Efficient Deer Allocation: a field test of Gossen's law

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Abstract

Empirical evidence suggests that Gossen's law of decreasing marginal utility does not always apply in cultural, hobby and recreational contexts. This can have significant implications for efficient resource allocation. In the presence of increasing marginal utility, benefits are maximised by concentrating resource access in a small number of individuals, rather than widely distributing access. Satisfaction ratings from a panel of 698 hunters who undertook 2,917 red deer hunts provide a test of Gossen's law with respect to number of deer killed. Latent class ordered logit models outperformed random parameters models and provided evidence of weak non-decreasing marginal utility for all classes of hunter. Study results are applied to test potential efficiency gains from imposing a one red deer per hunt bag limit.

Keywords

Gossen, Satisfaction, Ordered logit, Red deer, hunting, New Zealand

Introduction

Because game is a scarce, rival resource, game management on public land requires consideration of both the total harvest permitted at any time and the allocation of that harvest amongst hunters. The fishery economics literature (Anderson and Seijo 2010, Clark 2006) demonstrates two reasons for inefficiency of open-access to biological resources. First, individual harvesters do not fully consider the effect of their harvests on the future productivity of the resource, which may result in sub-optimal stock size, or even extirpation. Second, there are intra-temporal externalities when an individual's harvest affects either the costs or volumes of others' harvests. Hence, individuals' harvests might be limited for biological and/or economic reasons.

Open-access game management regimes address neither the total harvest problem, nor the distribution problem. Consequently, fish and game managers frequently implement a variety of management strategies to address harvest and distribution (Apollonio et al. 2010). Some systems limit individuals' harvests through daily or seasonal bag limits for individual harvesters, but do not set an overall harvest limit. In such cases, harvesters' behaviours determine overall harvest, over which the manager has no control in the short term. Other systems set a total harvest limit without attempting to allocate the harvest to individuals. An example is derby fisheries, which typically result in short seasons and over-capitalization (Hackett 2011). More-refined systems address both problems by setting aggregate harvest limits and using administrative processes to allocate harvests amongst potential harvesters, including lottery, merit or market systems. Examples include draws for limited numbers of game tags in many US states, and individual transferable quotas in commercial marine fisheries.

Currently, New Zealand public land deer hunting operates under an open-access system. Whilst there is a legal requirement to have a permit to hunt on public land, permits are available almost instantaneously over the internet[1], free of charge, and have no restrictions on numbers or types[2] of game animals harvested. For nearly all public land hunting areas there are no season restrictions, and there are no reporting requirements, so information on effort and harvests is absent. A recent, significant change in society's perceptions of New Zealand game animals is embodied in The Game Animal Council Act 2013[3], which provides the opportunity to manage game as "Herds of Special Interest" (HOSI). Management plans for HOSI can specify harvest limits and the allocation of those harvests to individual hunters, which presents a challenge to New Zealand game managers because of the absence of information about the value of game harvests, and about how game harvest importance differs amongst resource users.

All New Zealand game animals are non-native, having been introduced through an extensive acclimatization program (McDowall 1994, Wodzicki 1950). After an initial period of managed recreational hunting, proliferation of game animals resulted in removal of restrictions on hunting, and extensive government initiatives to reduce game numbers, including employment of government hunters and payment of

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[1] https://huntingpermits.doc.govt.nz/huntingpermits/start

[2] Male/female, age, trophy status, etc.

[3] http://www.legislation.govt.nz/act/public/2013/0098/latest/DLM4105024.html

bounties for killing what had become pest species (Hunter 2009, Yerex 2001). The development of commercial markets for game species and aerial hunting methods, particularly hunting and live-recovery from helicopters dramatically increased wild game harvests and reduced game numbers to a fraction of their former levels (Caughley 1983, Challies 1985, Figgins and Holland 2012). Today, public land wild game are hunted by a mix of self-guided recreational hunters, commercially guided recreational hunters, commercial aerial shooting, commercial live capture, and publicly-funded aerial shooting.

After deciding the permitted or desired harvest from any HOSI established for recreational hunting there remains the problem of allocating that harvest amongst the hunters. Harvest right allocation methods include random allocation, merit, and price, amongst others. Random allocation, such as lotteries used in many jurisdictions to allocate game harvest rights, has a significant drawback in that it does not ensure the hunters who would benefit most from harvesting game do so. The potential for such inefficient allocation compounds in situations where hunters can harvest more than a single animal. With a fixed harvest, hunters harvesting multiple animals reduce the total number of hunters who are able to harvest an animal rather than go home empty-handed. That may have little consequence from an efficiency perspective if the marginal benefits of harvest for hunters who make multiple kills equal or outweigh the marginal benefits forgone by hunters who do not get to make a kill. Whether that happens is an empirical question addressed by this research. Gossen's Law (Gossen 1983), otherwise known as the law of diminishing marginal utility (Marshall 1920), suggests there may be efficiency gains from reallocation of harvest from high-harvest hunters to low-harvest hunters.

Efficient allocation

The Utilitarian paradigm measures social welfare (W) as the sum of all individuals' utilities (U_i).

$$W = \sum U_i$$

Individual utility is an increasing function of the individual's harvest (h_i), which is assumed to exhibit diminishing marginal utility:

$$U_i = f_i(h_i), \qquad f_i' > 0,\ f_i'' < 0$$

Assuming all individuals' utility functions are smooth, continuous, and monotonic, maximising social welfare subject to a total harvest limit (H) yields the Lagrangian:

$$\mathscr{L} = \sum f_i(h_i) + \lambda(\sum h_i - H)$$

Which has the following first order necessary conditions for utility maximization:

$$(1)\ \delta\mathscr{L}/\delta h_i = f_i'(h_i) + \lambda = 0 \qquad \forall\ i$$
$$(2)\ \delta\mathscr{L}/\delta\lambda = \sum h_i - H = 0$$

Condition (1) implies that $f_i'(h_i) = \lambda$ for all individuals, which is Gossen's second law (Gossen 1983), requiring that marginal utility is the same for everyone. In the special case where individuals are identical, equal harvests are the most efficient solution.

