

Additional Sensitivity analysis

This document includes some additional sensitivity analysis of the model used in M.A. Janssen and K. Hill (in review) Benefits of grouping and cooperative hunting among Ache hunter-gatherers: Insights from an agent-based foraging model, submitted to *Human Ecology*.

Outcomes

The Null model

Classic prey choice models specify the overall return rate of foragers can be expressed as

$$R = \frac{\sum_1^n \lambda_i e_i}{(1 + \sum_1^n \lambda_i h_i)}$$

Since measured model parameters include λ_i (encounter rate per time searching) as well as e_i (mean kg meat acquired per pursuit) and h_i (mean pursuit time per encounter), we can solve for the long-term meat harvest rate (kg/hr) the equation above and then multiply by 5.92 hours per day to get the mean daily harvest rate. This is the Null model prediction. The measured model parameters also allow for a calculation of the expected proportion of foraging time spent in

search $1 - \frac{\sum_1^n \lambda_i h_i}{(1 + \sum_1^n \lambda_i h_i)}$ and the expected proportion of the total harvest contributed

by each prey type $\frac{\lambda_i e_i}{\sum_1^n \lambda_i e_i}$.

Harvest Prey Composition

Predicted composition of prey in the model harvest can be compared to two field databases on Ache hunting. The first is the composition of all prey hunted between 1980-1996 on foraging trips in which the anthropologist was present and weighed all game acquired throughout each day. This is the “observed” hunting database. The second is based on informant reports and was obtained by an Ache research assistant who kept a running tally of all game killed by the Arroyo Bandera community from 1994 to 2000. This information comes from daily interviews with all hunters as they return from multiday forest treks with their families. The prey composition of the “interview” database was published in Hill et. al. (2003). Casual inspection and subsequent analyses shows more large prey and less dependence on armadillos in the “observed” harvest data than from the “interview” data (Table S9). This data comes from an earlier time period when less depletion had taken place due to Paraguayan poachers operating in the Mbaracayu reserve. We compare our simulation model results to the mean of the two harvest proportions to evaluate model fit.

Table S9. Percentage of total prey harvested by species for Ache hunters from observed and interview databases between 1980-2000.

Common Name	Obs. harvest 1980-96	Intv. harvest 1994-2000	Mean
Guan	0.267	0.200	0.233
Capuchin monkey	19.354	6.600	12.977
9-B Armadillo	20.434	46.400	33.417
Red Brocket deer	8.796	2.800	5.798
Coatimundi	7.505	2.900	5.202
Peccary (collared)	6.319	2.000	4.160
Tegu lizard	0.696	1.400	1.048
Paca	11.876	18.600	15.238
Tapir	0.000	9.800	4.900
Peccary (white lipped)	16.518	5.300	10.909
King vulture	0.106	0.001	0.053
Piping Guan	0.166	0.001	0.084
Howler monkey	0.180	0.001	0.090
Naked-tail armadillo	0.408	0.700	0.554
Agouti	0.803	0.400	0.601
Tinamou	0.050	0.100	0.075
Tayra	0.000	0.100	0.050
Rabbit	0.018	0.001	0.010
Boa constrictor	0.434	0.400	0.417
Crab eating fox	0.000	0.100	0.050
Collared anteater	0.129	0.400	0.264
7-B armadillo	0.000	0.001	0.000
Black vulture	0.088	0.200	0.144
RB toucan	0.011	0.001	0.006

Sustainability of hunting

The agent based model includes prey harvest and reproduction through time according to the density dependent logistic growth equation. Because maximal population growth takes place at a density of 0.5 K only species that decline to relative encounter rates below that are in danger of extirpation. Figure S6 shows a hundred year simulation of hunting and the resultant relative prey densities after that time. This model includes 15 hunters in the 584 km² model landscape (0.0257 hunters/km²). The ethnographic hunter density of the pre-contact Ache in their core use area is nearly identical, with 557 Northern Ache living in a core area of ~5,500 km² in 1970, and about ¼ of the population composed of adult males of active hunting age (0.0253 hunters/km²). Howler monkeys are most depleted species because of their low densities and low reproductive rates. The simulation suggests that Ache hunting of this species is not sustainable in our model landscape. The other two species showing final encounter rates (eg. densities) lower than 0.5 are collared anteater (undercensused because nocturnal and arboreal) and boa constrictor (we crudely estimated r_{max} for this species). The simulation suggests that all major prey species are hunted sustainably in this landscape..

