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Analysis

Environmental Uncertainty and Self-monitoring in the Commons: A Common-pool Resource Experiment Framed Around Bushmeat Hunting in the Republic of Congo

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ABSTRACT

Bushmeat is often a common pool resource issue and is a major threat to wildlife in west and central Africa. Participatory monitoring systems have been proposed to both better monitor natural resources and to engage resource users in Community Based Natural Resource Management systems, in a variety of social-ecological systems. However, studies of self-monitoring schemes in bushmeat hunting systems are scarce, and there are no empirical studies of the impact of self-monitoring on bushmeat hunting. We used a lab-in-the-field common pool resource experiment framed around a bushmeat hunting system, in which participants made individual decisions on time allocation between hunting and farming under three different conditions: without communication between group members, with communication, and with communication and a self-monitoring system. We found that self-monitoring was associated with a lower level of hunting and lower rate of resource decline. However, contrary to expectations, communication alone was not enough to lower hunting levels. We draw on behavioural economic and psychological research on environmental and social uncertainty and self-perception to explore how the act of self-monitoring could have changed behaviour by changing how participants perceived the resource, each other, and themselves. Our results support the notion that hunter self-monitoring could be a useful tool to initiate behaviour change, as well as providing estimates of resource trends.

1. Introduction

The hunting of wildlife for meat, or “bushmeat”, is one of the most urgent threats to wildlife in the tropics, driving many species towards extinction (Ripple et al., 2016). Bushmeat hunting is a Common Pool Resource (CPR) dilemma, although rarely explicitly treated as such (but see Mavah, 2011 and Rickenbach, 2015). CPRs are natural or man-made resources in which yield is subtractable (i.e. the resource can be depleted through overexploitation) and exclusion is difficult but non-trivial (i.e. restricting people's access to it is difficult, but not impossible. Ostrom et al., 1992). Tropical forest lands are often the property of the state, which almost always lacks the means to enforce the law (Wilkie and Carpenter, 1999) while traditional means of management have been undermined by loss of customary land rights (Mavah, 2011; Walters et al., 2015), or overwhelmed by economic, demographic, and technological changes, in many cases leaving bushmeat a de facto open access resource with limited enforcement of restrictions on hunting (Bennett et al., 2007).

Community Based Natural Resource Management (CBNRM) has been proposed as a means to meet these governance challenges (FAO, 2011). According to Nelson et al. (2008), interest in CBNRM “is rooted in the empirical failures of strictly centralized natural resource management policies and practices, broader trends in favour of decentralization in rural development and economic policy, and the desire to create stronger synergies between local economic interests and global conservation objectives”. Self-monitoring is a form of locally based monitoring (Danielsen et al., 2009), in which estimates of resource use and/or trends are produced using records of resource harvesting as data. Self-monitoring is one possible component of CBNRM that has received significant attention in the bushmeat literature, with a number

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of documented implementations (e.g. Sirén et al., 2004; Noss et al., 2005; Rist et al., 2010). Monitoring, specifically involving monitors who are, or are accountable to, resource-users, appears to be critical to successful CBNRM and is included in Ostrom's (1990:94) design principles for successful management of commons, derived primarily from the extensive literature on the governance of fisheries, community forestry, and irrigation systems.

Evidence from resource systems other than bushmeat suggest that participatory monitoring can be both a cost-effective method for producing information on resources, and a platform for strengthening governance systems through the processes of empowerment and integration of resource users into decision making (Danielsen et al., 2005a, 2005b). A recent review of 35 studies of volunteer environmental monitoring (Stepenuck and Green, 2015) found an array of positive effects, including increased social capital (i.e. economic and social benefits), influence on natural resource management policies and practices, and increased community awareness. However, changes in attitudes and behaviour were only observed in five of these studies. Changes resulting from participatory monitoring schemes have included an increase in the number of locally initiated interventions aimed at conserving natural resources (Topp-Jørgensen et al., 2005), an increase in compliance with rules relating to resource use, and increased trust between stakeholders (Rijsoort and Jinfeng, 2005). Noss et al. (2005) note the usefulness of self-monitoring schemes in wildlife management, and propose that participatory methods can provide the "inputs and framework" for community level discussions about wildlife management, even when they do not provide highly accurate assessments of short-term changes in wildlife resources.

Despite this interest there are no empirical studies of the impact of self-monitoring on wildlife management performance. Economic experiments can provide a means of investigation (Ostrom, 2006), and framed field experiments, in which resource users participate in a representation of their own real-world resource system, have been used to explore human behaviour in a number of CPR systems (Cardenas and Carpenter, 2008). Because they include the resource users themselves as subjects, they have the potential to reveal behaviour in response to a broad range of factors specific to the case in question (van Vugt, 2009), which may diverge from those predicted (Ostrom, 2006).

Uncertainty is inherent to many CPR systems (Hine and Gifford, 1996) and social and environmental uncertainty are the major sources, including in bushmeat hunting systems. Each raises different problems. Environmental uncertainty is mainly a problem of optimality or efficiency, whereas social uncertainty is mainly a coordination problem (Messick et al., 1988). People must not only try to understand what is the best way to harvest a resource (i.e. find extraction rates that are profitable but do not destroy the resource), but also whether or not other people will cooperate in this strategy, and if not, how this in turn changes the optimal harvesting solution.

Most research on CPR dilemmas has been conducted under some social uncertainty, in which the intentions and actions of others are imperfectly known, usually by concealing the harvesting behaviour of individuals and only reporting aggregate group harvest. In general, reducing social uncertainty seems to increase cooperation, i.e. Sell and Wilson (1991), while a common social identity, reduction in group size, commitment, and feed-back on others behaviour can also increase cooperation (Van Dijk et al., 2004). The majority of CPR experiments provide a context of very low environmental uncertainty i.e. the size and rate of replenishment of the resource is known at all times, and group harvest level is reported (Cardenas, 2004; Janssen, 2013). Experimental research into the effect of uncertainty has found that when faced with uncertainty in CPR experiments, people tend to increase harvest rates (Hine and Gifford, 1996). Several reasons for this effect have been posited (Van Lange et al., 2013), including over-optimism or over-estimation of resource size (Gustafsson, 1999; Rapoport et al., 1992), the undermining of efficient cooperation (De Kwaadsteniet et al., 2006), and providing an excuse for non-cooperative behaviour (Van Dijk et al., 2004).

A number of studies have also tested social and environmental uncertainty simultaneously. Messick et al. (1988) found that allowing communication between players made decision making more optimal in a task with both social and environmental uncertainty. In a game setup somewhat close to a real natural resource situation, Janssen (2013) found that when players in a spatially explicit CPR experiment had complete information about resource size and players' harvest rates, their own harvest rates were higher than when they had only incomplete information. In this case it appears that being aware that others are harvesting at a high rate spurs people to do the same, and so the effect of combined social and environmental uncertainty may be unpredictable.