Even in the simple case of identical preferences, equalisation of marginal utilities may not be achievable for a number of reasons. First, stochasticity and hunter's skill affect each individual's harvest, which cannot be predetermined. Second, the number of animals each hunter harvests is usually a very small integer, so the assumption of smooth, continuous utility functions is invalid, suggesting the need for numerical solutions for allocation of a “lumpy” resource. However, the principle of, as far as is practical, equating marginal utility of harvest remains valid. Non-identical utility functions imply optimality of non-equal harvests ($h_i \neq h_j$). When hunter preferences are identical within groups, but differ between groups, equating marginal utility across and within classes implies equal harvests for individuals within classes, but unequal harvests for individuals in different classes ($h_k \neq h_m$).

Assuming that harvest can be allocated to individuals which, as noted, is not necessarily true because of skill differences as well as the probabilistic nature of harvests, even for hunters with similar skills, then for efficient resource allocation the manager requires information on the nature of $f_k(h_k)$ for each individual or class k.

There is some evidence that Gossen’s law is not always obeyed. For example, in the recreational context, Gan and Luzar (1993) identified increasing marginal utility from Louisiana duck hunting bag limits and Powers and Lackey (1976) identified increasing marginal utility from fish size. The theory of rational addiction (Becker and Murphy 1988, Stigler and Becker 1977), which posits a build-up of consumption or cultural capital, has been applied to explain increasing marginal utilities from successive events for a range of activities, including harmful addictions such as drug and alcohol consumption, and beneficial addictions such as participation in cultural and sporting activities (e.g. Alderighi and Lorenzini 2012, Castiglione and Infante 2016, Lee and Smith 2007).

Previous research has clearly identified hunter heterogeneity, but has identified relatively homogeneous groups of hunters, or hunter typologies. For example, Floyd and Gramann’s (1997) cluster analysis identified four types of hunter. Primary motivations for non-harvesters were to get away from it all and enjoy nature - harvesting game was of little importance to them. Outdoor enthusiasts were similar, but valued game harvest. High-challenge harvesters had a high level of focus on harvest and challenge, with attaining bag limits being important. Low-challenge harvesters were similar, but were somewhat less intense in these desires. Schroeder et al. (2006) used cluster analysis to group waterfowlers into five participant clusters: long time, less-engaged, recreational-casual, social, and achievement-oriented. The latter group put particularly high importance on harvest. Notably, satisfaction differed across the five types of hunters. Two studies used the same data to examine Norwegian grouse hunters using cluster analysis (Wam et al. 2012, Wam et al. 2013), which identified three hunter types. Experience seekers exhibited declining willingness to pay per bird bagged as bag size increased, whereas northern traditionalists’ willingness to pay was largely independent of bag size. Of most relevance to the current study, about one third of hunters belonged to the bag-oriented group, which had increasing marginal utility because willingness to pay per bird bagged significantly increased as bag size increased. This situation poses a significant challenge for resource managers in that the traditional approach of applying bag limits may not maximise social welfare – fewer hunters bagging more game each may be most efficient. Consistent with studies conducted elsewhere, New Zealand hunters display significant heterogeneity in motivations, preferences, and behaviours (Kerr and Abell 2014, Kerr and Abell 2016), but the welfare implications of different harvest levels remains unexplored.

This study recognises that one cannot assume diminishing marginal utility of harvest for New Zealand red deer hunting, and also recognises that marginal utility can vary by hunter type. I estimate utility functions based on reported satisfaction by New Zealand red deer hunters whilst concurrently accounting for hunter heterogeneity. The main aim of analysis was to test the existence of diminishing marginal utility from individuals' game animal kills on a single hunt, and to identify the potential significance for game management. The potential merits of a hypothetical one deer per hunt bag limit are assessed using model results.

Methods

A series of internet surveys provided the data. Kerr and Abell (2014) provides detail about those surveys, so only a brief description is provided here. Hunting media advertisements, and the Department of Conservation hunting permit web site hosted invitations for big game hunters to participate in an initial survey. This self-selection approach, which is likely to entail some avidity bias (Alessi & Miller, 2012; Cornicelli & Grund, 2011), was unavoidable because there was no database of New Zealand game hunters, or other way to draw a random sample of hunters. The initial survey collected personal information about hunters, including measures of their hunting activity, motivations, demographics, and game species targeted. The initial survey also included an invitation to register to join a panel to report each month on hunting activity. Monthly reports provided information on (*inter alia*) the amount of hunting undertaken as well as information on a single hunt from that month that was randomly selected by the survey administrators. For the selected hunt, survey participants reported their motivations, the game species targeted, game sightings, game harvests, and satisfaction. Matched data from the initial survey and the monthly activity surveys provides a comprehensive description of individual hunters and their activities throughout the year. Expert informants aided the development of both surveys, which were extensively pre-tested, and were approved by the Lincoln University Human Ethics Committee.

The initial survey was open from May 2011 to November 2011. Invitations to participate in each monthly activity survey, and a follow-up to non-respondents about ten days later, were emailed to panellists early each month to cover hunts over the period from June 2011 to June 2012. Of 1,466 active game hunters who chose to participate in the initial survey, 1,251 provided complete, useable surveys that were subsequently analysed. The majority of those hunters (n=961) elected to participate in the monthly activity surveys. Red deer are the most commonly hunted New Zealand game species. Of the 4,588 individual hunts for which hunters provided complete data, 2,917 hunts targeted red deer. The current study analyses those 2,917 red deer hunts by 698 different hunters.

Frey et al. (2003) successfully modelled pheasant hunters' satisfaction with the ordered logit model, but did not account for hunter heterogeneity. In order to do so, I modelled responses to a trinomial satisfaction scale with both random parameters and latent class ordered logit models, estimated with NLOGIT® software. Whereas previous studies have applied post hoc analysis to explore differences between groups formed exogenously through cluster analysis (e.g. Floyd and Gramann 1977, Schroeder et al. 2006, Wam et al. 2012, Wam et al. 2013), the random parameters and latent class models employed in the current study address heterogeneity endogenously.