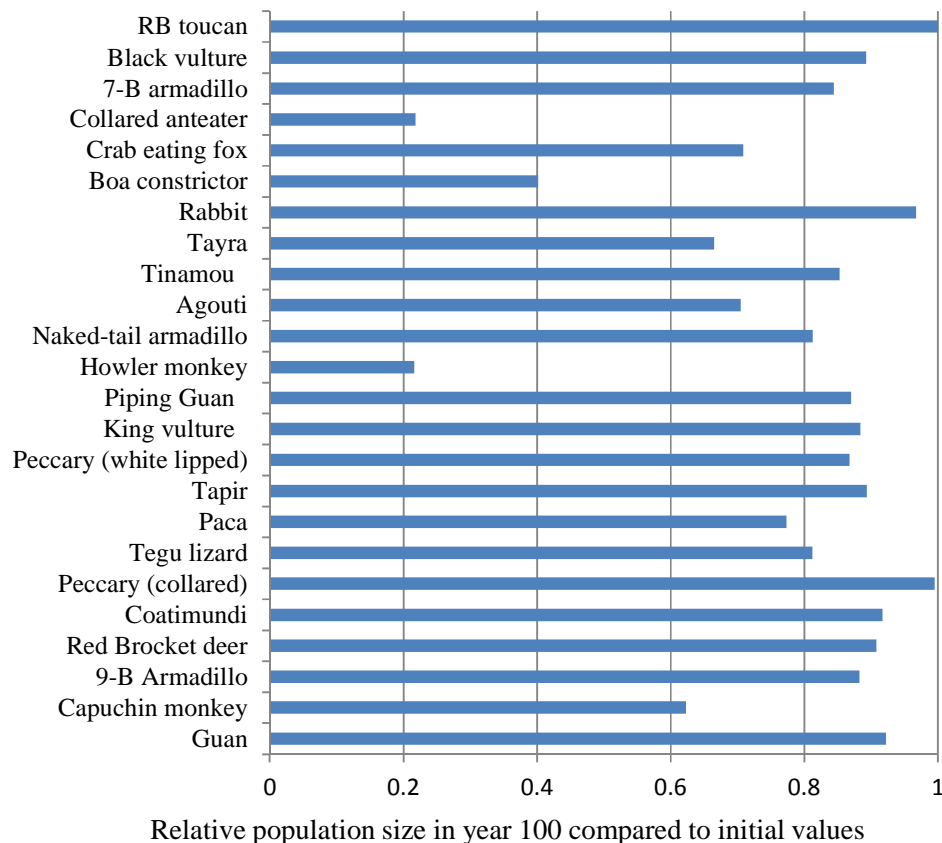


Figure S6. Encounter rates with primary prey species after 100 years simulated hunting (relative to time 0) at an ethnographically observed population density and applying the CCSP model.

Return rates by habitat

Because the modeling procedure keeps track of all agents through time we can analyze the overall foraging return rate for agents in each type of habitat. This is a function of both prey encounter rates and also the likelihood of encountering prey that can be cooperatively hunted. Results (Figure S7) suggest that Ache hunters should express a preference to hunt in riparian forest, which jibes with informant statements during ethnographic observation. The model shows that all vegetation types produce approximately a half a kilo of meat per hour of searching and pursuit. The bamboo vegetation has the lowest production level, just below 0.5 kilo per hour, while the riparian forest has the highest production level, around 0.65 kilo per hour. This probably explains why the null model results in nearly typical return rates. The food landscape is relatively uniformly dispersed and no specific locations need to be remembered or targeted by hunters in order to achieve a typical hunting return rate.