This paper aims to investigate the effect of self-monitoring on wildlife hunting, one of the most commonly proposed CBNRM approaches for wildlife management, using an experimental behavioural economics approach. Specifically, we tested how resource extraction rate in a CPR experiment (henceforth "game") differed under three conditions: (i) without communication, (ii) with communication between rounds, and (iii) with communication between rounds and a Self-Monitoring system (henceforth SM, and 'SM with communication'), in which participants (henceforth 'players') could voluntarily produce a public visual record of their hunting effort, success and failure at the end of each round. To do this, we modified an existing CPR game to more closely approximate a wildlife harvest system. We did this through the addition of environmental uncertainty, about resource size and regeneration rate, and by making the probability of harvesting success dependent on the size of the resource. In this manner, players could only learn about the resource through the process of harvesting, a situation analogous to most bushmeat harvest systems. We are not aware of any other study that has tested the effect of SM experimentally, or that has carried out a common pool resource experiment with bushmeat hunting communities.

2. Hypotheses

We considered hunting at a low level to reflect cooperative behaviour, because it supports the group-level objective of maintaining a productive resource, which is ultimately most profitable to the group. Conversely, hunting at a high level was considered to reflect uncooperative behaviour, because it risks resource collapse in an attempt to maximise personal profit at the expense of the group. The experiment was guided by the following hypotheses, H1: Communication would increase cooperation, and H2: SM would further increase cooperation. We expected players to hunt the least in this condition. We hypothesised that hunting would occur at a lower rate in the two conditions where communication was permitted as there is substantial evidence finding communication reduces harvesting in CPR games (Ostrom, 2006). Increased cooperation was expected to result in higher group earnings. However, due to a number of factors, including empirical findings elsewhere (i.e. Janssen, 2013), and the fact that SM was voluntary and open to abuse as players could intentionally use it to try to manipulate competitors, the alternative was also feasible, i.e. H3: SM would not improve cooperation. In addition to our central question, we further hypothesised that socioeconomic characteristics of players and psychological factors would influence behaviour.

3. Methods

3.1. Study Location and Socio-economic Context

The game was played in 10 villages within Forest Management Unit (FMU) Ngombé in the Northern Republic of Congo. The rural population is mostly made up of several Bantu and Bayaka ethnic groups, living in settlements on roads or major rivers. Bayaka includes a number of ethnic groups often referred to as Pygmies (Lewis, 2002), although it is now illegal to use the term in Congo. Unlike elsewhere in the region, Bayaka live in permanent settlements alongside Bantu, rather than as hunter-gatherers as they did in the past and as is often the case when Bayaka populations are described in the literature (Fa et al., 2016). Livelihoods in this area generally consist of a mix of farming, hunting, fishing, and casual labour. For many people hunting remains both a major source of protein and one of the only immediate means of earning cash income. Although Bayaka can still be seen using traditional hunting tools, the vast majority of hunting is carried out using modern methods. Bayaka tend to use snares rather than shotguns, while Bantu tend to use shotguns more. Bushmeat is consumed in the villages, but much of it is sold to traders who transport it to markets in urban areas (Hennessey and Rogers, 2008). While some forms of hunting are allowed in Congo, hunters routinely disobey regulations, by hunting at night with torches, using metal snares, hunting in the closed season, hunting protected species, and hunting without a license. However, despite the presence of ecoguard patrols, full enforcement of hunting regulations is technically challenging, politically complicated, and would place extreme hardship on communities. At the same time, management of hunting at the village level is virtually non-existent. Mavah (2016) argues that traditional modes of wildlife management were undermined, and new ones prevented from developing, by the abolition of customary land rights in the Public Land Law of 1983. Because of these factors, hunting in this area, as in much of the Congo basin, is largely a de facto open access resource.

3.2. Study Design

We carried out a Common Pool Resource experiment, in the form of a game framed around bushmeat harvesting. We use the following terminology to describe it:

Game: The standardized experimental set-up, including instructions, which did not change between sessions, aside from the experimental condition.

Condition: The three experimental conditions (Table 1).

Session: The game played once. Each session had five players.

Group: The five players in one session.

Round: Each session comprised 10 consecutive rounds (described as "years").

Turn: During each round, every player took a turn, one at a time, in which they anonymously chose to divide 12 units of effort (described as "months") between hunting and farming.

We played 30 sessions, with a total of 150 forest dwelling people from 10 different villages, the majority of whom were currently hunters, and all of whom had some experience of hunting. All sessions were played between May 2015 and January 2016. In our game, players independently and anonymously chose how much effort to expend on either hunting from a shared animal population, or farming. Players did not have difficulty understanding this set-up, because hunting and agriculture are two of the most important livelihood activities in this region. This framed field experiment was based on a forest harvest game (Gatiso et al., 2015; Janssen et al., 2013) but with the resource and harvesting modified to better represent wildlife population and hunting dynamics.

Table 1
Experimental conditions with number of sessions and players.

Condition	Rules
10 sessions, each with 5 players: No communication	No communication was permitted between players at any point during the game.
10 sessions, each with 5 players: Communication	Players had 2 min between rounds in which they could discuss whatever they wanted.
10 sessions, each with 5 players: SM and communication	Players had the option of reporting their hunting effort and success/failure using a board and counters between rounds, and had 2 min in which they could discuss whatever they wanted.

The order in which the different conditions was played in each village was randomised. No individual participated in more than one game. Players were chosen randomly when possible and opportunistically when it was not; i.e. when a player dropped out, or when villages were small and it was necessary to involve everyone available. Before playing the game, a village meeting was held in which the project objectives were explained. Potential players were told they would play a game about hunting, that it would take 3 to 4 h to play, that they would earn a participation fee of 1500 CFA (~2.70 EURO), and that they would earn more money depending on how they played the game.

Before playing, each group received training on how to play the game. The instructors followed a script, so all training sessions were as similar as possible (Appendix A). Efforts were made to reduce all elements of the game to simple concepts, to make the game as intuitive and easy to understand as possible, without requiring difficult calculations. Players played two practice rounds during training, and had to demonstrate understanding of the game to progress to the next part of the training. During the practice rounds, players made decisions publicly, and so were able to see and understand how all parts of the game functioned. At the end of each training session, players were asked questions to assess and demonstrate their understanding of the game's key concepts. Players who could not answer the questions correctly were replaced (two players out of 150).