The original dependent variable was overall satisfaction with the hunt, measured on a five-point Likert scale ranging from "very unsatisfied" to "very satisfied". Rollins and Romano (1989) identified four methodological difficulties in measuring satisfaction: self-selection, displacement, product shift and cognitive dissonance. Self-selection and displacement are related concepts in that both are based on recreators selecting activities and settings that are suited to them, and choosing to go elsewhere or pursue other activities if outcomes are unfavourable. Product shift and cognitive dissonance (and related concepts such as rationalization and multiple sources of satisfaction (Shelby & Heberlein, 1986)), are psychological adjustments and rationalizations that redefine activities or outcomes to avoid the need to change behaviour. Together, these responses suggest that measured recreational satisfaction should be generally high. This proved to be the case and the scale was collapsed into three categories, as explained in the results section.

Animal sightings and kills entered the models as a set of dummy independent variables indicating whether the hunter saw a red deer, and the number of red deer the hunter killed (none, at least one, at least two, at least three). An additional harvest-related independent dummy variable recognised the compensatory utility that a hunter who has not killed a deer attains when another member of the hunting party does so. Dummy independent variables avoid imposition of constant marginal utility from killing deer.

For the ordered logit model with three satisfaction categories, predicted probabilities for each satisfaction category are:

$$P(0) = P(\text{Not satisfied}) \quad = e^{-\boldsymbol{\beta}\mathbf{X}} / (1+e^{-\boldsymbol{\beta}\mathbf{X}})$$

$$P(1) = P(\text{Satisfied}) \quad = e^{(\mu-\boldsymbol{\beta}\mathbf{X})}/ (1+e^{(\mu-\boldsymbol{\beta}\mathbf{X})}) - e^{-\boldsymbol{\beta}\mathbf{X}} / (1+e^{-\boldsymbol{\beta}\mathbf{X}})$$

$$P(2) = P(\text{Very satisfied}) \quad = 1 - e^{(\mu-\boldsymbol{\beta}\mathbf{X})} / (1+e^{(\mu-\boldsymbol{\beta}\mathbf{X})})$$

Utility is $\boldsymbol{\beta}\mathbf{X}$. $\mathbf{X}$ is a vector of hunt and/or personal attributes, $\boldsymbol{\beta}$ is a vector of estimated model coefficients, which are marginal utilities, and μ is a constant that identifies the utility threshold between classes 2 and 3.

For dummy variables the marginal effects on satisfaction category probabilities are: $\Delta P_i = P_i[X_d = 1] - P_i[X_d = 0]\ \forall i$,. X_d is the dummy variable of interest (e.g. killed at least one deer) in the vector $\mathbf{X}$. The other hunt attributes in $\mathbf{X}$ are set to appropriate levels (e.g. the dummy for having seen a deer is set to one in assessing the difference in utility from killing more than one deer), whereas personal attributes are set to their means.

The primary purpose of this research is to test whether marginal satisfaction from kills of red deer is increasing or decreasing. Prior evidence suggest that both outcomes are possible, so a two-tailed z-test of significance of differences from zero of ($MU_1 - MU_2$) is applied, where MU_i is marginal utility from killing the i^{th} deer. Significant negative z-scores indicate increasing marginal utility of deer kills, whereas significant positive z-scores are indicative of decreasing marginal utility. The welfare effect of a one deer per hunt bag limit was modelled by estimating the difference in aggregate utility between that scenario and the status quo (no bag limit) scenario. A two-tailed z-test identified the significance of the estimated change in aggregate utility because of the bag limit ($U_{Bag\ limit} - U_{SQ}$). Distributions of marginal effects of number of kills on satisfaction probabilities, differences in marginal utilities for different numbers of kills, and welfare effects of reallocation of kills amongst hunters were developed with Monte Carlo simulations, each with 5,000 replications.

Results

Table 1 summarises hunter and hunt attributes respectively. Mean and median hunter age are both 40 years, and mean experience hunting big game (22 years) is also very similar to median experience (21 years). The average number of annual big game hunts (17) is more than the median (12) because of a large number of hunts undertaken by a small number of hunters. Some hunters were reticent to disclose their annual deer harvest, with only 531 responses to this question. The mode (2 red deer) was smaller than the mean, reflecting large annual harvests by a small number of hunters. Respondents were almost all male, with half from each main island, and 35% being members of the New Zealand Deerstalkers' Association. There is no reliable sampling frame against which to assess the representativeness of the sample. Hunters nominated their single most important reason for hunting game animals, with the modal response (50% of hunters) being to enjoy the outdoors. The harvest-related motivation of taking home meat was the second most common (19%) primary reason to hunt game animals, with the other harvest-related motivation, Trophy, a distant sixth at 5.6%.

The median hunt was a single day, with two hunters in the party travelling 80 kilometres each way at a cost of $50. As with annual harvests, there was significant non-response to the question about number of deer the individual killed on the hunt. The mean was 0.44, and the mode was zero. The modal motivation for the individual hunt (rather than for hunting game animals in general) was enjoying the outdoors (33%), but this was closely followed by obtaining meat (29%), indicating that primary motivations to engage in hunting *per se* can differ from primary motivations for any specific hunt. Two thirds of hunters saw a red deer, but less than one third of hunters managed to kill one. Only 8% of hunters personally killed more than one red deer.