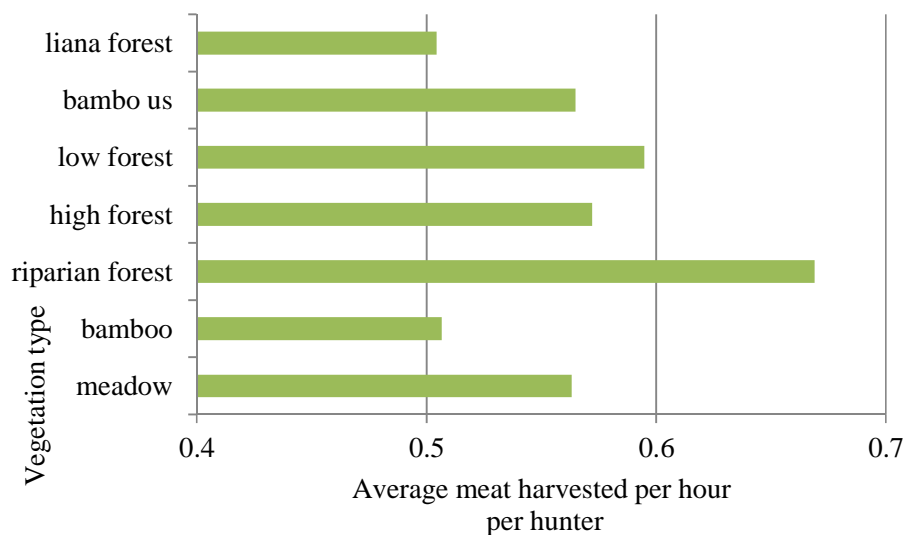


Figure S7. The average meat per hunter per hour in the cooperative hunting simulations for the seven vegetation types, based on the CCSP model. (CCSP stands for camps with coordinated search and cooperative pursuits)

Decision to pursue prey

All variants of our agent-based model assume that hunters decide whether to pursue an encountered prey based on the expected returns from a pursuit versus the averaged recent overall hunting returns (the default is 20 days). Alternative simulations specifying that agents always pursue any encountered prey type lead to only small changes in the main outcome parameters of each model (Table S10). This is because species that are most often ignored by agents in the primary models are very rare species. Analysis does show that lower ranked resources are more likely to be ignored when encountered (Figure S8). This is because stochastic variation in 20 mean return rates means that lower ranked resources are more likely to be out of the optimal diet set when hunters have a lucky run of high hunting success (Figure S9). The lack of a perfect correspondence between prey rank and percent of encounters ignored appears to be due to disproportionately encountering some prey in certain habitats that tend to have higher or lower than average return rates.

Table S10. Model outcomes when hunters always pursue every prey type encountered during foraging. These values can be compared to Table 3 in text where hunters only pursue prey items whose profitabilities are greater than the overall foraging return rate for the past 20 days. The model versions include IRS (Individual Random Movement), CUS = Camps uncoordinated search; CCS = camps with coordinated search; and CCSP (camps with coordinated search and cooperative pursuits).

	Average weight (kg/day/hunter)	% time searching	% days no catch (individual)	% of days no catch (camps)	Pearson's r predicted vs. observed prey composition
Always pursuit					
IRS	2.96 (0.10)	82.7 (0.19)	52.4 (0.57)	52.4 (0.57)	0.87
CUS	2.43 (0.10)	86.1 (0.19)	59.5 (0.64)	7.8 (0.82)	0.91
CCS	2.29 (0.10)	87.1 (0.18)	61.2 (0.68)	10.2 (0.86)	0.92
CCSP	2.81 (0.10)	81.2 (0.25)	61.0 (0.67)	8.6 (0.90)	0.96

