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BALANCING HUNTING REGULATIONS AND HUNTER SATISFACTION: AN INTEGRATED BIOSOCIOECONOMIC MODEL TO AID IN SUSTAINABLE MANAGEMENT

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Abstract:

Hunting of game animals needs to be regulated; either through the number of permits or the bag size allowed per hunter. Such regulations may, however, jeopardize hunter satisfaction, on which game managers depend. Consequently, finding the optimal hunting intensity is not straightforward. Using data from Norwegian grouse hunting, we show that an integrated approach combining sociology and bioeconomics can give markedly different priorities than an optimization based exclusively on bioeconomics. Three grouse hunter typologies with contrasting stated preferences regarding bag size and crowding were used to account for varying hunter behaviour. Omitting the social constructs from the model pushed the hunter density towards its upper limit, because the gain of selling one more permit generally superseded the loss in hunter satisfaction (expressed as willingness-to-pay). Although this strategy multiplied the overall profit, it produced a daily bag size that would be unacceptable to practically all hunters. We conclude that biosocioeconomic modelling is a valuable tool in the pursuit of sustainable game management.

Key-words: bioeconomic, game, grouse, harvest, typology, willingness-to-pay

1. Introduction

Around the globe, populations of game species cause concern for being either overabundant (e.g., moose: Serrouya et al. 2011; deer: Warren 2011) or declining (e.g., grouse: Storch 2007; caribou: Wittmer et al. 2005). To decide on the right action, managers normally depend on the engagement and goodwill of hunters. While hunting regulations are instrumental in keeping game populations within sustainable frames, we also need satisfied hunters in order to maintain hunting as an activity of the future (Heberlein and Kuentzel 2002; Schroeder et al. 2006). Additionally, hunting revenues may constitute a substantial part of rural economy (Sharp and Wollscheid 2009), and as such presents yet another reason for managers to take hunter satisfaction into account.

Historically, hunter satisfaction has been commonly viewed as being linearly related to hunting success, i.e. the number of animals killed (Mechling 2004). However, already four decades ago it was established that hunter satisfaction is determined by far more complex elements than such a consumptive measure (Hendee 1974). Since then research on the topic has more or less taken this "multiple-satisfaction" approach to heart (e.g. Decker et al. 1980; Vaske et al. 1986; Hazel et al. 1990; Hayslette et al. 2001). Principally, the factors that determine hunter satisfaction are strongly linked to hunting motivation. What Decker and Connelly (1989) state about deer hunters, "*...motivations for hunting deer are rooted in the areas of personal achievement, affiliation with friends and family, and appreciation of the outdoors*" (p. 462) seems to hold for hunters in general. A motivation that is quite weak, is to hunt for non-personal gains to benefit other stakeholders or the wider community (e.g., Ward et al. 2008). Often this leads to a disagreement between hunters and managers over what constitutes optimal animal densities (Diefenbach et al. 1997; Horton and Craven 1997; Finch and Baxter 2007; Wam and Hofstad 2007).

As a result, new harvest regulations must be carefully introduced in order not to critically reduce hunter satisfaction. Management agencies then need tools that can only be developed from truly interdisciplinary research, preferentially from all three relevant research fields; ecology, sociology and economics. Although ecological economics has come a long way towards interdisciplinary research (Söderbaum 2007; Wam 2010), the simultaneous integration of three such different research fields is still a rather novel approach. As has often been the case with interdisciplinary advances in natural resource management, fishery researchers are leading the way (Bunnefeld et al. 2011a). Pioneer biosocioeconomic models for the harvest of marine resources were presented several decades ago (e.g., Smith 1968; Krauthamer et al. 1987; Charles 1989), and in the last ten years inclusion of stakeholder behaviour has frequently been argued to be essential for successful fishery models (e.g., Mapstone et al. 2008; Fulton et al. 2011, Milner-Gulland 2011). Similar approaches in terrestrial systems seem to be lagging.

In this study we made a socioeconomic survey of habits, attitudes and stated preferences among grouse hunters in Norway, and used the data in an integrated *biosocioeconomic* model to evaluate the optimal balancing of harvest regulations and hunter satisfaction. While our overall model objective was to maximize landowner profit, we also contrast this with alternative scenarios that more directly prioritize hunter satisfaction. We kept the model framework fairly simple, but its parameterization is based on extensive empirical data, with the aim of having a model that is "*robust in the real world rather than optimal in the ideal world*" (Milner-Gulland 2010, p. 1). While some general recommendations for game managers can be drawn from the study, our main goal is to illustrate how a stronger inclusion of social constructs can be a valuable expansion to the traditional tools used in the pursuit of sustainable game management.

2. Materials and methods

2.1. Hunter satisfaction survey

An e-mail invitation to participate in a web-based questionnaire was sent to all grouse hunters (N = 8,129) registered with the two large public agencies “Norwegian State-owned Land and Forest Enterprise” and “The Finnmark Estate” (managing approximately 50% of Norwegian outfields). The questionnaire was available from 25/05/2010 to 01/10/2010, with a reminder e-mail sent 09/09/2010. Of the invitations sent, 256 bounced due to failed delivery and after eliminating 20 responses that were either blank, irrational or foreign, we were left with 3,107 respondents (response rate 40%). We also posted open survey invitations on various Norwegian hunting-related web-sites, and got an additional 186 respondents (an e-mail filter was used to avoid double participation). Because of the low sample size, and because descriptive statistics indicated that the responses did not deviate from those in the e-mail survey, all respondents have been pooled in this study.

The questionnaire contained 26 main questions, of which 14 were attitudinal and 12 were purely descriptive asking for hunter habits and demographic data. The questions ranged from simple closed-option tick boxes and balanced 5-point Likert scales to a majority of complex open-ended what-if-scenarios. The latter was preferred for questions addressing willingness-to-pay as it has been extensively shown that the open-ended answering format may reduce response bias (e.g. Boyle et al. 1985; Mitchell and Carson 1989; Pollicino and Maddison 2001). However, in some cases we were mainly interested in relative changes (e.g., when parameterizing the *shape* of the c_{tkl} function in equation 5), and we then gave a starting value (outlining, e.g., a normal situation worth 1,000 NOK for a week’s hunting, and thereafter asking for willingness-to-pay for increased bag sizes). While this may have given some slight bias, we believe it is less of a negative influence than what could have occurred from a potentially very large spreading of data. Questions that we deemed particularly difficult were addressed twice in two different formats (reverse-keying). The survey questions are described in more detail in Wam et al. 2013.

2.2. Hunter typology classification

We classified the respondents into hunter typologies using latent class analyses (LCA), specifically the cluster analysis package available in Latent GOLD® (version 4.5, Windows XP) (Vermunt and Magidson 2005). Typologies were determined with regard to ‘importance of bag size’, which basically reflects their acceptance for a regulated game hunting (i.e. limiting the yield allowed per hunter, or controlling it indirectly through the number of hunters). To determine which LCA models that best (in terms of parsimony) captured the heterogeneity in the stated preferences of our respondents, we used likelihood-ratio goodness of fit in relation to the degrees of freedom, classification errors as well as BIC_{LL} values. The typology classification is described in more detail in Wam et al. (2012).