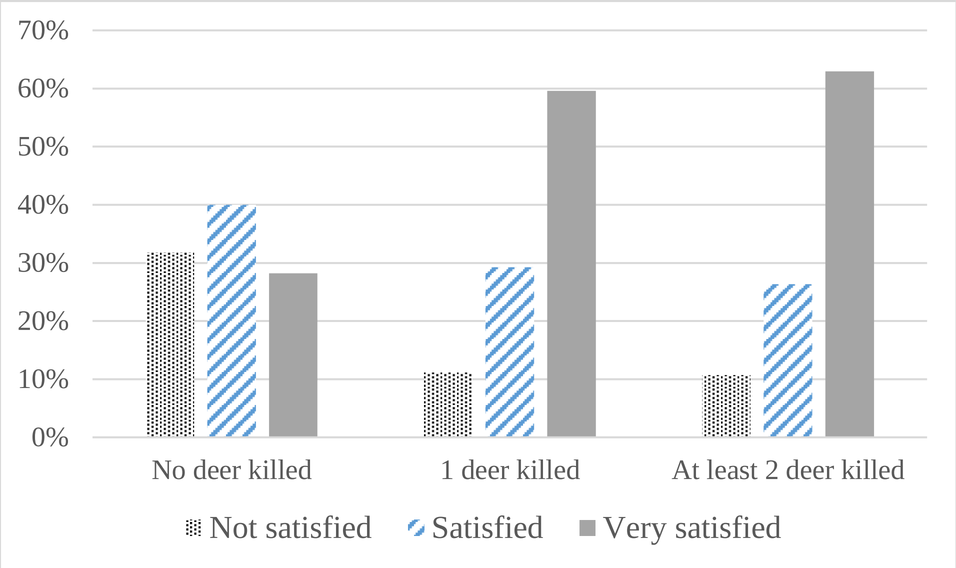
Table 1: Hunter and hunt descriptives

Variable	N	Mean	SD	Median
Hunters				
Age	697	39.74	13.05	40
Years of big game hunting experience	696	22.04	14.36	21
Days spent big game hunting per year	697	32.66	29.63	25
Big game hunts per year	696	16.97	21.53	12
Red deer killed per year	531	3.09	5.13	2
Male	698	97.9%		
Maori	698	8.3%		
North Island resident	698	50.1%		
NZ Deerstalkers' Association member	698	35.0%		
Primary motivation to hunt game: Enjoy outdoors	698	50.0%		
Primary motivation to hunt game: Meat	698	19.1%		
Primary motivation to hunt game: See wild animals	698	7.2%		
Primary motivation to hunt game: Excitement	698	6.6%		
Primary motivation to hunt game: Exit civilisation	698	6.2%		
Primary motivation to hunt game: Trophy	698	5.6%		
Hunts				
One way travel distance (km)	2910	136.95	184.01	80
One way travel time (hours)	2910	3.23	9.27	1.5
Cost of travel (NZ$)	2912	118.87	238.35	50
Days hunted	2909	2.16	2.00	1
Number of hunters in the party	2912	2.07	1.17	2
Number of red deer the individual killed	2763	0.44	0.88	0
Primary motivation for this hunt: Enjoy outdoors	2917	33.5%		
Primary motivation for this hunt: Meat	2917	29.4%		
Primary motivation for this hunt: Trophy	2917	10.9%		
Saw red deer	2917	64.0%		
Didn't kill a red deer	2763	68.2%		
Killed 1 red deer	2763	23.7%		
Killed 2 red deer	2763	6.0%		
Killed 3 or more red deer	2763	2.1%		
Didn't kill a red deer, but another party member did	2756	10.0%		

Consistent with previous deer hunting studies (e.g. Decker et al., 1980; Hammitt et al., 1990; Heberlein & Kuentzal, 2002; McCullough & Carmen, 1982), most hunters were satisfied with their hunts, and there were very few responses in the unsatisfied end of the scale. Consequently, "very unsatisfied", "unsatisfied" and "OK" responses were aggregated into a single category, resulting in a trinomial dependent variable coded as "not satisfied" (25% of responses), "satisfied" (37% of responses), "very satisfied" (38% of responses).

Figure 1 illustrates the relationship between self-reported satisfaction and the number of red deer the individual killed on the hunt. Differences are highly significant (χ^2 = 287.65, dof = 4, p < .001). This result suggests a positive relationship between the number of deer the hunter killed and their satisfaction with the hunt. There is a significant improvement in satisfaction from killing the first deer. Compared with those who did not kill a deer, more than double the proportion of hunters who killed one deer reported they were very satisfied. However, there is very little change from killing subsequent deer, with non-significant differences in reported satisfaction of hunters killing one or multiple deer (χ^2 = 0.837, dof = 2, p = .658). These results are supportive of the diminishing marginal utility hypothesis.

Figure 1: Satisfaction by number of red deer the hunter killed that hunt.



It is possible for a number of factors other than kills to affect satisfaction, including deer sightings, kills by other members of one's party, heterogeneous preferences, and other personal characteristics. Various statistical models explored these relationships, whilst accounting for respondent heterogeneity. Model fit was assessed using estimated coefficient significance, adjusted Rho^2, and information criteria (AIC, AIC3, BIC, aBIC, CAIC) scores. Latent class models were superior to random parameters models on these criteria. Both types of model are reported here (Tables 2 & 3). Initial testing also failed to identify any statistically significant class allocation variables in the latent class models. A four-class latent class model had the best overall statistical fit, and is retained for further analysis (Table 2).

Table 2: Latent class ordered logit satisfaction model.