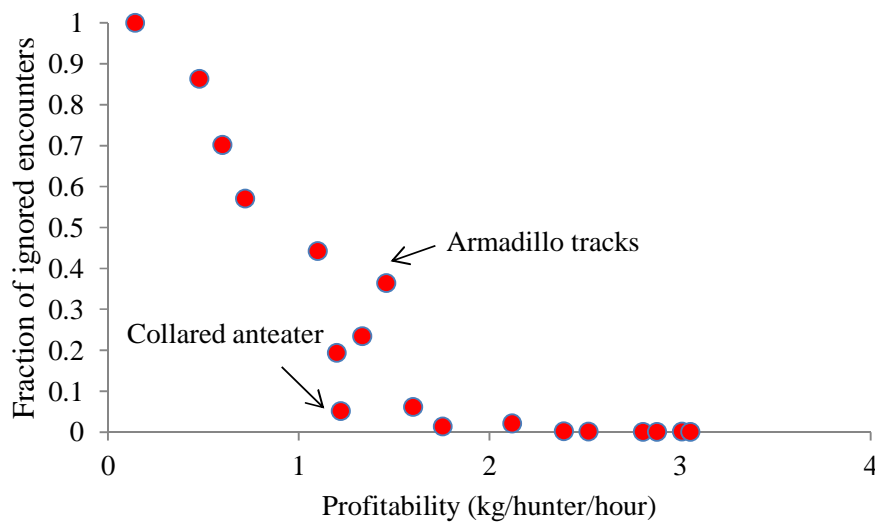


Figure S8. Proportion of all encounters in the CCSP model in which agents do not pursue specific prey types plotted against the mean profitability (return rate upon encounter) of each prey type. No prey type with a mean profitability over 2.3 kg/hour was ever ignored.

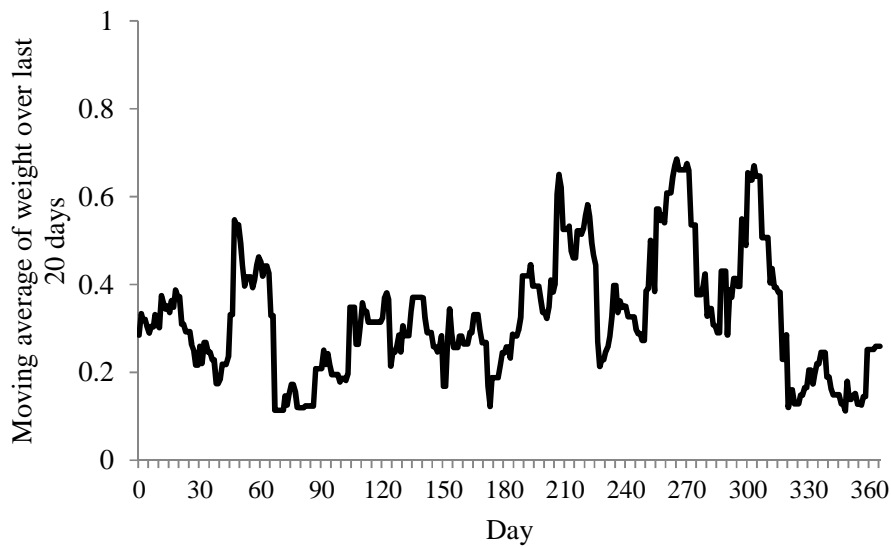


Figure S9. The mean hunting return rate for a single agent during the previous 20 days, plotted over a year. Stochastic fluctuation means that some prey types with mean profitability above the overall long term hunting return rate will occasionally be ignored.

Duration of stay at camp site

The effect of the duration of the campsite is evaluated by simulation the CCSP version of the model with 3 camps with 5 hunters each and different numbers of days that the camps stay at one location. For each duration we ran the model 100 times for one year. Figure S10 shows that the mean meat per hunter per day declines for longer durations. Figure S11 shows the effect of the duration of stay on the frequency of days without meat. There is a sharp increase in the frequency when we go from 1 to 2 days.