2.3. Model framework

Our biosocioeconomic model was developed for the planning of grouse hunting over a fixed period of time on a property with only one decision-maker. We thus assume that the property is large enough for cross-border migration of grouse to be negligible. Consequently, we do not address property right issues related to such movement, which is generally not a prevalent issue for grouse in Scandinavia (dispersal of willow ptarmigan *Lagopus lagopus*, e.g., is approximately 400 m for adults and 4,200 m for juveniles, Brøseth et al. 2005). The basic management issue we are addressing is how to best allocate a given hunting quota between varying numbers of hunters, considering both landowner profit and hunter satisfaction.

The model was built on a matrix framework reflecting different hunting zones, with added functions of density-dependency operating on the hunter satisfaction parameters (i.e. willingness-to-pay indices). The grouse population projection was kept simple with set recruitment rates and the notion that hunting should not reduce next year's density of adult birds (1 year and older). While this simple strategy omits essential biological dynamics, we believe a more complex model (including e.g., weather stochasticity, migration or innate population fluctuations) will mask the socioeconomic aspects that are of main interest here (see also discussion).

In the model, the grouse population is projected at one-year intervals in a modified zone-version of the basic Leslie matrix (Leslie 1945), assuming discrete reproduction and mortality (natural and hunting). The number of individuals is counted after reproduction, immediately before the hunting season commence. No differentiation is made of sex and age of birds, as this to very little extent can be intentionally selected for by grouse hunters in a shooting situation (Hörnell-Willebrand et al. 2006; Bunnefeld et al. 2009, 2011b). The various hunting zones correspond to distinguishable bioeconomic units. They may be set to reflect basic differences in, for example, grouse productivity, infrastructure (roads and cabins), or terrain type (steepness and ruggedness). If G_{tk} is the number of grouse present in zone k at time t, then:

$$\vec{\mathbf{G}}_{t+1,k} = \vec{\mathbf{G}}_{tk} - \vec{\mathbf{S}}_{tk} - \vec{\mathbf{M}}_{tk} + \mathbf{G} \cdot \vec{\mathbf{G}}_{tk} \qquad (1)$$

where $\vec{\mathbf{G}}_{tk}$ is the vector of population zone structure (number of birds per zone k) at time t, $\vec{\mathbf{S}}_{tk}$ is the number of birds shot by the hunters, $\vec{\mathbf{M}}_{tk}$ is the natural mortality and $\mathbf{G}$ is the population projection matrix. The latter is given by:

$$\mathbf{G} = \begin{bmatrix} r_{11} & 0 & \cdots & 0 \\ 0 & r_{21} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & r_{ij} \end{bmatrix} \qquad (2)$$

where r_{ij} is the discrete recruitment rate (number of juveniles observed per adult). Although not included here, $\mathbf{G}$ can easily be expanded to include movement of birds across zones, which may be relevant to other hunting regulations such as the use of refugee areas. Basically, what is available as hunting quotas (q_{tk}) are $r_k \cdot G_{tk}$. Naturally, the number of shot birds can never exceed the hunting quotas, and because we were not interested in temporal population effects in this study, we assume that the quotas are fully utilized ($s_{tk} = q_{tk}$). However, as grouse hunting is more or less additive to other causes of death (Pedersen et al. 2004; Pöysä et al. 2004; Sandercock et al. 2011), the available quotas is delimited with a compensation factor:

$$q_{tk} = c \cdot (r_{tk} \cdot G_{tk}) \text{ , } c = [0, 1] \quad (3)$$

Sale of hunting permits (including accommodation) is the only source of income in the model. The price obtained per permit can, however, be made quite complex through the zone framework. We may, for example, differentiate the zones to accommodate for various hunting packages, such as simple accommodation versus luxurious ‘full package deals’; local versus visiting hunters; or regulating the use of hunting dogs. However, as our main focus in this study is the basic dynamics of bag size, crowding effects and hunter satisfaction, we have kept example scenarios quite simple. The total net profit from grouse hunting (π) on the property throughout the planning period can be summarized as:

$$\pi = \sum_{t=1}^{T} \sum_{k=1}^{K} \sum_{l=1}^{L} \left[p_{tkl} \cdot h_{tkl} - fc_t - hc_{tk} \cdot h_{tkl} \right] \quad (4)$$

where p_{tkl} is the willingness-to-pay of each hunter typology l for their total hunting days in a given zone, and h_{tkl} is the number of hunters of a given hunter typology that is actually hunting in the various zones (also termed the number of permits). The proportional distribution of hunter typologies is fixed and not a variable to be optimized. The number of hunters cannot exceed the number of harvestable grouse, or reach a density higher than 5 km^{-2} (see crowding tolerance, section 2.4 and Table 1). Operating costs for running the property is included with a fixed part (fc_t) that applies even when no permits are sold, and an elastic part (hc_{tk}) that depends on the number of hunters and in which zone they hunt. Because planning periods in grouse management generally are short (5-10 years), we do not take into account discount factors and rate of interest.

We want non-linearity added to our basic profit equation, in order to include more complex density-dependent relationships regarding the hunters’ willingness-to-pay. Of particular interest is the importance of bag size and the tolerance for crowding. For a given hunting quota, both the bag size and the crowding tolerance are determined by the number of permits sold. We therefore expand the price function p_{tkl} in equation 4:

$$p_{tkl} = d_{tkl} \cdot (a_{tkl} + b_{tkl}) / c_{tkl} \quad (5)$$

where d_{tkl} denotes the number of days each hunter normally hunts per season, a_{tkl} is what they on average spend on on-site accommodation (offered by and paid to the landowner), b_{tkl} is a function reflecting the hunters’ willingness-to-pay for the number of birds they bag per day, and c_{tkl} is a function reflecting the effect of crowding. Overall, the price function mimics a classic Beverton-Holt curve (Beverton and Holt 1957), so that the price obtained per sold permit approaches a lower limit when the number of hunters increases.

Our survey data showed that not only the level but also the shape of b_{tkl} varied with hunter typology. We found that second-order polynomials best described this bag-dependent relationship for all three typologies (Table 2), so that:

$$b_{tkl} = \left[\delta_l \cdot \left(q_{tk} / \sum_{l=1}^{L} \left(d_{tkl} \cdot h_{tkl} \right) \right)^2 + \lambda_l \cdot q_{tk} / \sum_{l=1}^{L} \left(d_{tkl} \cdot h_{tkl} \right) + \gamma_l \right] \cdot q_{tk} / \sum_{l=1}^{L} \left(d_{tkl} \cdot h_{tkl} \right),\ q/dh = [0.5, 20] \quad (6)$$

where q/dh denotes the available quotas per hunter-day (birds per hunter per day), which depends on the number of permits that are sold at time t in a given zone k. Because very few, if any, hunters are likely to hunt with a hunting quota of zero, we have a minimum daily bag size (0.5 birds). Likewise, the daily bag size must have an upper limit, and for the purpose of this study it was set at 20 birds.