	Class 1	Class 2	Class 3	Class 4
Constant	1.486***	2.055***	-0.309	-1.379***
μ (category threshold)	1.616***	3.380***	4.571***	1.656***
NZ Deerstalkers' Association member	0.251	0.208	0.091	0.873***
Saw a red deer	1.335***	0.219	1.434***	1.007***
Killed at least one red deer	0.712	0.906**	4.594***	0.765**
Killed at least two red deer	0.289	1.674***	-1.089	-0.106
Didn't kill a deer, but the party did	0.643	0.067	5.713***	0.6232*
Meat hunt	-1.181***	-0.854**	-1.365**	-1.074**
Meat hunt x Killed at least one red deer	1.523**	-1.168**	0.378	1.969***
Class probability	0.311***	0.230***	0.195***	0.264***
LL (constants only model)	-2984.141			
LL (full model)	-2527.055			
N	2756			
K	39			
Individuals	698			
Adjusted Rho^2	0.140			
Normalized fit measures: AIC = 1.862, AIC3 = 1.876, CAIC = 1.960, BIC = 1.946, ABIC = 1.901				
*, **, *** ⇒ significant at α < .10, .05, .01 respectively				

In the latent class model (Table 2), hunters in all classes were more satisfied if they saw a deer, but the effect is not significant for Class 2. For all classes there was a significant negative effect for hunts that were primarily motivated by obtaining meat. However, this effect was offset reasonably closely if the meat hunter killed a deer (except for Class 3), meaning that meat hunters who killed a single deer were about as satisfied as non-meat hunters who did not kill a deer.

For Class 1 hunters, satisfaction was not affected significantly by whether the hunter, or another member of the hunting party, killed a deer, unless the hunt was primarily motivated by obtaining meat. For other classes, killing the first deer increased satisfaction. Killing a second (or more) deer only had a positive effect for Class 2, with the marginal effect of the second kill being of greater magnitude than the first kill. Hence, Classes 1, 3 and 4 appear to exhibit diminishing marginal utility, but Class 2 does not.

Table 3: Random parameters ordered logit model.The dependent variable is satisfaction, measured on a three point scale: Unsatisfied, Satisfied, Very Satisfied. 200 Halton draws**.**

Parameter	Mean	Scale parameter
Non-random parameters		
Constant	0.704***	
μ (category threshold)	2.182***	
NZ Deerstalkers' Association member	0.174***	
Cost of travel	0.000**	
Urban resident	-0.175***	
Meat hunt x Killed at least one red deer	0.870***	
Random parameters		
Saw a red deer	0.789***	1.181***
Killed at least one red deer	1.267***	0.783***
Killed at least two red deer	0.425**	1.429***
Individual did not kill, but the party did	1.162***	1.479***
Meat hunt	-1.770***	0.588***
Heterogeneity in Random Parameter Mean		
Meathunt: Hunter's Age	0.022***	
LL (constants only model)	-2975.06	
LL (full model)	-2622.89	
N	2741	
K	17	
Individuals	695	
Adjusted Rho^2	.113	
Normalized fit measures: AIC = 1.926, AIC3 = 1.932, CAIC = 1.969, BIC = 1.963, ABIC = 1.943		
*, **, *** ⇒ significant at α < .10, .05, .01 respectively		

Results for the random parameters ordered logit model (Table 3) were broadly similar to the latent class model. Hunters benefitted from seeing a deer, gained increasing benefits from killing deer, and were appreciative of other party members killing a deer when they did not. As with the latent class model, meat hunters were less satisfied than other hunters unless they killed a deer. The significant scale parameters indicate a high level of inter-hunter heterogeneity.

Table 4: Hunter and hunt attribute means by class membership. Numeric superscripts indicate significant class mean differences using Tukey HSD test at $p \leq .05$.

	Total	Class 1	Class 2	Class 3	Class 4	F	Sig
Annual game hunts	16.97	18.43	16.96	17.18	15.13	0.748	.524
Annual days game hunting	32.66	34.70	31.89	32.85	30.92	0.583	.626
NZDA member	0.35	0.35	0.36	0.30	0.37	0.514	.673
Experience (years)	22.04	23.19	22.42	18.98	22.42	2.320	.074
Age (years)	39.74	40.92[3]	40.38[3]	36.53[1,2]	39.80	3.116	.026
Importance of killing game	1.86	1.78	1.96	1.94	1.83	2.437	.064
Importance of trophy	1.75	1.67	1.80	1.73	1.81	1.267	.285
Importance of harvesting meat	2.51	2.53	2.47	2.53	2.51	0.233	.873
Main reason to hunt is meat	0.19	0.20	0.19	0.17	0.19	0.145	.933
Main reason to hunt is trophy	0.06	0.05	0.08	0.03	0.07	1.257	.288
Annual red deer harvest	3.09	2.83	3.29	3.28	3.06	0.213	.888
Killed one deer this hunt	0.24	0.26[3]	0.24	0.19[1]	0.24	2.912	.033
Killed 2 or more deer this hunt	0.06	0.09	0.08	0.07	0.08	0.481	.695
Number of deer killed this hunt	0.44	0.50[3]	0.43	0.35[1]	0.44	3.291	.020
This hunt was a meat hunt	0.29	0.32	0.29	0.27	0.29	1.253	.289
This hunt was a trophy hunt	0.11	0.09[2]	0.14[1,4]	0.11	0.09[2]	4.505	.004
Satisfaction	1.12	1.61[2,3,4]	0.57[1,3,4]	0.92[1,2,4]	1.15[1,2,3]	341.271	.000

Importance is coded on a 4-point scale from 1 (Not important) to 4 (Extremely important)
Satisfaction is coded: 0 Not satisfied, 1 Satisfied, 2 Very satisfied

There are very few significant differences between class members (Table 4), with individuals assigned to their modal probability class. Class 3 hunters were, on average, younger than Class 1 and 2 hunters, but the age differences were not large. Overall, mean red deer kills per hunt was 0.44 deer per hunter. Class 1 hunters killed the most deer per hunt, and Class 3 hunters killed the fewest. However, the only significant difference in number of kills per hunter was between Classes 1 and 3. Class 2 hunters were more likely to be on hunts motivated by trophy than were Class 1 and 3 hunters. Most notably, reported satisfaction was significantly different (χ^2 = 1243.79, dof = 6, p < .001) between classes (Tables 4 & 5). Class 1 hunters were the most satisfied, with 71.4% of them stating they were very satisfied with their hunt, and only 10.1% were not satisfied. On the other hand, 59.0% of Class 2 hunters reported that their hunt was not satisfying

Table 5: Reported hunt satisfaction

	Class 1	Class 2	Class 3	Class 4	Total
N	954	722	550	686	2912
Not satisfied	10.1%	59.0%	31.6%	8.2%	25.8%
Satisfied	18.6%	24.7%	44.4%	68.5%	36.7%
Very satisfied	71.4%	16.3%	24.0%	23.3%	37.5%

Monte Carlo simulation with 5,000 replicates produced a distribution of the marginal satisfaction effects of deer kills. For non-meat hunters, killing the first deer significantly increased the probabilities of being very satisfied in the random parameters model, and for hunters in Classes 2, 3 and 4 of the latent class model, with the biggest effects occurring in Class 3 (Figure 2). The pattern is somewhat different for meat hunters. There are significant positive effects for Classes 1, 3 and 4, but no significant effects for Class 2. For the random parameters model there is a stronger effect than for non-meat hunters.