While playing practice sessions we noticed that even slight modifications of the instructions could result in very different behaviour during the game. We thought this could be due to a demand effect, whereby players used the game instructions as a cue to how they were "supposed" to behave, and played the game accordingly, and that this desire to behave "correctly" was caused by the presence of a white European researcher (Cilliers et al., 2015). We tested this possibility by playing the Dictator Game 20 times in one village (10 men and 10 women, Appendix B). The Dictator Game is a simple economic experiment commonly used to measure altruism (Cardenas and Carpenter, 2008), in which one anonymous player is given a sum of money (in this case 4000 CFA = 6.15 EURO), and must choose what proportion to gift to a second anonymous player. Gifts approaching 50% are thought to indicate altruism, while those approaching 0% indicate selfishness. We found significantly larger gifts in the presence of a white researcher and Bantu assistant than in the presence of two Bantu assistants (40% of stake given to an anonymous member of their community with a white man present versus 8.9% with only Bantu present ($F = 39.013$, $P \leq 0.001$, $N = 20$). We therefore removed the white researcher from all phases of the game, although he was still present in the village during the experiments.

The game was played over 10 rounds (or "years"), and all five players took a turn in every round. We informed players that there would be 10 rounds. Players chose to expend 0 to 12 units of effort ("months") to hunting in each round, with the remaining effort dedicated to farming. Hunting was not always successful, and the likelihood of success depended on the number of animals remaining. Farming was always successful. Although in reality farming success is also likely to fluctuate, we chose this set-up because in this area farming success is not affected by prior farming activity in the same way that hunting is, nor is one person's success dependent on the farming behaviour of others. A successful hunt was worth 50 CFA (0.08 EURO), an unsuccessful hunt 0 CFA, and each month of farming was always worth 10 CFA (0.02 EURO). Players hunted by drawing at random from a sack, which always contained 100 marbles. Red marbles signified a "kill", and black marbles signified a failed hunt. There were 80 red marbles at the beginning of the game, and the maximum possible was 100. Players were made aware of this during instruction. The total number of marbles remained constant, but the ratio of red to black marbles changed as a function of number of animals killed and regeneration at the end of each round. The ratio of red to black marbles drawn by players is analogous to Catch Per Unit Effort (CPUE) often used in natural resource monitoring (Rist et al., 2010); e.g. if a player dedicates 10 months to hunting and draws 8 red marbles ("kills"), then he might infer that there are still a lot of animals left (~80% of maximum), but if he only draws 2 he might infer there are few left (~20%). We began with 80 marbles so hunting always had an element of chance, even at the beginning of the game. Decisions were made in private and earnings told to the player at the end of his turn. The player then returned to join the others in the waiting area where a researcher was also waiting to ensure players did not communicate, except during allotted communication phases. Although players took turns to harvest the resource sequentially, they knew that in each round all players faced the same conditions.

In the Communication and SM with communication treatments, players had a two-minute period in which they could discuss anything they wanted. We restricted communication to 2 min based on practice runs, in which communication typically did not last this long. We used Pearson correlations to test whether players communicated more about resource decline as the animals remaining became fewer. In the SM with communication treatment, they also had access to a board divided into strips, and black and red counters corresponding to the black and red marbles. In each round, they were able to place the counters on the board and so publicly record their hunting success and failure e.g. If they went hunting four times and were successful twice and unsuccessful twice, they could place two red counters and two black counters on the board. They were shown this during instruction, and had to demonstrate their understanding by accurately reporting one practice turn, and also reporting a turn inaccurately, to demonstrate that they understood they could also use the system dishonestly.

At the end of each round the total number of animals killed by the group was deducted from the number remaining, and a number of new animals added based on the number of animals remaining. Regeneration was calculated using a density dependent logistic growth model, as is often used in simple population models (e.g. Robinson and Redford, 1991), rounded to the nearest whole number:

$$Growth = r*\frac{(K-N)}{K}*N$$

where growth is the number of new animals added to the resource, r is a constant growth rate, N is population size, and K is carrying capacity. We used a growth rate of 0.4 and a carrying capacity of 100 animals. Maximum regeneration was set at 10, amounting to a maximum sustainable harvest of 2 animals per hunter per turn, and occurred at 50% of the maximum population (50 animals. Fig. 1). Therefore, growth was highest when it was near 50% of maximum, and was lowest when the resource was near zero or 100%. All players faced the same growth function. This was explained to the players (with reference to ecological processes), but the numerical growth rate was not, as we reasoned that in the real world information about the state of wildlife resources is always uncertain. Players were also never certain of the number of animals left, and were not informed of the number of animals killed by others or by the group combined, and so players could only infer the resource state via their hunting success. At the end of the game, every animal left was shared equally between players (50 CFA per animal = 10 CFA per player per animal), representing the potential future value of the resource. We chose to share the remaining animals between players because in real life people value a healthy resource after they retire from hunting, either as a source of food, family income, or non-tangible benefits, for themselves and for their descendants. This is an incentive for cooperation, provided other players also cooperate. Therefore, maintaining an animal population size of around 50% had three benefits to players:

1. A high rate of regeneration, and so an increase in the total number of new animals added to the resource over the game and hence a higher total value of the resource.

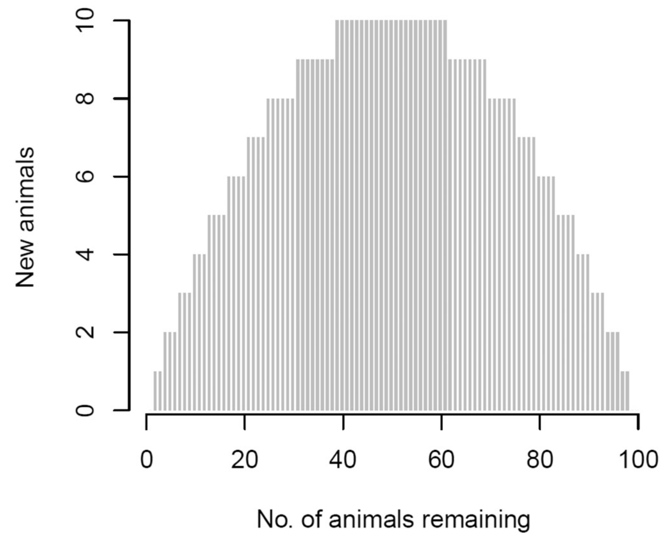

Fig. 1. The stock regeneration in our game, calculate with an growth rate of 0.4 and carrying capacity of 100 animals.

2. A higher success rate when hunting than when the resource is depleted (but not when it is above 50%), and hence a higher income for a given time spent hunting.
3. A higher payoff at the end of the game, as all remaining animals are shared between players.

Players answered questions to ensure that they understood these benefits. Players also had to demonstrate that they understood that the maximum payoff would accrue to the group if all players kept hunting to a sustainable level, but that each individual player could earn more by increasing his own hunting; i.e. they were facing a CPR problem.

At the end of the game each player's earnings were calculated as income from every successful hunt, every month spent farming, and the share of all remaining animals. After the game each player completed a questionnaire, which included questions about ethnicity, education, time they had lived in the village, age, income from different activities, value of livestock owned, the combined value of all household assets worth 20,000 CFA or more, area farmed, and familial relationships to other players.