In the function regulating the effect of crowding:

$$c_{tkl} = 1 + \alpha_l \cdot (o_k \cdot h_{tkl} / km_k^2)^{\beta_l}\ ,\ h / km^2 = \langle 0,5],\ \beta > 0 \quad (7)$$

α and β are constants tailoring the negative effect that increased hunter density (h/km^2) has on the hunters' willingness-to-pay, while o_k is a factor that corrects the hunter density for varying observability (not all hunter groups are actually seen by other hunters, see section 2.4). While a linear or second-order polynomial fitted the crowding function equally good (Table 2), it would involve unnecessarily complex transformation of data to be compatible with the aspired Beverton-Holt framework of the overall price function.

2.4. Model parameterization

Parameter values pertaining to the grouse transition matrix were determined from work on Scandinavian populations of willow ptarmigan: range of recruitment rates and hunter densities from Steen and Erikstad (1996) as well as Hörnell-Willebrand (2005), and range of mortality compensation factors (equation 3) from Sandercock et al. (2011). Range of property sizes and administrative costs were determined based on Andersen et al. (2010). The remaining parameter values (all related to equation 5) were obtained from the survey conducted in this study.

In equation 5, two specific functions of willingness-to-pay needed to be parameterized: 1) the importance of bag size (b_{tkl}); and 2) the effect of crowding (c_{tkl}). The two factors did not interact to have a cumulative effect on the *relative* change in the willingness-to-pay, i.e. the latter was consistently reduced by the same factor when increasing the density of observed hunters, whether the bag was considered satisfying or not (Table 1). We therefore maintain that the two factors could be parameterized separately, and subsequently combined in the full price function.

The bag function (b_{tkl}) could be straightforwardly parameterized from the survey data as we had asked the hunters directly about their willingness-to-pay for a bagged bird given three different yields (low, intermediate and high). The willingness-to-pay per bird was transformed to per day by simply multiplying it with the given bag size. The crowding function (c_{tkl}) was more complicated to parameterize, because we had score indices for three levels of hunter density (low, intermediate, high), but pay data only for two levels (low, intermediate) (Table 1). As it turned out, the two sets showed the same relative change when going from low to intermediate hunter density. We therefore applied the relative change from intermediate to high in the score indices to the pay data (using individual observations, not averages).

In the survey, crowding was addressed by stipulating hunter encounters (0-1, 4-6 and 10+ groups of hunters seen per day). When transforming these into hunter densities we assumed a terrain size of 10 km^2 (making 0.05, 0.50 and 1.00+ hunters seen per day and km^2). The relationship between hunter densities and hunter encounters is likely to vary considerably from terrain to terrain. We estimated ours from 1) the empirical finding that Norwegian ptarmigan hunters walk an average of 16.2 km/day (Brøseth and Pedersen 2000); and 2) the assumption that average visibility in the terrain is 300 m (thus, the average hunter overlooking an area of 9.7 km^2). Typical hunting intensities in Scandinavia are 1-4 hunting days/km^2 (Hörnell-Willebrand 2005). Divided by the average number of ptarmigan hunting days for Norwegian grouse hunters (15 days per hunter per season, this study), these figures correspond to 0.07-0.27 hunters/km^2 accumulated over the season. If all hunters hunt at the same time and are 100% observable to each other (no spatial or temporal distribution), hunter encounters per km^2 would correspond to the actual number of hunters per km^2. However, that is normally not the case, and therefore we included an observability factor o_k in equation 5 (section 2.3).

All statistics pertaining to the model parameterization was carried out in R (version 2.14.2, The R Foundation for Statistical Computing). Central measures are mean ± 1 SE unless stated otherwise.

2.5. Model optimization

Non-linear numerical optimizations of the model were ran in GAMS (distribution 20.7 – Windows NT), with CONOPT2® as the solver (Brooke et al. 1998). As our model property we chose a hypothetical area in central Norway with 10.000 ha (100 km^2) of grouse hunting terrain. Because we were not interested in any temporal effects in this study, the planning period was set to one year only. We took an adjusted scenario-based approach, running the model for a wide array of parameter values (Table 3), but focusing on one parameter at a time in order to deduct its individual effect. We started from a base scenario where parameters, to our best knowledge, resemble the most typically situation encountered in Scandinavia. From the base scenario we rescaled parameters up- and downwards to evaluate their effects on the model output. Our primary objective function was set to maximize the net profit stemming from grouse hunting on the property (equation 4).

3. Results

3.1. Hunter typologies

We identified three distinct hunter typologies: “The Experience Seeker”, “The Bag Oriented” and “The Northern Traditionalist”, who constituted 43, 32 and 25% of the respondents, respectively. Several variable sets gave a significant model fit (Wam et al. 2013). Here we use the model with the lowest classification error (3.8%) and the highest number of indicator variables. Demography, hunting habits and attitudes differed to various extents between the three typologies (Table 1). “The Experience Seeker” and “The Bag Oriented” were somewhat overrepresented by citizens from the southern region of the country, while “The Northern Traditionalist” was more frequent in the north. The latter typology had a lower income than the other two, but spent as much on grouse hunting related activities as the “The Bag Oriented”. However, a lesser part of it would potentially create direct income for grouse hunting properties (i.e. fees and accommodation).

3.2. Hunter satisfaction (willingness-to-pay)

The typologies valued a given bag size markedly different (Figure 1a-c). “The Experience Seeker” and “The Bag Oriented” had similar willingness-to-pay at low bag sizes, but strongly deviated for larger bag sizes. The willingness-to-pay for “The Experience Seeker” then declined, while for “The Bag Oriented” it increased. “The Northern Traditionalist” had a substantially lower willingness-to-pay than the other two typologies, and it was also the least affected by bag size. In contrast, the typologies were very much in agreement concerning crowding: raising the number of observed hunter groups from 0.06 to 0.48/day/km^2 almost halved their willingness-to-pay (Figure 1d, typologies shown collectively because the difference between them was negligible).

Combining the effects of bag size and crowding in the full price function (equations 5-7) produced curves that followed the shape of the crowding function, albeit with stronger differentiation between the hunter typologies. A higher bag size not only increased the differences in willingness-to-pay, but also changed the order of who was willing to pay the least or the most. Although the full price function spatially is of a higher dimension in the model, we present it here in the *xy* space to give a clearer view of the functional relationship between bag size and crowding (Fig. 2).