Figure 2: Marginal effects of killing first deer. P0 = probability (Not satisfied), P1 = probability (Satisfied), P2 = probability (Very satisfied).

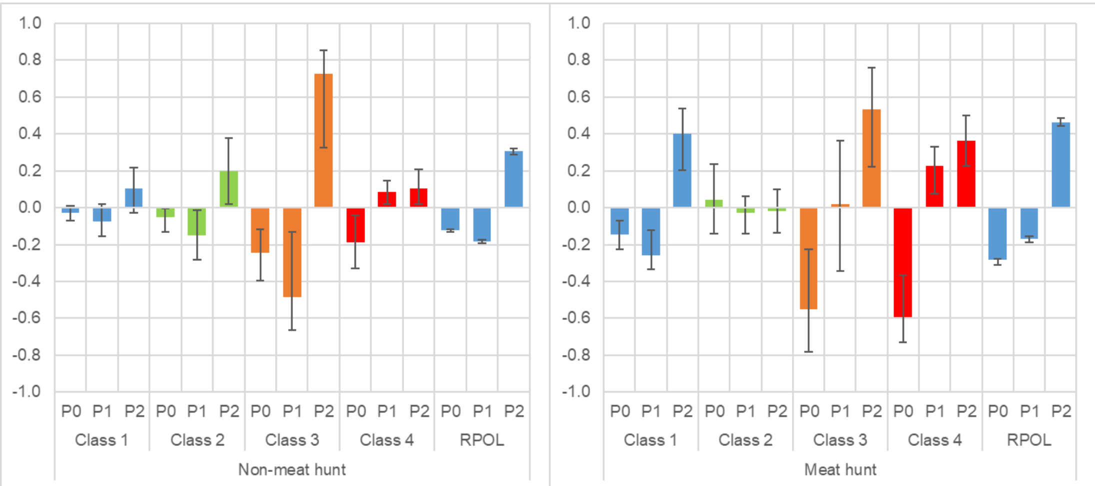
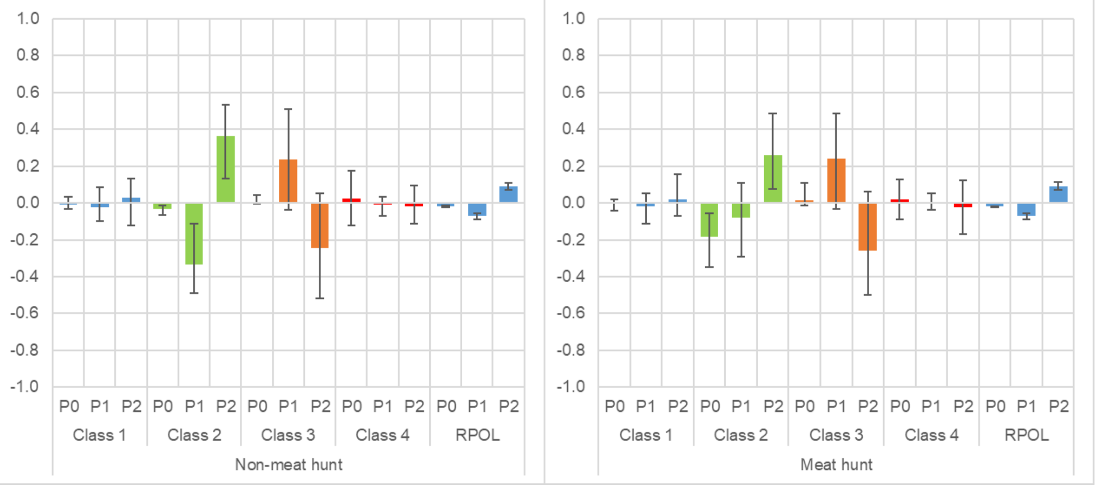


Figure 3: Marginal effects of killing second deer. P0 = probability (Not satisfied), P1 = probability (Satisfied), P2 = probability (Very satisfied).



Outcomes are not as clear-cut for the second kill (Figure 3), and differ little between hunt motivations. Apart from Class 2, all marginal effects are non-significant for the latent class model. For Class 2 hunters there is a significant increase in satisfaction from a second kill. All marginal effects are significant, albeit small, in the random parameters model.

The magnitude, sign and significance of differences in marginal utility for first and second kills provide a test of diminishing and/or increasing marginal utility (Table 6). The random parameters model and Classes 3 and 4 in the latent class model exhibit diminishing marginal utility. Marginal utility differences for one and two deer kills are not significantly different from zero for Class 1 hunters. The negative signs on marginal utility differences for Class 2 are consistent with increasing marginal utility. This difference borders on significance for meat hunters ($\alpha = .051$), but is not statistically significant for non-meat hunters.