3.3. Subject Characteristics

All participants were male. Our 150 subjects were Bayaka (51%), Bantu (46%), and other (4%). Bayaka tended to have lower incomes, livestock assets, and household assets, be more dependent on hunting than Bantu (Table 2). Mean schooling was 4.7 years, with 41% having three or less years, below which people tend to be illiterate.

3.4. Statistical Analysis

We used Generalized Linear Mixed Models (GLMM. Baayen, 2008) with different response variables and predictors in different models. We tested for serial correlation using the Wooldridge test (Wooldridge, 2002), and found positive serial correlation (chisq = 303.33, df = 10, p-value < 0.001), meaning OLS estimates of standard errors would be smaller than true standard errors. We therefore opted to use a single mean value for each player across the whole game, rather than one for each round of the game. The full list of predictor variables is presented in Table 3, and the model specifications in Tables 4 and 5. Our response variables for each of the three models were:

1) Time spent hunting versus time spent farming over the course of the game (binomial distribution and logit link). This is possible in R

Table 2
Subject characteristics. Monetary values reported as CFA (1 euro = ~655 CFA).

	Bantu	Bayaka	Other
N	69	77	4
Mean years in village	14.0	19.6	12.8
Mean age	33.1	31.4	34.8
Mean years of schooling	6.7	2.9	6.0
Median hunting income	160,000	189,000	0
Median total income	332,500	250,000	452,500
Median livestock assets	15,000	0	2500
Median items assets	55,000	15,000	58,750
Median field area (m2)	675	0	450
Primary source of income			
Hunting	49%	80%	25%
Agriculture	14%	4%	25%
Fishing	22%	8%	50%
Other	15%	8%	0%

using a two-column matrix of hunting and farming per turn as the response. Less time hunting indicated more cooperative behaviour.
2) Time spent hunting versus time spent farming in the last turn minus the previous three turns, to test for an end game effect.
3) Total game earnings of each player (Poisson distribution and log link). Players in more cooperative groups expected to earn more.

To test for an end game effect we ran a model on a subset of data, which included only the last four rounds of the game. For the response variable we subtracted last round behaviour from the mean behaviour of the previous three rounds, to yield a single normally distributed response variable. This model structure was otherwise identical to model 1.

We log or square root transformed skewed covariates, and then z-transformed all co-variates to a mean of zero and a standard deviation of one (Aiken and West, 1991). We included observation (player) nested within session, and village as random effects. The sample size for this model was a total of 150 players. We used Pearson correlations to test whether hunting effort in the different rule conditions was correlated within a village; i.e. if villages that hunted at a higher level in one condition also hunted at a higher level in the other conditions, and to test whether players communicated more about resource decline as the animals remaining became fewer.

The models were fitted in R (R Core Team, 2016) using the function glmer of the R package lme4 (Bates et al., 2015). To test the significance of our models we used likelihood ratio tests (Dobson and Barnett, 2008), comparing the fit (deviance) of a full model with the fit of a reduced model (Forstmeier and Schielzeth, 2011), comprising only the control variables and the random effects (including the random slopes). We checked for influential cases by excluding cases one at a time from the data and comparing the model estimates derived for these data with those derived for the full data set. We found no overly influential cases. Variance Inflation Factors were derived using the function vif of the R-package car (Forstmeier and Schielzeth, 2011) applied to a standard linear model excluding the random effects and random slopes. This did not indicate collinearity to be an issue (maximum VIF: model 1 = 1.41, model 2 = 1.43, and model 3 = 1.44).

Table 3
The predictor variables included in the generalized linear mixed models. Not all variables were included in every model. See model results tables for which variables were included in each model.

Variable	Description
Predictors	
Condition	The three experimental conditions, discussed at length in Sections 1 and 3.2 of the main text: 1) No communication. 2) Communication. 3) SM with communication
First round hunting effort	The player's number of months dedicated to hunting in the first round of the game. First round behaviour is less constrained by factors that are internal to the experiment, and so a truer indicator of a players innate propensity to cooperate or not.
Number of animals killed by the rest of the group	The total number of animals killed over the course of the game by the rest of the group. When considering earnings, the most important factor effecting an individual's outcome is the behaviour of the rest of the group. This is fundamental to CPR dilemmas.
Age	The age of the player. Age has been linked to cognitive traits such as risk aversion and patience.
Education	Number of years of school attendance of the individual. Years of education is linked to cognitive capacity and numeracy, and so may influence performance
Ethnicity	The ethnic group that the individual identified with.
Hunting income	The player's absolute annual income from hunting.
Hunting dependence	A variable constructed from non-hunting cash income, area farmed, and value of livestock owned. All hunters were ranked for each variable, and all three rankings were summed. Ranks were summed, so that hunters who earned money from other sources, farmed large areas of land, and kept livestock had the lowest scores.
Size of household	The number of people living in a household, defined as a group of people sharing meals and residing together.
Items Assets	The total value of all household items worth 20,000 FCFA or more.
Participation in cooperative	Whether the player had contributed either money or time towards a cooperative, such as an agricultural project.
Time in village	Number of years living in village.
Relatedness	The relatedness of a player to other members of their group. We used reported relatedness as a proxy, and assigned each relationship a value based on expected average genetic relatedness for that relationship; i.e. 0.5 for siblings or parent/son relationships, 0.25 for uncles/nephews or cousins. Relatedness is predicted by evolutionary psychology to be a major determinant of cooperation.
Extended family	The number of non-blood familial relationships in the group for each, i.e. relationships such as "little brother" or "uncle" where no blood line could be established. These relationships are common in the study area and in many parts of Africa, and might be expected to represent a stronger association, and hence cooperativeness, than other kinds of non-blood relations.
Controls	
Game order	The order in which the session was played. We played three sessions in a village on consecutive days. We included this variable to control for learning between games, for example if later groups benefited from hearing about the game from individuals who had already played.
Turn order	The order in which the player took his turn within the group. In each round, each took a turn. The order that each player took their turn was the same in every round. We included this variable in case there was an influence of turn order on hunting level.
Random effects	Individual, session, village were included to control for the hierarchical structure of observations.

Table 4
Results of the GLMM in which the response variable was a two column matrix of time spent hunting versus time spent farming, with a positive response indicating an increase in hunting.