3.3. Model optimization scenarios

When optimizing the model for the base scenario (Table 3), the hunter density was kept close to the maximum allowed by the minimum daily bag size: 0.40 hunters per km^2. The income generated per permit was then 1,656 NOK, while the overall profit for the 100 km^2 sized property was 391 NOK/km^2. There were nine birds available to each hunter, or an average daily bag size of 0.60 birds (based on the hunters’ typical number of hunting days). Some factors had a stronger influence on the model outcome than others. We will address them in increasing order of importance:

3.3.1. The effect of property size and running costs

The size of the property as well as the fixed administrative costs naturally affected the overall profit, but singly had no bearing on the hunter densities and achieved bag sizes. If we adjusted the fixed administrative costs proportionally to the property size, their effect diminished completely. The hunter densities were more strongly affected by the administrative cost per sold permit. Increasing this cost not only reduced the overall profit (e.g., raising the cost from 50 to 250 NOK lowered the overall profit from 391 to 312 NOK/km^2), but also reduced the hunter density, as the drop in income per permit was partly counteracted by simultaneously reducing the crowding effect (hence, gaining a higher income per permit). However, the hunter density was not reduced until a certain threshold was passed, at which the cost increment exceeded the drop in income. Because the gain of having one less hunter was only about 30 NOK/permit (base scenario, varying with typology), this threshold was quite high (occurring at a permit cost of 603 NOK, base scenario). With a different hunting quota, the threshold shifted, as this also affected the gain per permit when adjusting the hunter density.

3.3.2. The effect of hunting days, accommodation and bag size

Increasing the number of hunting days per hunter had a negative effect on the hunter density, because fewer permits given the restriction of the minimum daily bag size. However, as each hunter then generated more income, the effect on the overall profit was positive, albeit not very large (an increase of, e.g., 50% more hunting days raised the profit from 391 to 444 NOK/km^2).

Altering the payment for accommodation had a more dynamic effect, as it changed not only the profit; the income per permit; and the hunter density, but also the daily bag sizes. The latter two were, however, only affected when the payment for accommodation was strongly reduced (>50% compared to the base scenario). For less strong reductions the potential income from accommodation (i.e. more hunters) was greater than the willingness-to-pay for a higher bag (i.e. fewer hunters), and so, the model kept the hunter density at the maximum allowed set by the minimum daily bag size.

Altering the bag size directly by increasing the hunting quotas strongly influenced the hunter density, and thereby, also the profit. However, the income *per permit* was less affected, as the model increased the hunter density so that the daily bag size remained constant (for moderate quota alterations). Again there were threshold values, above which there was more to gain by rather reducing the hunter density (thereby obtaining a large daily bag size, and a high willingness-to-pay per permit).

The minimum daily bag size was one of the most influential factors in the model. If omitted, the hunter density more than doubled (from 0.40 to 0.88 hunters per km^2). The income per permit then dropped and its source shifted: more of it came from payment for accommodation (62-70%, depending on typology) rather than bagged birds. In the base scenario, accommodation contributed 47-53% of the total income per permit. Conversely, if the minimum daily bag size was raised, the hunter density was correspondingly reduced (to, e.g., 0.10/km^2 if given a bag limit of two birds per day, a typical situation in Norway). The hunters would then pay on average 270 NOK/day, which is substantially higher than in the base scenario (110 NOK/day), but still a little lower than what is the current market situation in Norway (302 NOK/day, Table 1). Selling less permits thus created a substantial gain in hunter satisfaction, as indicated by the income per permit.

3.3.3. The effect of typology mixes and crowding

The income per permit for "The Bag Oriented" was 10% higher than for the "The Experience Seeker" and 31% higher than for the "The Northern Traditionalist". Altering the proportional distribution of hunter typologies affected the daily bag size and the overall profit, but not the hunter density. Having 100% "The Bag Oriented" generated an overall profit that was 17% higher than having 100% "The Experience Seeker" and 60% higher than having 100% "The Northern Traditionalist".

The effect of crowding had a strong influence on the hunter density. Reducing the observability factor made room for more hunters without lowering the hunters' willingness-to-pay (fewer of the hunters would actually be seen by others). However, due to the minimum daily bag size, the hunter density was not affected other than for quite extreme values (the threshold being 83% observability in the base scenario). Consequently, observability had a rather weak effect on the income per permit (and the overall profit). For example, reducing it to 25% raised the income per permit from 1,656 to 1,820 NOK, while increasing it to 75% made the income per permit drop to 1,452 NOK.

4. Discussion

In the optimization runs, the model generally kept the hunter densities at moderate to high levels, thus producing very low bag sizes and substantial crowding. Clearly, the potential in the hunters' willingness-to-pay was not capitalized on; selling a high number of permits for a low price was more advantageous than selling fewer permits for a higher price. This particularly applied to "The Bag Oriented" and "The Northern Traditionalist", who were willing to pay increasingly more for higher bag sizes. Leaving out the density dependent bag- and crowding effects altogether drove the hunter density towards its upper limit. While this simplified scenario void for social constructs produced a very high profit, it practically nullified hunter satisfaction. Very few, if any, grouse hunters would find it acceptable to obtain a daily bag size of <0.1 birds. Therefore, inclusion of social constructs in this study was not only beneficial, but even necessary in order to obtain a realistic model.

4.1. Model framework

Some may find our grouse population projection too simple because of its lack of temporal aspects. However, our model was not intended to function as an applied tool for determining hunting quotas. Like Sandercock et al. (2011), we strongly maintain that for grouse, quotas must be determined from bird counts conducted prior to the start of the hunting season. The annual variation in extrinsic factors influencing grouse production is too high to be sufficiently predicted by a model aimed at applied use. Complex demographic models may have great supplementing value to forecast what-if scenarios (e.g. Aanes et al. 2002), but the usefulness of coupling these with economic optimization is limited.

Nevertheless, inclusion of season is a temporal aspect that could possibly be a valuable expansion of our model. Some parts of the hunting season are more favourable to grouse hunters than others: of the annual hunting days reported in our survey, 52% occurred in September, 29% in October, 11% in November-January and 8% in February-March. Likewise, the willingness-to-pay declined with season. The decline is likely caused by a combination of gradually fewer birds left to hunt; increasingly inclement weather; and fulfilment of the hunting desire. Skonhoft and Gudding (2010), for example, included season in their bioeconomic model for ptarmigan hunting, with 'days' as the unit of time. Unfortunately, for our purpose of study we lack empirical data on the relationship between hunting effort and harvest, which we expect to vary with season (Kastdalen 1992; Hörnell-Willebrand 2005). The inclusion of season must therefore be put on hold until someone establish reliable CPUE (catch per unit of effort) data for Scandinavian grouse hunting.

4.2. Model parameterization

Our model was parameterized from substantial and up-to-date empirical data. Still, our data has its share of weaker elements as well. One of these is the question of how many hunters in a given terrain are actually seen by each other. Hunters are not only separated in space, but also in time. As it turned out, though, our model was only marginally sensitive to the observability factor (o_k), provided the minimum daily bag size (0.5 birds per hunter per day) was included. Because this bag size is rather low compared to what is normally obtained by Scandinavian ptarmigan hunters (e.g., 2.7 in Bröseth and Pedersen 2000; 1.0-4.1 in Hörnell-Willebrand 2005), a model scenario without it obviously is not realistic. Yet, in combination with high grouse productivity (larger quotas), the observability factor will have a key influence. This illustrates well why the aforementioned inclusion of season could be advantageous.