The effects of a hypothetical one deer per hunt bag limit are modelled within hunter groups, with each group consisting of hunters with the same primary hunt motivation (i.e. meat hunt or non-meat hunt) within a particular class. Hence, there are eight groups for the latent class model and two for the random parameters model. Within-group effects are modelled by reallocating kills amongst the group, with the total number of hunts by each group remaining constant. Under the bag limit scenario, second and subsequent kills are hypothetically re-allocated to hunters who did not make a kill. This re-allocation may not be possible in practice, but this scenario provides a basis for understanding the maximum potential impacts of the bag limit. It is not possible to test the efficiency of reallocation of the total bag between classes because model coefficients are non-comparable across classes in the latent class model because of scale differences. Again, 5,000 Monte Carlo simulations modelled the distributions of change in utility (Table 7). Utility from a zero-kill hunt in each group was an arbitrary constant, which had no effect on estimated change in utility from the one deer limit policy.

Table 6: Marginal utility from deer killed by hunter class and specific hunt motivation

	Class 1		Class 2		Class 3		Class 4		RPOL	
	Non-meat hunt	Meat hunt	Non-meat hunt	Meat hunt	Non-meat hunt	Meat hunt	Non-meat hunt	Meat hunt	Non-meat hunt	Meat hunt
Marginal utility of first kill (MU1)	0.712	2.235***	0.906**	-0.262	4.594***	4.972***	0.765**	2.734***	1.267***	2.137***
Marginal utility of second kill (MU2)	0.289	0.289	1.674***	1.674***	-1.089	-1.089	-0.106	-0.106	0.425**	0.425**
Difference (MU1-MU2)	0.423	1.947*	-0.769	-1.937*	5.684***	6.061**	0.871*	2.840***	0.842***	1.712***
Z (MU1-MU2)	0.503	1.765	-0.965	-1.951	2.609	2.556	1.690	3.802	3.204	5.607
P(Z)	.615	.078	.335	.051	.009	.011	.091	.000	.001	.000

*, **, *** $\Rightarrow$ significantly different from zero at $\alpha < .10, .05, .01$ respectively

Table 7: Estimated change in utility from imposition of a hypothetical 1 deer bag limit.

	Class 1		Class 2		Class 3		Class 4		RPOL	
	Non-meat hunt	Meat hunt	Non-meat hunt	Meat hunt	Non-meat hunt	Meat hunt	Non-meat hunt	Meat hunt	Non-meat hunt	Meat hunt
Without bag limit										
Hunts with zero kills	430	163	368	104	287	90	335	105	1219	386
Hunts with one kill	143	94	90	73	66	32	99	59	463	293
Hunts with multiple kills	41	30	31	24	20	17	30	20	253	127
With bag limit										
Hunts with zero kills	326	126	320	73	261	70	288	74	591	197
Hunts with one kill	298	161	169	128	112	69	176	111	1344	609
Change in utility	59.323	74.045	-8.440	-48.320	141.244	117.961	39.142	89.614	688.397	460.445
Z ($U_{Bag\ limit} – U_{SQ}$)	0.942	1.990	-0.279	-1.771	2.654	2.576	1.955	4.156	6.456	7.010
P(Z)	.346	.047	.780	.077	.008	.010	.051	.000	.000	.000

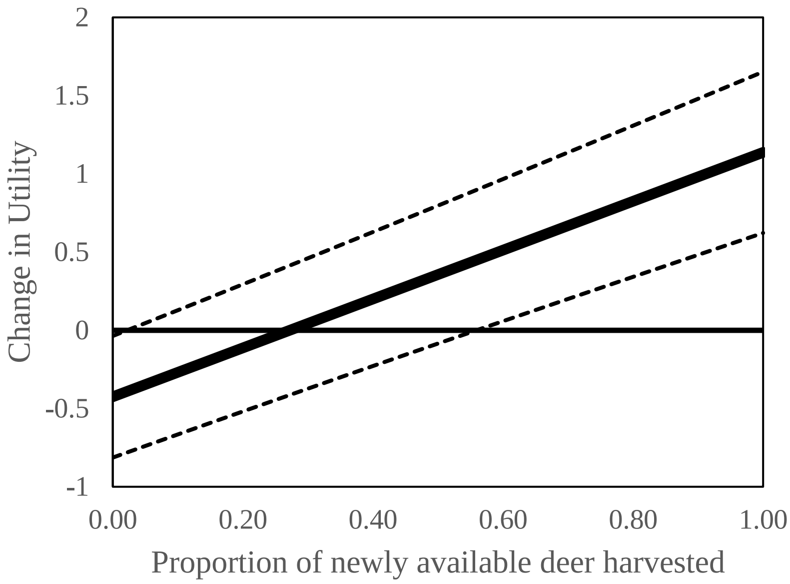
Significant positive changes in aggregate utility occur for the random parameters cases, and for Classes 3 and 4, and for Class 1 meat hunts in the latent class model. There is a non-significant positive effect for non-meat hunters in Class 1. The bag limit would enhance welfare for these three classes. Results for Class 2 are less clear. For both hunt motivations the sign of utility change for Class 2 is negative. However, mean utility change is not significant for non-meat hunts, but is close to significant for meat hunts.

It is unrealistic to expect that all the deer not killed because of the bag limit by hunters who formerly made multiple kills (newly available deer) will be killed by formerly unsuccessful hunters. Hence, the estimates in Table 7 represent a best case scenario. The assumption is relaxed for the random parameters ordered logit model in Figure 4, which reports results from a 5,000 draw Monte Carlo estimation procedure. The change in utility from each newly available deer is defined as:

$$\Delta U = p_{harv} [MU_1 + p_m MU_{1MH}] - MU_2$$

Here, p_{harv} is the probability of a newly available deer being harvested, MU_{1MH} is the coefficient on "Meat hunt and killed at least one deer", and MU_1 and MU_2 are the marginal utilities of the first and subsequent deer killed, respectively. Meat hunters took 24% of hunts on which a deer was not killed, but were 1.4 times as likely to kill a deer as non-meat hunters. Consequently, $p_m = .3387$ is the expected proportion of newly available deer killed by meat hunters.

Figure 4: Change in aggregate mean utility per "newly available deer" from a one deer bag limit as a function of the proportion of newly available deer killed by formerly unsuccessful hunters. Dashed lines identify the 95% confidence interval.



