcher, R. L. Pressey, G. R. Russ, S. Sutton, H. Sweatman, R. Tobin, D. R. Wachenfeld, and D. H. Williamson. 2010. Adaptive management of the Great Barrier Reef: a globally significant demonstration of the benefits of networks of marine reserves. *Proceedings of the National Academy of Sciences* 107:18278-18285. http://dx.doi.org/10.1073/pnas.0909335107

Mullen, B., and L. Hu. 1988. Social projection as a function of cognitive mechanisms: two meta-analytic integrations. *British Journal of Social Psychology* 27:333-356. http://dx.doi.org/10.1111/j.2044-8309.1988.tb00836.x

National Environmental Research Program (NERP). 2011. *Multi-year research plan: tropical ecosystems hub. July 2011-December 2014.* National Environmental Research Program, Canberra, Australia. [online] URL: http://www.environment.gov.au/biodiversity/science/nerp/publications/tropical-ecosystems-hub.html

Pollnac, R., P. Christie, J. E. Cinner, T. Dalton, T. M. Daw, G. E. Forrester, N. A. J. Graham, and T. R. McClanahan. 2010. Marine reserves as linked social-ecological systems. *Proceedings of the National Academy of Sciences* 107:18262-18265. http://dx.doi.org/10.1073/pnas.0908266107

Queensland Treasury and Trade. 2012. *Queensland regional profiles: Townsville City*. Queensland Treasury and Trade, Brisbane, Queensland, Australia. [online] URL: http://statistics.oesr.qld.gov.au/qld-regional-profiles?region-type=LGA_11&region-ids=6797

Roberts, C. 2012. Marine ecology: reserves do have a key role in fisheries. *Current Biology* 22:R444-R446. http://dx.doi.org/10.1016/j.cub.2012.04.030

Ross, L., D. Greene, and P. House. 1977. The "false consensus effect": an egocentric bias in social perception and attribution processes. *Journal of Experimental Social Psychology* 13:279-301. http://dx.doi.org/10.1016/0022-1031(77)90049-X

Sadovy, Y., and M. Domeier. 2005. Are aggregation-fisheries sustainable? Reef fish fisheries as a case study. *Coral Reefs* 24:254-262. http://dx.doi.org/10.1007/s00338-005-0474-6

Schill, D., and P. A. Kline. 1995. Use of random response to estimate angler noncompliance with fishing regulations. *North American Journal of Fisheries Management* 15:721-731. http://dx.doi.org/10.1577/1548-8675(1995)015<0721:UORRTE>2.3.CO;2

Solomon, J., S. K. Jacobson, K. D. Wald, and M. Gavin. 2007. Estimating illegal resource use at a Ugandan park with the randomized response technique. *Human Dimensions of Wildlife* 12:75-88. http://dx.doi.org/10.1080/10871200701195365

St. John, F. A. V., G. Edwards-Jones, J. M. Gibbons, and J. P. G. Jones. 2010. Testing novel methods for assessing rule breaking in conservation. *Biological Conservation* 143:1025-1030. http://dx.doi.org/10.1016/j.biocon.2010.01.018

St. John, F. A. V., A. M. Keane, G. Edwards-Jones, L. Jones, R. W. Yarnell, and J. P. G. Jones. 2012. Identifying indicators of illegal behaviour: carnivore killing in human-managed landscapes. *Proceedings of the Royal Society B: Biological Sciences* 279:804-812. http://dx.doi.org/10.1098/rspb.2011.1228

Sutton, S. G. 2008. *Recreational fishers' perceptions about the costs and benefits of the 2004 Great Barrier Reef Marine Park zoning plan*. Report to the Marine and Tropical Sciences Research Facility. Reef and Rainforest Research Centre Limited, Cairns, Queensland, Australia.

Sutton, S. G., and R. C. Tobin. 2009. Recreational fishers' attitudes towards the 2004 rezoning of the Great Barrier Reef Marine Park. *Environmental Conservation* 36:245-252. http://dx.doi.org/10.1017/S0376892909990270

Warner, S. L. 1965. Randomized response: a survey technique for eliminating evasive answer bias. *Journal of the American Statistical Association* 60:63-69. http://dx.doi.org/10.1080/01621459.1965.10480775

Whatley, M. A., J. M. Webster, R. H. Smith, and A. Rhodes. 1999. The effect of a favor on public and private compliance: how internalized is the norm of reciprocity? *Basic and Applied Social Psychology* 21:251-259. http://dx.doi.org/10.1207/S15324834BASP2103_8

Wright, V. L. 1980. Use of randomized response technique to estimate deer poaching. *Wildlife Society Bulletin* 8:342-344.

Appendix 1. Formulas used for RRT data. See Horvitz et al. (1976) for more detail.

The proportion of the population (n) with the non-sensitive attribute (π_y) is given by (1).

$$\pi_y = \frac{P_2}{(P_2+P_3)} = \frac{P_2}{(1-P_1)} \qquad (1)$$

The proportion of the population with the sensitive attribute ($\hat{\pi}_A$) when (π_y) is known, is estimated by (2); with P being the probability of selecting the sensitive attribute (P=P_1) and $\hat{\lambda}$ being the observed P of "yes" in the RRT section.

$$\left(\hat{\pi}_A \middle| \pi_y\right) = \frac{\hat{\lambda}-(1-P)\pi_y}{P} \qquad (2)$$

The variance is given by (3), with λ being the probability of a "yes" response ($\lambda = P\pi_A + (1-P)\,\pi_y$)

$$\text{var}\left(\hat{\pi}_A \middle| \pi_y\right) = \frac{\lambda(1-\lambda)}{nP^2} \qquad (3)$$