All survey data asking respondents to evaluate imaginary situations are subject to deliberate or unintentional cognitive bias (Liljas and Blumenschein 2000). One traditional way to mitigate such bias is to repeat the same question with a different phrasing, which we did in our survey. While the actual gain from applying such follow-up questioning may be less than aspired (Herriges and Shogren 1996), at least it serves to elucidate the scope of the bias. Our survey data had one noticeable discrepancy revealed by follow-up questioning: when asked directly *at what bag sizes* the willingness-to-pay per bird would level out, the hunters stated an average of six birds per day. When asked *how much* they would pay per bird given various bag sizes, however, their prices still slightly increased (or decreased) when going from 8-10 to 15-20 birds. This also illustrates how question formulation may shape the response. By stipulating three levels of bag size, we made the respondents automatically consider the second alternative to be of intermediate value.

Apparently, there is room for improvement in our formulation of questions *if* our sole purpose had been to establish the most realistic willingness-to-pay functions. One such improvement would be to include more than three bag size levels. We needed, however, to cover a broad range of topics (demography, habits and attitudes), and as respondent patience is limited, some lack of precision had to give. Accordingly, our willingness-to-pay data are best viewed as an index of relative hunter satisfaction rather than the actual price elasticity for Scandinavian grouse hunting. Assuming that willingness-to-pay reflects satisfaction is not without its pitfalls either, but this is an unavoidable inadequacy we have to accept when attempting to put monetary terms on people's non-material preferences (Wam 2010).

4.3. Applied relevance and conclusion

Our study has applied implications for the decision-making process of natural resource management. Typically, this process involves balancing the views and aspirations of multiple stakeholders and, in our case, even diverse segments within a stakeholder group. The number of alternative management strategies quickly rises in such settings, and it becomes difficult to determine a single best policy (e.g., Sainsbury et al. 2000; Mapstone et al. 2007). The use of management strategy evaluation methods ('MSE', Smith 1994) is therefore slowly driving the objectives of complex management away from 'optimality' and towards 'adequacy, robustness and feasibility' (Bunnefeld et al. 2011a).

The competing optimal strategies identified in our study confirm that this shift may be a good thing: optimizing one single quantitative measure such as net profit, and including a few nonmonetary restrictions such as adhering to the biological sustainable yield ('MSY'), is not enough to keep game management sustainable. Frustrated hunters will most likely abandon hunting as an activity, or start overstepping rules and regulations. Inclusion of metrics of individual or social matter must therefore be given a key driving role in the modelling of sustainable game management (and its subsequent practical implementation).

In conclusion; our study illustrates how biosocioeconomic modelling can be a valuable tool in the pursuit of sustainable game management. In the case of grouse hunting, it shows that the optimal course for the landowner may largely be at the expense of hunter satisfaction, even when the latter is positively related to the price obtained per sold permit. On a general note, this emphasizes the need to incorporate less traditional elements such as behavioural, psychological and social aspects into the more traditional bioeconomic modelling.

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Table 1. Demography, hunting habits and attitudes among three grouse hunter typologies in Norway (based on a survey conducted in 2010, *N*=3,293 respondents). Typologies were classified with latent class analysis (Latent GOLD®, cluster package). Note that the typologies may not significantly differ for all listed variables, and that not all significant variables are included here (* = part of the most parsimonious LCA model). NOK ≈ €0.125.

	"The Experience Seeker"	**"The Bag Oriented"**	**"The Northern Traditionalist"**
Percent of respondents	43%	32%	25%
Place of living [a]			
Southern Norway	61%	60%	45%
Northern Norway	39%	40%	55%
Personal gross income (per year)	507' NOK	498' NOK	470' NOK
*Ptarmigan hunting days/year (current)	12.4	15.1	17.5
Total hunting related spending (per year)	10.550 NOK	11.825 NOK	11.692 NOK
Spending on hunting permits (per day)	245 NOK	250 NOK	188 NOK
Spending on accommodation (per day)	89 NOK	86 NOK	65 NOK
Crowding tolerance [b]			
If seeing 1-2 hunter groups/day	2.26	2.37	2.36
If seeing 5-6 hunter groups/day	3.41 (-51%)	3.44 (-46%)	3.38 (-43%)
If seeing 10+ hunter groups/day	4.09 (-81%)	4.04 (-70%)	3.91 (-67%)
Willingness-to-pay for a one week's permit [c]			
If seeing 1-2 hunters (bag satisfying)	2,045 NOK	2,020 NOK	1,810 NOK
If seeing 5-6 hunters (bag satisfying)	1,144 (-44%)	1,093 (-46%)	1,029 (-43%)
If seeing 1-2 hunters (bag *not* satisfying)	1,426 NOK	1,259 NOK	1,240 NOK
If seeing 5-6 hunters (bag *not* satisfying)	789 (-45%)	678 (-46%)	688 (-45%)
*Willingness-to-pay per bagged bird [d]			
If bagging 1-3 birds/day	90 NOK	91 NOK	58 NOK
If bagging 8-10 birds/day	57 (-37%)	118 (+30%)	64 (+10%)
If bagging 15-20 birds/day	40 (-56%)	124 (+37%)	67 (+16%)

[a] Northern region = Nordland, Troms and Finnmark. Southern region = remaining counties.

[b] 1-5 scale, where 1=acceptable and 5=not acceptable. Percentages refer to going from the lowest to the two higher densities.

[c] Percentages refer to going from the lower to the higher hunter density for a given bag satisfaction.

[d] Not including lodging etc. We omitted answers >300 NOK, as we presumed these were given per day not per bird (*N*=157).

Table 2. Model goodness-of-fit for estimated willingness-to-pay for ptarmigan hunting as a function of bag size and crowding, respectively, among three hunter typologies : "The Experienced Seeker" (ES), "The Bag Oriented" (BO) and "The Northern Traditionalist" (NT). Based on a survey conducted in Norway 2010 (N=3,293 respondents).