In the short term a one deer bag limit would increase aggregate welfare only if a significant proportion of the newly available deer were harvested by formerly unsuccessful hunters. The expected threshold to maintain current aggregate utility is $p_{harv} = .272$, although the 95% confidence interval is large (.026 ~ .562). Whether that would occur or not is beyond the present study, but is a question worthy of further research, as are the equity implications where the impacts differ across hunter classes. If the bag limit were to reduce overall harvest it would likely increase the future deer population, so long term implications may be important. However, that argument may not be relevant where the deer population must be sustained within a predefined maximum for environmental or other reasons.

Discussion

The latent class and random parameters models confirm hunter heterogeneity, with latent class models fitting the data better across the range of criteria assessed. Significance of parameters differs markedly between classes. The one common effect across all classes is that on hunts primarily motivated by meat harvest hunters have lower mean satisfaction than do hunters motivated by other reasons. Class 1 hunters gain significant welfare from seeing deer, but kills by themselves or other party members do not significantly affect satisfaction. The exception is for hunters primarily motivated to hunt for meat. For those hunters, mean satisfaction is less than for hunters hunting for other reasons, unless the meat hunter makes a kill, which leaves them about as well satisfied as non-meat hunters who have made a kill. Similarly, the meat-hunting motive differentiates Class 2 hunters. Non-meat hunters obtain significant satisfaction from their first and second kills, with the second kill adding even more satisfaction than the first. Again, meat hunters have lower mean satisfaction absent a kill, and killing deer does not increase their satisfaction to the same extent as for non-meat hunters. Class 2 hunters do not gain satisfaction from seeing deer. Class 3 hunters enjoy seeing deer and gain a large amount of satisfaction from killing one deer, but no additional satisfaction from killing subsequent deer. If class three hunters do not kill a deer, they gain satisfaction from other members of their party doing so, unlike members of other classes. The random parameters model provided consistent results. In the absence of killing a deer, meat hunters were less satisfied than others, but the additional marginal utility for meat hunters from killing their first deer meant they were as satisfied as other hunters who had made a kill.

The primary research aim was to test whether New Zealand red deer hunters exhibit decreasing marginal utility from killing red deer. Evidence is mixed. The random parameters model suggests they do. However, the latent class model, which clarifies distinctions between hunters with different types of preferences, indicates the finding may not be universal. For two classes of hunter (Classes 3 and 4) marginal utility of deer kills is clearly diminishing. The Wam et al. (2012, 2013) “Experience seekers” are congruent with these hunters. Class 1 hunters’ satisfaction, the highest of all classes, is not significantly influenced by kills, a situation not unique to New Zealand red deer hunting – these hunters closely align with “Nonharvesters” (Floyd and Gramann 1997), “Less-engaged participants” (Schroeder et al. 2006) and “Northern traditionalists” (Wam et al. 2012, 2013). Class 2 hunters exhibit increasing marginal utility, consistent with “Bag-oriented” hunters in the Wam et al. (2012, 2013) typology.

There are no overtly observable differences in personal characteristics of the Class 2 hunters compared with other hunters. However, Class 2 hunters reported the lowest satisfaction levels of all hunters. They were also more likely than other classes to be on a trophy hunt, although that is still a small fraction (14%) of Class 2 hunts. What is more, the proportion of trophy hunters cannot explain the possible increasing marginal utility for Class 2 meat hunts.

The secondary research aim was to explore the potential efficiency effects of a hypothetical one deer per hunt bag limit. Within most hunter groups there was either no significant effect or a positive effect on efficiency from the bag limit, the exception being Class 2 meat hunts. These predictions must be treated with caution because they assume a proportional reallocation of kills within each class. That may not occur in practice, and the total number of kills within a group or a class may change because of the bag limit. Relatively uniform kill rates across classes suggest this may not be important, but behavioural responses need consideration. For example, Class 1 hunters, who are highly satisfied and whose utility is largely independent of kills, may not change their kills at all or may have a disproportionately small increase in the number of hunters making a kill. The random parameters model provides useful insight into the critical role of increased success in efficiency of the bag limit.

There are two problems that cannot be resolved with the existing data; identification of the distribution of kills after imposition of the bag limit, and cross-class utility change evaluation. These matters require further research.

Kill distributions could be evaluated ex post (i.e. learning by doing), or ex ante by surveying hunters to predict their behavioural responses to a bag limit. Cross-class utility change comparisons are not possible for the latent class model because scale effects preclude coefficient comparisons across classes. This problem might possibly be addressed by (1) using monetary estimates of the value of a kill, which are independent of scale, (2) using statistical models that have uniform scale or permit relative scale estimation, or (3) choosing a simplified management objective, such as maximisation of the number of very satisfied hunters.

Hunter heterogeneity and the importance of the meat-hunt motivation drive differences in the value of a kill. This suggests that reallocation of kills, such as through a tag system, could yield efficiency gains, making hunters more satisfied overall. However, the game manager is unable to identify the hunters who would get the largest benefits from killing deer based on the hunters' observable attributes. One potential solution would be to sell tags at a price that clears the market for the target deer harvest. While that would result in an economically efficient allocation of deer kills, it would transfer benefits from the hunters to the fee recipients. The consequence is a potential decrease in hunters' total benefits, the very group whose welfare the policy seeks to enhance. Selling deer tags at a market clearing price is unlikely for that reason.

Analysis of satisfaction data has provided new insights into New Zealand red deer hunters and the potential for future management. As with hunters in other locations, New Zealand red deer hunters display significant heterogeneity, with some being highly harvest-focussed while the quality of experience for others is largely independent of harvest. Ignoring heterogeneity will result in sub-optimal management. For one relatively small group of hunters there is limited evidence of increasing marginal utility of killing deer. For all other groups, a bag limit would have either no effect or a positive effect in aggregate on the value of deer killed, provided the number of successful hunters is increased significantly. These results suggest potential benefits from further research to test the existence of increasing marginal utility, and to test the welfare impacts of a bag limit.

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