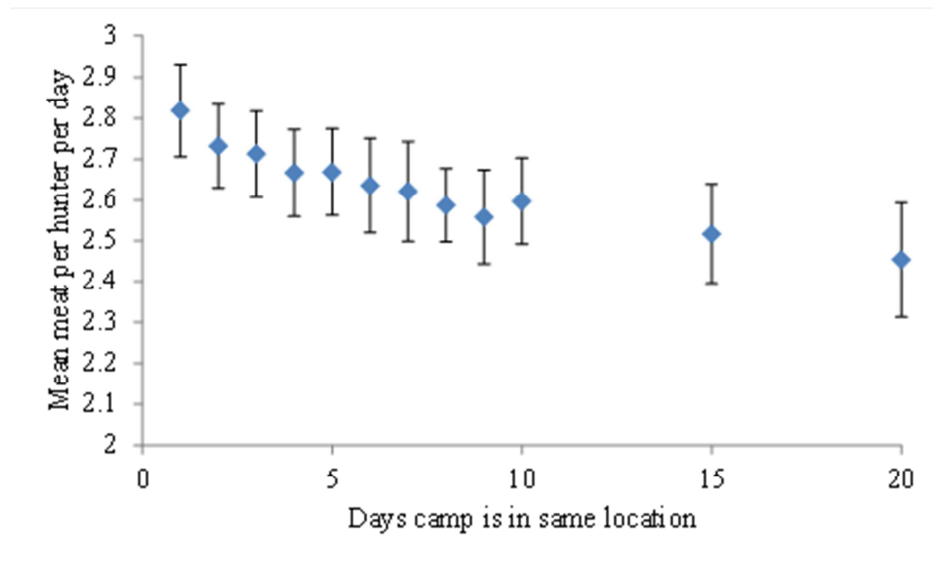


Figure S10: Mean meat per hunter per day (plus the standard deviation) for different durations the camp stays in the same location.

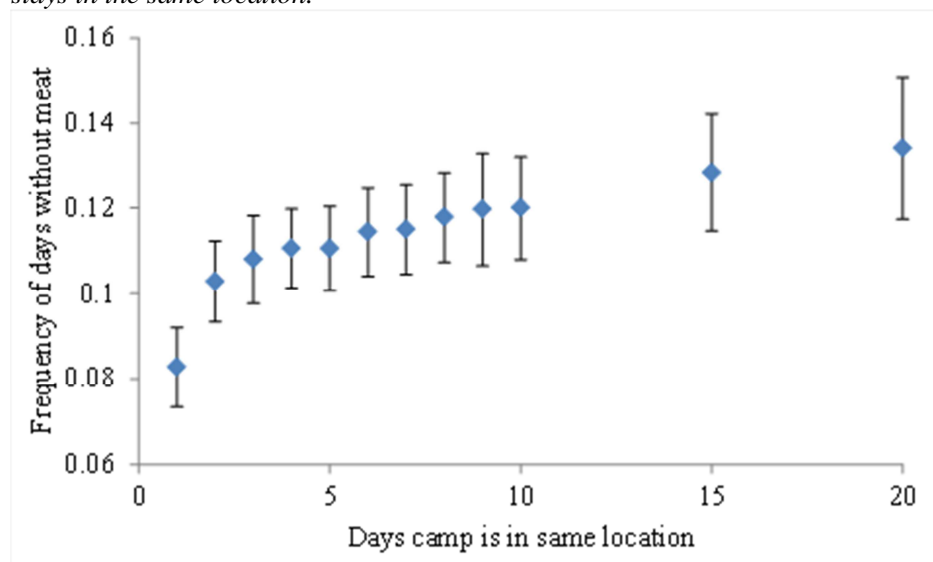


Figure S11: Frequency of days without meat (plus the standard deviation) for different durations the camp stays in the same location.