Response variable: time hunting versus time farming					
Predictor variable	Estimate	SE	χ^2	df	p
Intercept	0.18	0.09	NA[a]	NA	NA
Communication	−0.09	0.08	16.526[b]	2	< 0.001***
Self-monitoring	−0.43	0.07			
Ethnicity: other	0.37	0.24	1.821[c]	2	0.40
Ethnicity: Bayaka	−0.02	0.07			
Age[d,f]	−0.01	0.03	0.114	1	0.72
Size of household[d,f]	−0.03	0.03	0.764	1	0.37
Years in school[f]	−0.02	0.04	0.112	1	0.72
Hunting income	0.08	0.03	6.592	1	0.01**
Hunting dependence	−0.05	0.03	1.755	1	0.15
Value of assets[d,f]	0.02	0.05	0.183	1	0.65
Time living in village[e,f]	0.02	0.04	0.377	1	0.49
Relatedness[d,f]	−0.11	0.03	11.047	1	< 0.001***
No. friends in group[f]	−0.01	0.03	0.06	1	0.80
Hunting in first round[f]	0.28	0.04	17.468	1	< 0.001***
Experience in a co-op	0.10	0.08	1.444	1	0.20
Game order[f]	0.09	0.04	3.763	1	0.02*
Turn order[f]	0.01	0.03	0.111	1	0.73

* = p < 0.05.
** = p < 0.01.
*** = p < 0.001.
[a] Not shown because of having a very limited interpretation.
[b] The test refers to the overall effect of rule condition as obtained from comparing the full model with a reduced model lacking it.
[c] The test refers to the overall effect of Ethnicity as obtained from comparing the full model with a reduced model lacking it.
[d] log transformed.
[e] Square root transformed.
[f] z-Transformed.

Table 5
Number of animals remaining and earnings at the end of the game, and their increase over the No communication condition.

	No. animals remaining			Earnings		
Rule	Mean	SE	Increase (%)	Mean	SE	Increase (%)
No communication	14.7	4.5	.	2119	563	.[a]
Communication	19.6	4.7	33%	2247	561	6%[b]
SM with communication	31.6	6.8	115%	2563	630	21%[ab]

Although within condition earnings were significantly higher in SM with communication than in No communication, the variable as a whole did not contribute significantly to the model, and should be treated with caution.
[a] Indicate significant differences in earnings.
[b] Indicate significant differences in earnings.

4. Results

4.1. The Effect of Condition on Hunting Effort

We used effort invested in hunting versus effort invested in farming by each player over the course of the game as the response variable in the first model. As each is the inverse of the other, we will refer only to time invested in hunting, as "hunting effort", for the purposes of discussion. A low time investment in hunting indicates cooperative behaviour. Players dedicated between 0 and 12 effort units ("months") to hunting per round (Fig. 2). Individual hunting effort ranged from 13 to 90 months over the course of an entire game, from a potential maximum of 120, and group hunting effort ranged from 135 to 394 months, from a potential maximum of 600. The full model was highly significant (likelihood ratio test comparing full and null model: $\chi^2 = 54.01$, df = 15, $P < 0.001$. Table 4). SM with communication reduced the likelihood of choosing hunting over farming by 43% (estimate = −0.43, SE ± 0.07, $\chi^2 = 16.526$, P < 0.001. Post-hoc test: z = −5.76, P < 0.001), but hunting effort in the No communication and Communication conditions were not significantly different from each other. We found a significant effect for real world hunting income, which had a small positive effect on hunting level, a highly significant effect but small negative effect of relatedness, and a highly significant and small to moderate positive effect of first round hunting level. The model testing for the presence of an end game effect found no significant effect (likelihood ratio test comparing full and null model: $\chi^2 = 15.703$, df = 16, $P = 0.47$).

4.2. Village Level Correlations

There was no relationship at the village level between mean hunting effort in the No communication condition and the Communication ($r(8) = 0.02$, $p = 0.95$) or SM with communication conditions ($r(8) = 0.06$, $p = 0.87$. Fig. 3). However, there was a very strong correlation between hunting effort in the Communication and SM with communication conditions ($r(8) = 0.98$, $p < 0.001$), suggesting a strong effect of village, aside from those variables included in the model, that mediated how individuals played the game.

4.3. Accuracy of Self-monitoring Reporting

Inspection of the data suggested that dishonesty when reporting catches to the group was rare, with most reporting being accurate. The presence of both under and over-reporting suggests that error rather than dishonesty may have accounted for some of the under-reporting. Catch was reported correctly in 81.4% of turns, under-reported in 12% and over-reported in 6.6%. By comparing transcripts of discussions during the games and records of reporting, we noticed only one occasion in which a player intentionally misled their group by hunting at a high level, while reporting a low level and strongly advocating for reducing the group hunting level.

4.4. Resource Depletion and Earnings

The resource declined over the course of the game in all conditions (Fig. 4 and Table 5). In all conditions, resource decline was fastest at the beginning of the game, and appeared to have reached an equilibrium by the end of the game. At the end of the game, the remaining resource ranged from zero to 81 animals, and the number of new animals generated over the course of the game ranged from 29 to 100. Mean group earnings ranged from 1534 FCFA to 2600 FCFA, meaning that players in the most cooperative group earned 70% more than in the least cooperative group. Individual earnings ranged from 1390 FCFA to 3250 FCFA, the highest earning individual earning 134% more than the lowest. The highest individual earnings accrued to a player in the game with the largest range in earnings, who defected while the rest of the group was generally cooperative. This happened in the SM with communication condition and the player used the monitoring system to manipulate other players. The defecting player earned 85% more than the player in the group who earned the least. The model using individual earnings as the response variable was highly significant (likelihood ratio test comparing full and null model: $\chi^2 = 57.352$, df = 16, $P < 0.001$. Table 6).

Although individual earnings were 21% higher in the SM with communication condition, and 6% higher in the Communication condition, than in the communication condition, this term was not significant. This may be due to an insufficient sample size, or number of rounds played. However, the hunting level of other players had a large impact on an individual's earnings with an increase of one SD in animals killed by others resulting in a fall in earnings of around 20% for the individual (estimate ± SE = −0.206 ± 0.010, z = −20.248,

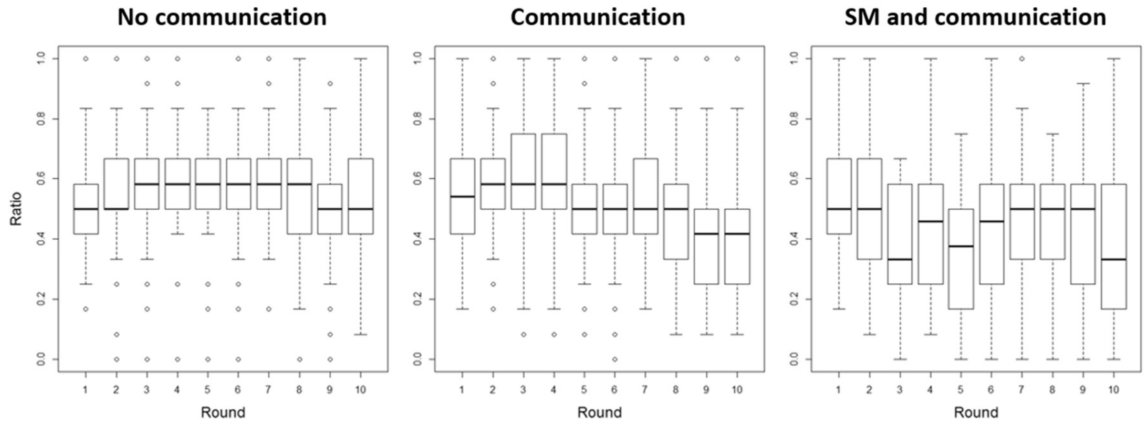

Fig. 2. The ratio of hunting to farming in each round in each condition. Median shown as solid line, top and bottom of box upper and lower quartiles. Whiskers indicate 1.5 times the inter-quartile distance, outliers shown as points.