	Model	F_{dfe}	$r^{2\ a}$	*p-value*
Willingness-to-pay in relation to bag size	Linear model $y = \beta 1+\beta 2\cdot x$			
	ES: $99.6 – 3.52\cdot x$	$598_{2,868}$	0.172	<0.001
	BO: $86.0 + 3.03\cdot x$	$184_{1,177}$	0.135	<0.001
	NT: $59.0 + 0.51\cdot x$	$7.8_{1,775}$	0.004	0.005
	Second-order polynomial $y = \beta 1+\beta 2\cdot x+\beta 3\cdot x^2$			
	ES: $112.6 – 7.92\cdot x + 0.22\cdot x^2$	$328_{2,867}$	0.186	<0.001
	BO: $75.1 + 7.36\cdot x – 0.28\cdot x^2$	$106_{1,176}$	0.151	<0.001
	NT: $57.8 + 0.91\cdot x – 0.02\cdot x^2$	$4_{1,774}$	0.004	0.018
	Michaelis Menten $y = \beta 1\cdot x /(\beta 1+x)$			
	ES: $45.3\cdot x / (-1.07 +x)$	$45_{2,867}$	0.175	<0.001
	BO: $140\cdot x / (1.17 +x)$	$1_{1,176}$	0.152	0.397
	NT: $67.7\cdot x / (0.28 +x)$	$1_{1,774}$	0.006	0.419
Willingness-to-pay in relation to crowding	Linear model $y = \beta 1+\beta 2\cdot x$			
	ES: $2,060-1,582\cdot x$	$767_{2,092}$	0.268	<0.001
	BO: $2,009-1,548\cdot x$	$494_{1,445}$	0.255	<0.001
	NT: $1,840-1,409\cdot x$	$387_{1,210}$	0.242	<0.001
	Second-order polynomial $y = \beta 1+\beta 2\cdot x+\beta 3\cdot x^2$			
	ES: $2,208 – 2,705\cdot x+ 1,022\cdot x^2$	$400_{2,091}$	0.276	<0.001
	BO: $2,173 – 2,805\cdot x+ 1,144\cdot x^2$	$260_{1,444}$	0.264	<0.001
	NT: $1,961 – 2,333\cdot x+ 840\cdot x^2$	$200_{1,209}$	0.248	<0.001
	Sigmoid function[a] $y = \beta 1/(1+ \beta 2\cdot x^{\beta 3})$			
	ES: $2,093 / (1 + 4.3 \cdot x^{2.2})$	$12_{2,091}$	0.276	<0.001
	BO: $2,048 / (1 + 2.4 \cdot x^{1.4})$	$5_{1,444}$	0.168	0.032
	NT: $1,833 / (1 + 2.2 \cdot x^{1.5})$	$6_{1,209}$	0.171	0.015

[a] Note that the r^2 value may not be fully comparable between linear and nonlinear regression models (Cameron and Windmeijer 1997).

Table 3. Parameter sensitivity in a biosocioeconomic model for optimizing the number of ptarmigan hunting permits, with an objective function to maximize annual landowner profit. Only one parameter was re-scaled at a time. The numbers below shaded areas are the model output (same as those given in the last row). Based on a survey conducted in 2010 with N=3,293 respondents.

Parameter	**Base scenario**	**Re-scaled scenarios**			
		I	**II**	**III**	**IV**
Property size	100 km^2	10	50	250	1,000
		0.40; 9 (0.6);	0.40; 9 (0.6);	0.40; 9 (0.6);	0.40; 9 (0.6);
		1,657; -1,862	1,656; 139	1,657; 539	1,657; 614
fc_t (fixed administrative cost)	25,000 NOK	0	2,500	50,000	100,000
		0.40; 9 (0.6);	0.40; 9 (0.6);	0.40; 9 (0.6);	0.40; 9 (0.6);
		1,656; 639	1,656; 614	1,656; 139	1,656; -361
hc_{tk} (costs added per permit)	50 NOK	0	25	250	1,000
		0.40; 9 (0.6);	0.40; 9 (0.6);	0.40; 9 (0.6);	0.12; 29 (2.0);
		1,656; 411	1,656; 400	1,656; 312	3,552; 59
a_{tkl} (accommodation per day)	see Table 1	0	-50%	+100%	+500%
		0.39; 9 (0.6);	0.40; 9 (0.6);	0.40; 9 (0.6);	0.40; 9 (0.6);
		906; 84	1,149; 189	2.679; 799	6,773; 2,437
d_{tkl} (number of days hunted)	see Table 1	-75%	-50%	+50%	+100%
		0.36; 10 (2.7);	0.66; 5 (0.7);	0.27; 13 (0.7);	0.20; 18 (0.6);
		1,004; 90	758; 212	2,660; 444	3,632; 468
q_{tk} (total hunting quota)	3.5 birds/km^2	0.5	1.5	7.5	15.0
		0.06; 9 (0.6);	0.17; 9 (0.6);	0.68; 11 (0.8);	0.41; 36 (2.5);
		1,888; -143	1,837; 57	1,506; 735	3,664; 1,241
Minimum bag/hunter/day	0.50	0.00	1.00	2.00	5.00
		0.88; 4 (0.28);	0.20; 18 (1.2);	0.10; 35 (2.4);	0.04; 88 (6.0);
		927; 514	2,519; 243	4,056; 152	8,452; 95
o_k (observability)	50%	0%	25%	75%	100%
		0.40; 9 (0.6);	0.40; 9 (0.6);	0.40; 9 (0.6);	0.35; 10 (0.7);
		1,896; 487	1,820; 457	1,452; 310	1,420; 228
Density dependent effects	see Fig. 1 and 2	No bag effect[a]	No bag/crowd[a]	No bag/crowd[b]	
		0.40; 9 (0.6);	0.40; 9 (0.6);	3.50; 1.0 (0.1);	
		1,661; 393	1,903; 489	1,264; 3.976	
% hunter typologies[c]	see Table 1	100; 0; 0	0; 100; 0	0; 0; 100	
		0.40; 9 (0.7);	0.40; 9 (0.6);	0.40; 9 (0.5);	
		1,668; 397	1,839; 464	1,402; 290	
Number of hunters/km^2	0.40				
Bag size/hunter (per day)	9 (0.6)				
Gross income per permit	1,656 NOK				
Overall profit per km^2	391 NOK				

[a] Assuming a fixed willingness-to-pay per bird, not varying with bag size, and equalling the one stated for 1-3 birds/day (see Table 1).