Optimal group size

When two different goods or services both have some utility, it is theoretically possible to specify amounts of the two that represent combinations of equal utility. These can be plotted as points on an x,y axis (x amount of good 1, y amount of good 2). A line connecting all combinations of equal utility is called an “indifference curve” because consumers are presumed to be indifferent to all combinations on the line. In evolutionary biology we presume that equal utility implies equal fitness, so the indifference curves are actually fitness isoclines. On the same x,y graph we can also specify what amount of each good can actually be obtained according to different alternatives in the option set. A line connecting possible combinations is referred to as the budget constraint. The optimal solution for any consumer is determined by the point at which the consumer’s budget constraint function is tangent to the highest possible indifference curve. In our example the tradeoff between mean meat return rate and probability of a day with no meat can be plotted as a function of group size and movement patterns. If we imagine that both goods have some utility to foragers, a simple assumption is that they are substitutable at some rate. This produces a linear indifference curve. Because the constraints function has a sharp inflection point, the optimal solution under these conditions will almost always be near the inflection point (Figure S12).

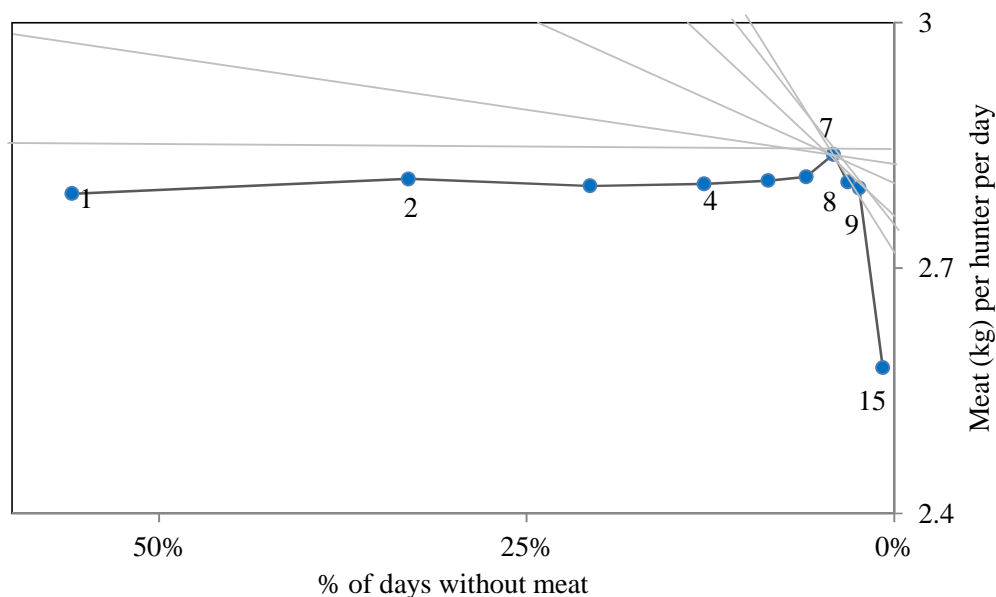


Figure S12. The set of utility substitution slopes (grey lines) that lead to band sizes of 7 hunters as the optimal solution for trading off the gains in mean harvest rate against the gains in reduced risk of a day without meat in Ache bands. Note that about 90% of all possible slopes that assume a linear substitution rate between these two “utilities” will intersect the measured budget slope at its inflection point around 7 hunters. If the substitution function is more complimentary (convex with respect to the origin), the optimal solution will virtually always be at 7 hunters.

One important qualification to this conclusion should be mentioned. The optimal group size in the above model is dependent on the effect of encounter suppression when hunters interfere with each other’s discovery of prey types that are spooked by humans. If we remove this component of the model, the cost of living in large groups is diminished quite significantly and the benefits of cooperative hunting become paramount. With no encounter rate suppression,

there appears to be no limit to the optimal group size, suggesting that very large bands might be favored under some conditions (Figure S13).