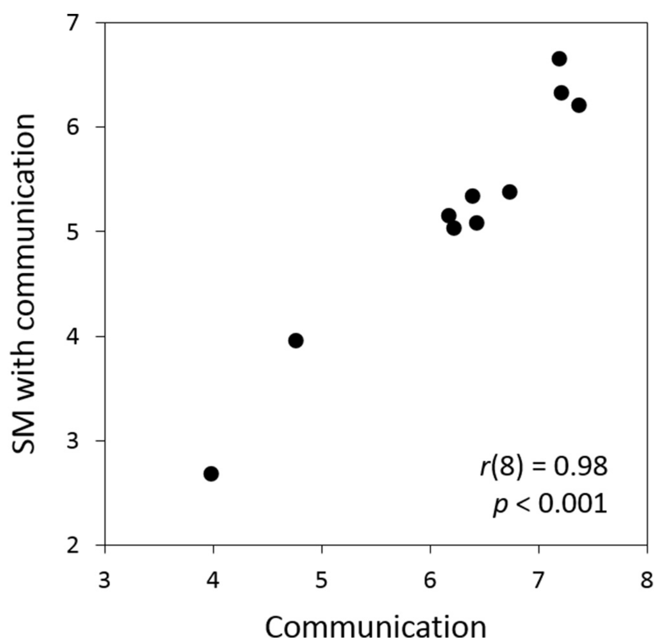

Fig. 3. Mean hunting effort in each village was correlated in the Communication and SM with communication conditions but neither were correlated with the No communication condition.

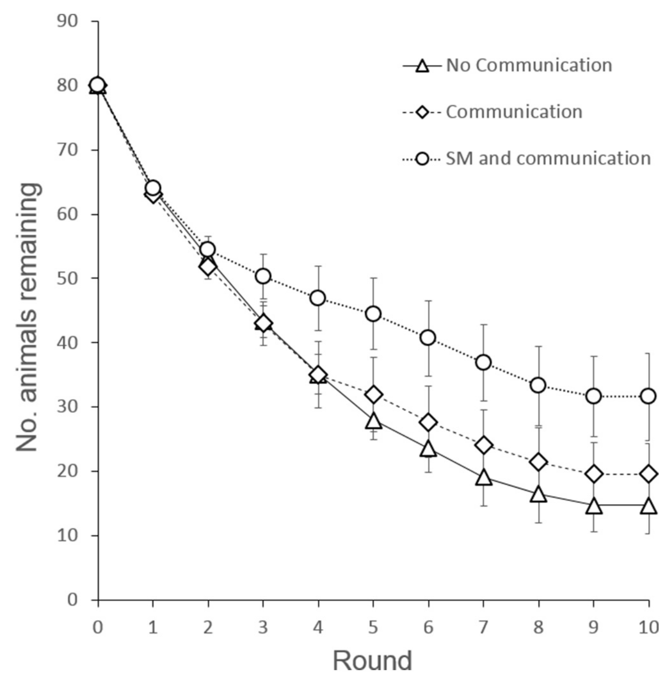

Fig. 4. Resource size at the end of each round in each condition, with standard error bars.

P < 0.001), and condition did predict hunting level in the previous models. Increasing relatedness to other players increased earnings (estimate ± SE = 0.011 ± 0.003, z = 3.376, $P = 0.001$), while individual hunting effort in the first round decreased earnings (estimate ± SE = −0.012 ± 0.005, z = −2.505, $P = 0.012$).

4.5. Communication

Players used the communication period to discuss a range of issues (Table 7). Unfortunately, due to small sample it was not possible to test the effect of communication on game outcomes, but we report raw data and broad patterns where possible. All groups that had the option to communicate or monitor did so. 88% of individuals participated in communication in both monitoring and SM and monitoring conditions, and all players with the option to self-monitor did so. Players referred to the natural resource dilemma in the majority of games (i.e. "We will live to see the consequences of our poor management", "We have to cooperate", and "We need a strategy") indicating that they indeed understood the game situation. Discussions about hunting in the game sometimes concerned the mechanics of the game i.e. "hunting is a waste of time when the resource is depleted" and "we should reduce hunting so the resource can recover", but also often referred to factors relevant to real hunting, but not hunting in the game i.e. "The government and NGOs are right to tell us to reduce hunting" and "We need to rest, because we don't go to the forest every day [in real life]". No players shared how many animals they had taken verbally (aside from when they caught zero), meaning that in Communication treatment players could only infer the resource state form their own hunting success rate, and through other's estimation of resource state, such as "the animals are few now" or "hunting is hard now". Players were aware when the resource declined, and spoke more about resource decline as the remaining resource became lower in both treatments allowing communication (Communication: r(98) = −4.0, $p < 0.001$. SM with communication: $r(98) = -4.5$, p < 0.001).

5. Discussion

We did not find support for H1 (communication alone would increase cooperation), and found support for H2 over H3 (Self-monitoring increased cooperation, rather than decreasing it). Most socioeconomic

Table 6
Results of the GLMM in which the response variable was individual player earnings.

Response variable: earnings					
Predictor variable	Estimate	SE	χ^2	df	P
Intercept	7.526	0.057	NA[a]	NA[a]	NA
Communication	0.114	0.125	1.728	2	0.421[b]
SM with communication	0.217	0.059			
Ethnicity: Other	−0.016	0.016	−0.483	2	1.000[c]
Ethnicity: Bayaka	−0.007	0.009			
Age[d,f]	0.006	0.005	0.802	1	0.370
Size of household[d,f]	0.005	0.005	1.070	1	0.301
Years in school[f]	0.001	0.005	−1.481	1	1.000
Animals killed by group	−0.206	0.010	37.800	1	< 0.001***
Hunting income	< 0.001	0.003	−1.570	1	1.000
Hunting dependence	0.002	0.010	0.133	1	0.715
Value of assets[d,f]	−0.002	0.003	0.249	1	0.618
Time living in village[e,f]	−0.004	0.005	−0.479	1	1.000
Relatedness[d,f]	0.011	0.004	5.201	1	0.023*
Extended family[f]	0.001	0.004	−1.615	1	1.000
Hunting in first round[f]	−0.005	0.005	4.041	1	0.044*
Experience in a co-op	−0.001	0.009	−1.322	1	1.000
Game order[f]	−0.06	0.068	−1.492	1	1.000
Turn order[f]	0.00	0.003	−1.476	1	1.000

* = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.
[a] Not shown because of having a very limited interpretation.
[b] The test refers to the overall effect of condition as obtained from comparing the full model with a reduced model lacking it.
[c] The test refers to the overall effect of Ethnicity as obtained from comparing the full model with a reduced model lacking it.
[d] log transformed.
[e] Square root transformed.
[f] z-Transformed.

and psychological variables were either non-significant or had only small effect sizes, aside from first round hunting level.