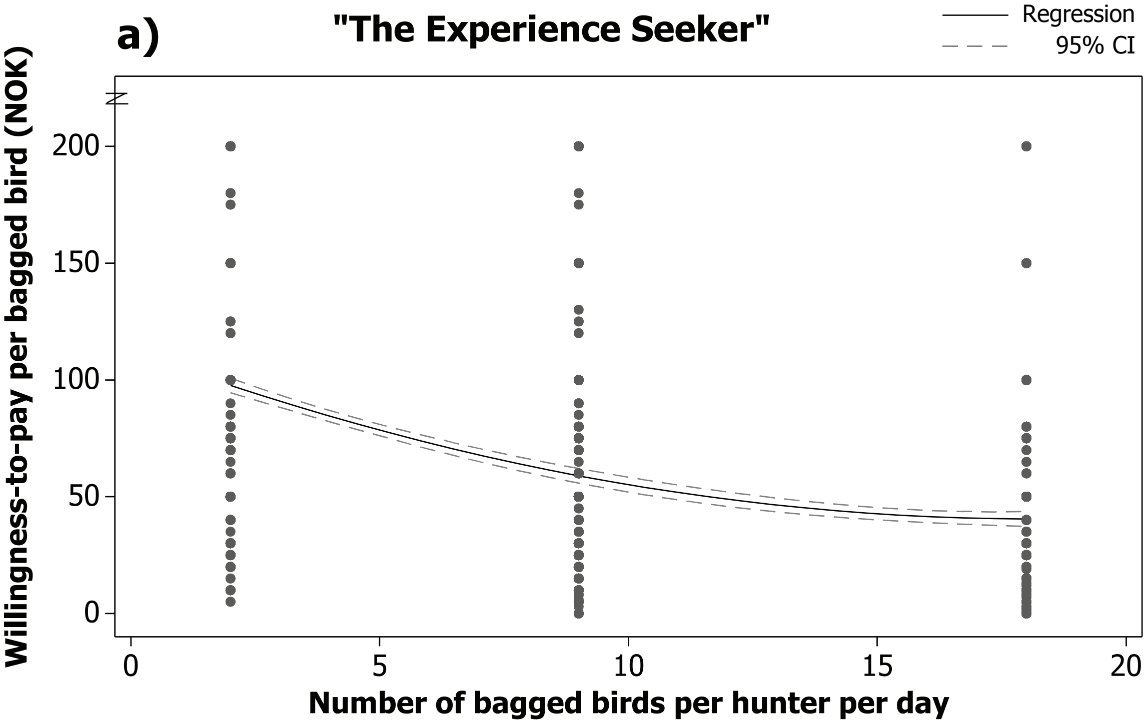
[b] As for footnote[a], but in addition, leaving out the lower limit on daily bag size.

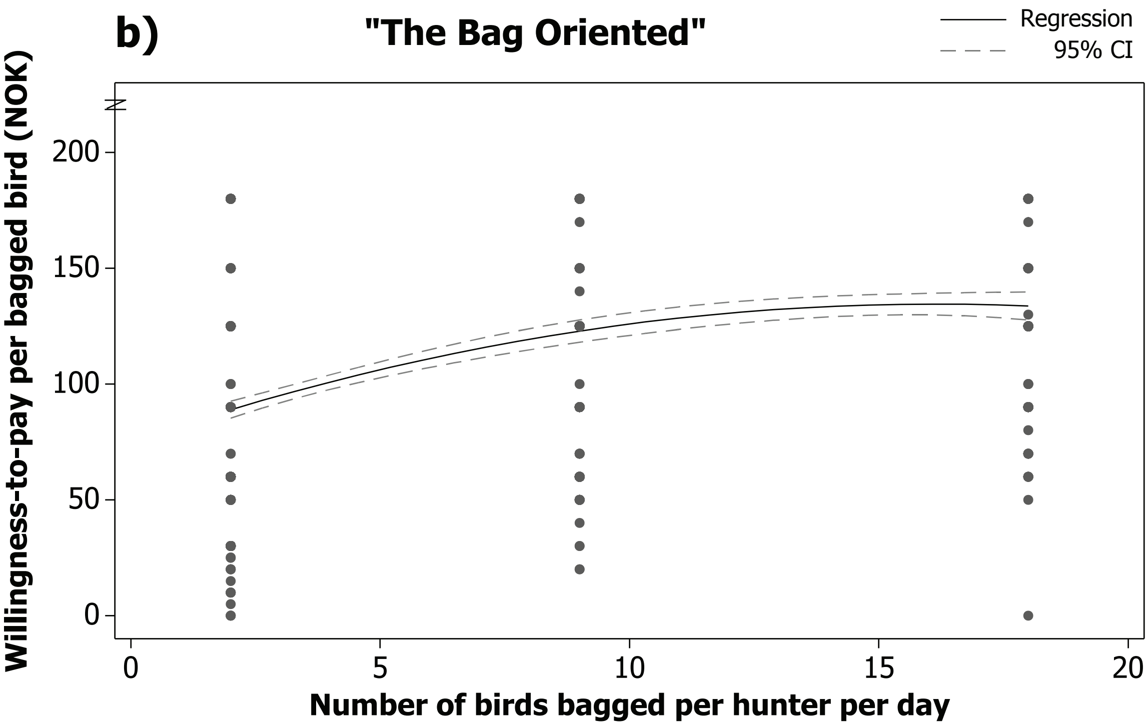
[c] "The Experience Seeker"," The Bag Oriented" and "The Northern Traditionalist", respectively.

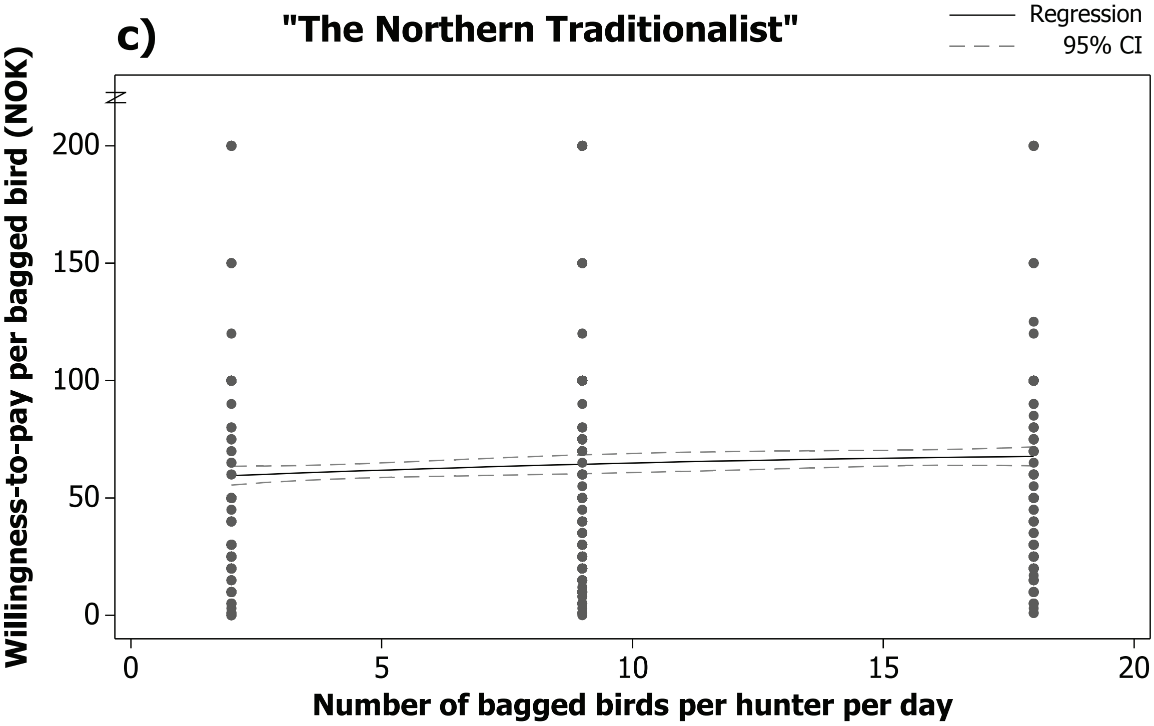
Figure 1a-d. Willingness-to-pay for **(a-c)** a bagged ptarmigan given various yields, or **(d)** a week's hunting given various levels of crowding, among different typologies of Norwegian grouse hunters. Based on a survey conducted in 2010 with *N*=3,293 respondents.