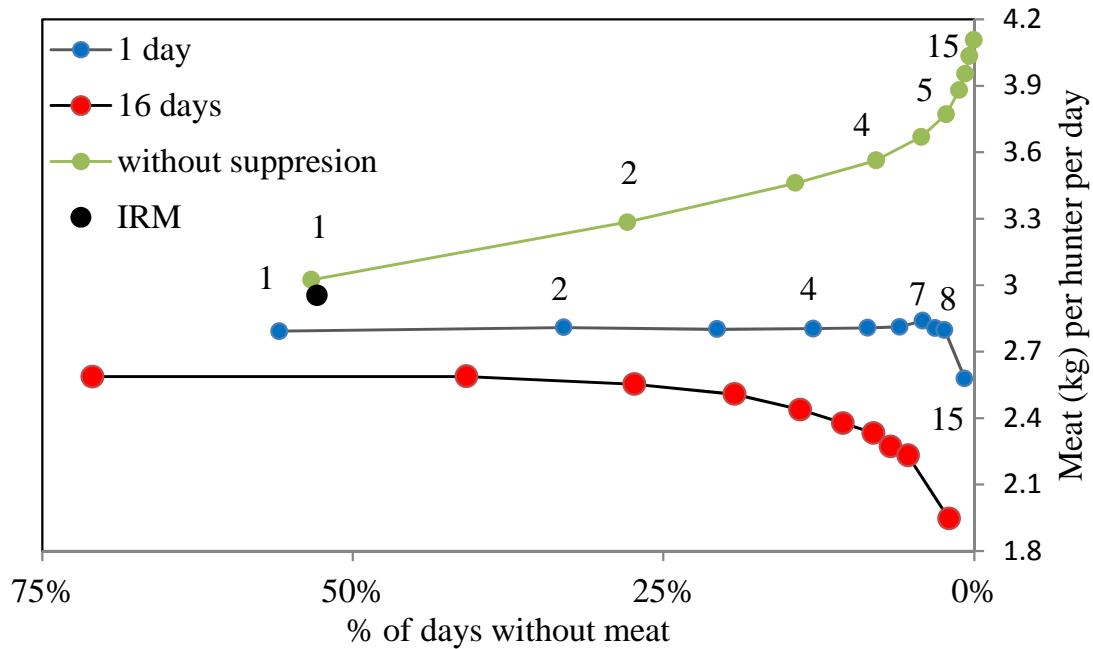


Figure S13. The effects of group size and mobility patterns on mean harvest rate and risk of no meat when encounter suppression is not a component of the model. Notice that under these conditions the benefits of cooperative hunting make larger group sizes advantageous.

Additional sensitivity analysis

A number of parameters used in the model are not based on direct observations but on expert judgment of the authors. We test the sensitivity of the model, compared to the default parameter settings, of these parameters. Each model configuration is simulated 100 times. In Table 9 we present the average weight of meat caught per hunter per day. The standard deviation for 100 runs is about 0.1 and is not depicted for each set of runs to keep the table readable.

Table S11: The average weight of meat (kg) per hunter per day for the different model configurations.

	Random	Uncoordinated	Flocking	Cooperative hunting
Default	2.95	2.41	2.26	2.82
R_D (10 / 30)	2.98 / 2.99	2.44 / 2.46	2.30 / 2.30	2.82 / 2.83
T_S (1 / 3)			2.29 / 2.32	2.81 / 2.84
T_A (5 / 15)			2.35 / 2.25	2.82 / 2.81
T_C (5 / 15)			2.34 / 2.23	2.83 / 2.83
D_{min} (0 / 0.2)			2.30 / 2.30	2.82 / 2.80
D_{max} (1 / 5)				2.55 / 2.95
W (0.25 / 0.75)		2.43 / 2.45	2.27 / 2.31	2.81 / 2.85
P_S (0.8 / 1)		2.43 / 2.36	2.30 / 1.92	2.84 / 2.49

References

Hill, K., McMillan, G., & Fariña, R. (2003). Hunting Related Changes in Game Encounter Rates from 1994 to 2001 in the Mbaracayu Reserve, Paraguay. *Conservation biology*, 17(5), 1312-1323.