5.1. Why Did Self-Monitoring Reduce Hunting?

Players mostly used the self-monitoring system relatively honestly, and it enabled them to reduce their hunting level to the benefit of the group. This requires explanation, given that there were no direct negative consequences for players who played dishonestly. In fact, players could very easily hunt at a high level, while reporting a low level of hunting, with no risk of being caught. They could even leverage their reputation as a responsible hunter, created through false reporting, to try to manipulate others into reducing *their* hunting, so allowing them to claim more of the resource themselves. However, this happened egregiously on only one occasion, when one player did exactly that. The ability to sanction non-co-operators typically stabilizes group cooperation at a high level, whereas cooperation typically collapses in the absence of the ability to sanction (Gürerk et al., 2006). Although our experimental set-up did not allow for the imposition of penalties, other studies have found that when able to do so, people are generally willing to engage in costly sanctioning, with the proximate cause being strong negative emotional responses to free-riders (Fehr and Gächter, 2002). There is therefore a clear social pressure to hunt at a low level in the context of our game, but in the absence of a means of detecting free-riding, this becomes only a reason to *report* hunting less, rather than *actually* hunting less. A second finding that requires explanation is that SM with communication increased cooperation, while communication alone did not. Which mechanisms determine this behaviour is an empirical question, but several authors have proposed potential explanations for similar phenomena in CPR and other economic experiments. These explanations fall into three categories, related to how individuals perceive the resource, their group, and themselves, and are discussed below.

The first category encompasses environmental uncertainty; i.e. how people perceive the resource. Environmental uncertainty concerns both resource size and regeneration rate. Experimental studies of environmental uncertainty have found that when resource size is uncertain, there is a general tendency to over-estimate the amount of resource available for harvesting, and to increase harvests (Van Dijk et al., 2004). Uncertainty may undermine normative pressures that might otherwise promote restraint, by depriving players of the information required to operationalise a norm, even if all agree to it, thus obstructing the translation of an abstract goal (cooperation) into a certain one, harvesting less (Hine and Gifford, 1996). Self-monitoring reduces uncertainty by combining information from all players in a group, and by leaving a physical record over time. Reducing uncertainty may make it a less credible excuse for selfish behaviour. Reducing environmental uncertainty may therefore reduce selfish behaviour, even when improved estimates are not explicitly used as a basis for decisions about harvest rates.

The second category relates to social uncertainty; i.e. how people understand the behaviour and intentions of others (Jager et al., 2002). Relevant factors may include group identification, as well as communication with and social pressure exerted by other group members. Communication may help by reducing perceived uncertainty through the creation of group identity, or by eliciting social norms (Bicchieri,

Table 7
Topics players communicated about. Numbers indicate the number of times that subject was spoken about by a single player.

	Communication			Communication and monitoring		
	% games (n = 10)	Mean per game	SD	% games (n = 10)	Mean per game	SD
Speakers per round		1.8	0.22		1.9	0.33
Signal agreement	80	2.6	1.41	90	1.6	0.75
Signal disagreement	10	0.1	0.45	40	0.7	0.85
Attempt to give order to another player	20	0.3	0.70	30	0.4	0.57
Signal individual intent	70	1.2	0.84	80	1.1	0.66
Signal respect for another player	90	2.2	1.42	100	2.6	1.49
State game is going well	0	0.0	0.00	20	0.5	1.03
State resource is overexploited	90	2.8	1.14	80	2.6	2.26
Call to reduce hunting - vague	100	4.0	1.86	100	5.6	2.38
Call to reduce hunting - specific	90	2.4	1.90	90	2.2	1.28
Call to reduce hunting - total	100	6.4	2.65	100	7.8	3.74
Call to Increase hunting - vague	40	0.4	0.24	40	0.9	1.11
Call to increase hunting - specific	50	0.6	0.43	0	0.0	0.00
Call to increase hunting - total	70	1.0	0.77	40	0.9	1.30
Reference to game mechanics	90	4.3	2.14	100	5.6	2.38
Reference to real world e.g. "we need to reduce hunting so our children will know the animals"	80	2.0	0.83	80	2.0	1.50

2002). Individuals differ in their predispositions to cooperation. More self-centred individuals tend to defect more, because they see co-operation as offering an uncertain gain (or certain loss), and defection as a certain gain (or uncertain loss. Biel and Gärling, 1995). Reducing social uncertainty may change the perception of this balance for self-centred individuals, making gains from cooperation and losses from defection more certain. While communication is often enough to increase cooperation, this was not the case in this study, where an effect was only seen when self-monitoring also occurred. Perhaps uncertainty reduced the ability of communication alone to overcome the CPR dilemma.

The third category relates to how a person perceives themselves. Humans are social animals, and much of their evolved and learned moral psychology relates to how people should interact within groups (Cosmides, 2004). In the context of our game, players are subject to two contradictory motivations: to maintain a positive view of themselves, and to gain from cheating (Mazar et al., 2008). The act of self-monitoring entails reporting behaviour in a way that is precise rather than vague (as in the Communication condition), and so dishonesty becomes an active decision. This may draw the players attention to the moral dimension of resource use (i.e. free riding), through mechanisms such as the *Self-concept threat* (in which immoral behaviour threatens one's ability to consider themselves as moral individuals), *Categorization* (in which situational factors force one to reconstrue an action as more morally deviant than before), and *Attention to Standards* (in which being reminded of one's moral standards makes failing to meet them more salient and so more damaging to self-concept (Mazar et al., 2008).

Many of these explanations function by activating moral and social norms, drawing attention to them, and reducing the uncertainty that makes it easier to shirk them. We did not find that greater information about other's behaviour resulted in higher levels of resource extraction, as it has in other CPR experiments in which monitoring was externally imposed rather than carried out voluntarily by the players (Janssen, 2013). This may be related to framing, with our scheme more likely to be seen as a platform to facilitate collective action and information about resource size, rather than as a way to detect free-riders. Alternatively, inaccurate, even sometimes dishonest reporting may provide a space for trust and cooperation, even while it enables selfish behaviour, whereas complete information may serve to undermine trust because selfish behaviour is apparent to all. In such a scenario, an intermediate level information facilitates cooperation, while too much or too little information undermines it.

5.2. Psychological and Socio-economic Factors

Socioeconomic factors were mostly not significant determinants of the outcome in any of the models. We found no significant effect of ethnicity on our response variables. This is interesting, given the large differences seen between the two populations, including differences in income, hunting dependence, years in school, livestock assets, and area of agricultural land, suggesting that whatever influenced behaviour was independent of these contextual factors. Focusing on the first model using hunting effort, the most direct measure of individual behaviour, as a response variable (Table 5), we found no effect of age, size of household, or value of assets owned. Although years in school predicts literacy and numeracy, and hence many aspects of cognitive capacity, we found no effect of years of schooling. This is often the case in CPR experiments, and may reflect the fact that CPR problems are social dilemmas, as well as economic ones, and that solutions hence often are social (Kollock, 1998). We found no effect of experience with real world cooperatives although others have done so (Cilliers et al., 2015), but experience with cooperatives was generally very low in our location, and our sample size was also small compared to other studies.

Hunting effort in the game increased with real world hunting income (estimate ± 0.091 SE ± 0.03, $\chi^2 = 6.71$, $P = 0.01$), but not with degree of hunting dependence. Whether real world hunting income predicted hunting effort because of underlying psychological traits, such as hunters being less cooperative or more likely to discount the future, or a heuristic (i.e. frequent hunting is a strategy that in the real world, so it could work in the game) is unknown. First round hunting level significantly predicted subsequent hunting level (estimate ± 0.28 SE ± 0.04, $\chi^2 = 17.468$, $P < 0.001$), and reflects the effect of individual differences between players. In the same study area, Rickenbach et al. (2015) found that Bayaka tended to discount the future more steeply than Bantu, while nearby Salali and Migliano (2015) found that Bayaka discounted the future more heavily when they lived in remote villages, and less so when they lived alongside Bantu in a logging town. Our experiment may not be suitable for evaluating differences between these populations. Alternatively the differences between populations may not be that large, because Bayaka lived in permanent settlements in all cases. We found no relationship between experience of other livelihoods, including farming, and hunting effort. The genetic relatedness of players had a small significant effect on hunting (estimate ± −0.11 SE ± 0.03, $\chi^2 = 10.78$, P < 0.001), with more closely related players spending less time hunting, but extended familial relationships ("little-brother", "uncle", etc.) did not, and neither did years living in the village.

The strong correlation between outcomes in the Communication and SM with communication with communication in games played in the same village is puzzling, and we are not aware of another study finding such a strong effect. There are three more plausible explanations: Collusion, chance, and an unobserved village level characteristic. We noticed no evidence of a shared strategy that would suggest players had colluded before the game began. Indeed harvesting rates were diverse in most rounds of all games. The probability that this correlation was simply a chance occurrence was less than one in a thousand. It is possible to envisage some village level characteristic, such as trust or cooperativeness, that mediated behaviour, and that only had an effect when players could communicate, but was not captured by the individual level socio-economic variables measured. However, more obvious and measurable factors such as village size and market integration do correspond to the observed behaviour.

6. Limitations and Applications

A limitation specific to our experiment is that hunter self-monitoring systems in the real world will mostly have input from wildlife managers, who would be able to analyse data and make recommendations about extraction levels. However, wildlife resources have a number of characteristics that make quota based harvesting systems inappropriate (e.g. complexity, stochasticity, and uncertainty), and participatory, adaptive management approaches a more realistic option (van Vliet et al., 2015). Consequently, the role of wildlife professionals is less relevant to our game, in which the resource is simple so that depletion is relatively easy to detect. Real world complexities such as multi-species harvesting, spatial distribution and quality difference of patches, and the need to convert raw catch data into abundances indices, would potentially make bushmeat monitoring schemes more reliant on external support than those in other systems, such as community forestry schemes.

This experiment is also limited in the number of treatments tested. We chose treatments considered most relevant to the context: treatments that mirrored the current situation (communication without monitoring), likely real world implementations (self-monitoring with communication), and a baseline. Other relevant questions can be envisaged with relevance to hunting e.g. different types of self-monitoring. Adding an additional treatment of Self-monitoring without communication would have enabled us to test whether the reduction in hunting was due to self-monitoring assisting with coordination, or altering perceptions of the resource i.e. by reducing social or environmental uncertainty.

More generally, two major criticisms directed towards economic experiments are that they lack realism and therefore are not generalizable, and that they are susceptible to demand effects (Levitt and List, 2007), meaning that researchers are not measuring the variables they think they are measuring. In combination, these criticisms would indicate that economic experiments are not useful for understanding the "real world". The long-term cumulative effects of dishonesty, corruption, and dissatisfaction that can undermine CBNRM for example (Nielsen and Lund, 2012), are not considered here. However, there is growing evidence that prosocial behaviour in experimental settings is correlated with real world behaviour ((Benz and Meier, 2008; Cilliers et al., 2015; Fehr and Gächter, 2002; Rustagi et al., 2010), pointing towards the existence of general across-situational traits.

Furthermore, generalizability is not solely a problem of experimental economics (Falk and Heckman, 2009), and in the case of self-monitoring, generalizing the findings of one implementation of a scheme (even across several villages) may be problematic, given the variation in social-ecological systems. It is therefore necessary to recognize the potential of economic experiments, which is to allow the testing and formulation of hypotheses in a controlled setting, with human subjects. This is particularly relevant to the governance of bushmeat harvest systems, which is understudied relative to other CPRs, and where there is an absence of CPR experiments.

In the case of hunter self-monitoring, observational data are rare, real world schemes tend to involve small numbers of villages and be short term, and measuring outcomes is difficult. Many questions are also made difficult or impossible to study in a natural setting, as bushmeat hunting is often criminalized. Theory concerning decision-making in wildlife management is spread across several disciplines, including psychology, economics, and sociology (Keane et al., 2008), and the experimental method has been used extensively in addressing questions of importance in each of these disciplines. The game presented here could easily be adapted with simple rule changes, in order to study the impacts of a range of factors of interest to bushmeat researchers and wildlife management practitioners, including social (e.g. number of players, leadership, social norms, and multi-generationality), environmental (e.g. size and regeneration rate of resource, multi-species communities, and spatial management), and economic (e.g. value of resource and different forms of sanctioning) factors.

7. Conclusions

The act of self-monitoring reduced hunting effort, increased earnings, and reduce the rate of resource decline in a CPR experiment framed around bushmeat hunting. Although we can only speculate on the mechanisms by which this worked, it appears that the activity of self-monitoring encourages pro-social behaviour, supporting the notion that self-monitoring can assist in management of bushmeat hunting CPR systems by changing the behaviour of hunters (Noss et al., 2005). While studies of real world schemes have often sought to test accuracy (Rist et al., 2008) or to describe various aspects of the scheme, such as wildlife offtake or participation rates, self-monitoring may be just as valuable for its normative effects, and its potential to facilitate community level collective action, as one component of CBNRM in bushmeat harvest systems. Although largely absent from the bushmeat literature, economic experiments have the potential to generate and test hypotheses related to wildlife governance, providing insights, which would be extremely difficult to obtain through alternative methodologies. We also highlight the importance of demand effects using the Dictator Game, and recommends that researchers undertaking experimental studies should consider carefully how to avoid these when planning their experiments.

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Appendix A

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