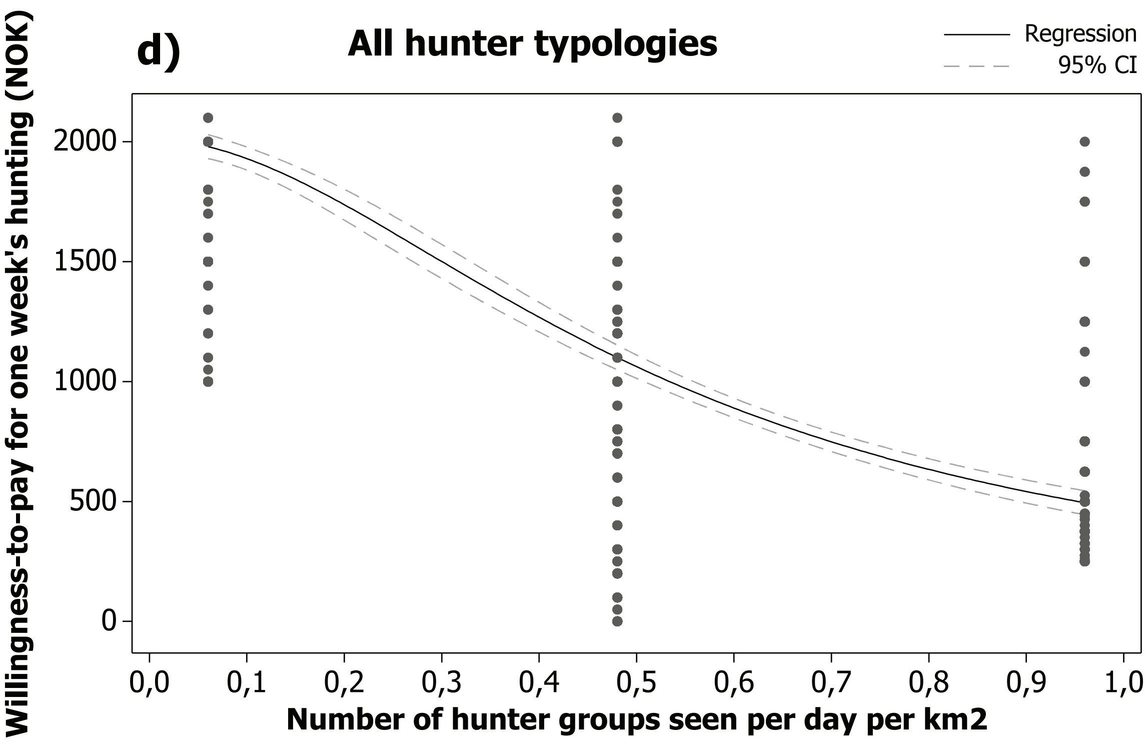
Figure 2. Norwegian grouse hunters' total willingness-to-pay for their normal number of ptarmigan hunting days throughout the season in relation to crowding, given they obtain **(a)** low yields (1 ptarmigan/day); and **(b)** higher yields (5 ptarmigans/day), and assuming an hunter observability of 25% (i.e. every fourth hunter is actually seen by others). Based on a survey conducted in 2010 with *N*=3,293 respondents.

- We present a biosocioeconomic model targeted at grouse hunting management.
- Omitting social constructs from the model multiplied landowner profit...
- …but practically nullified hunter satisfaction.
- Integrated multidisciplinary models are needed to keep game management sustainable.

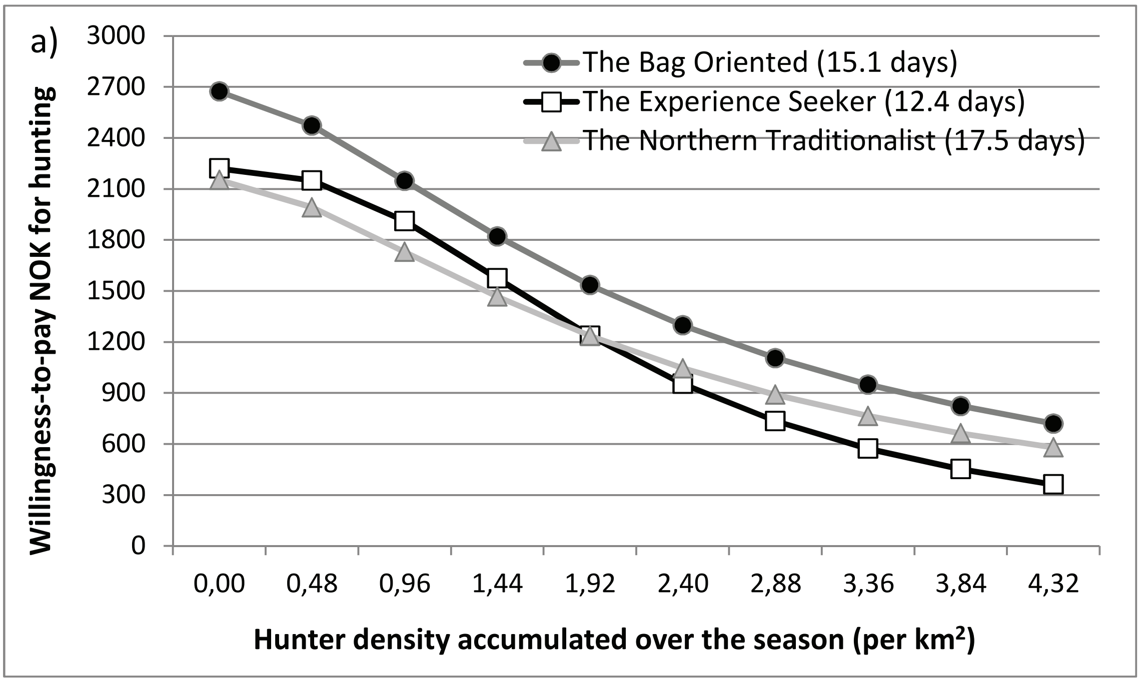

a)
"The Experience Seeker"
Regression
95% CI
Willingness-to-pay per bagged bird (NOK)
200
150
100
50
0
0
5
10
15
20
Number of bagged birds per hunter per day


b)
"The Bag Oriented"
Regression
95% CI
Willingness-to-pay per bagged bird (NOK)
200
150
100
50
0
0
5
10
15
20
Number of birds bagged per hunter per day

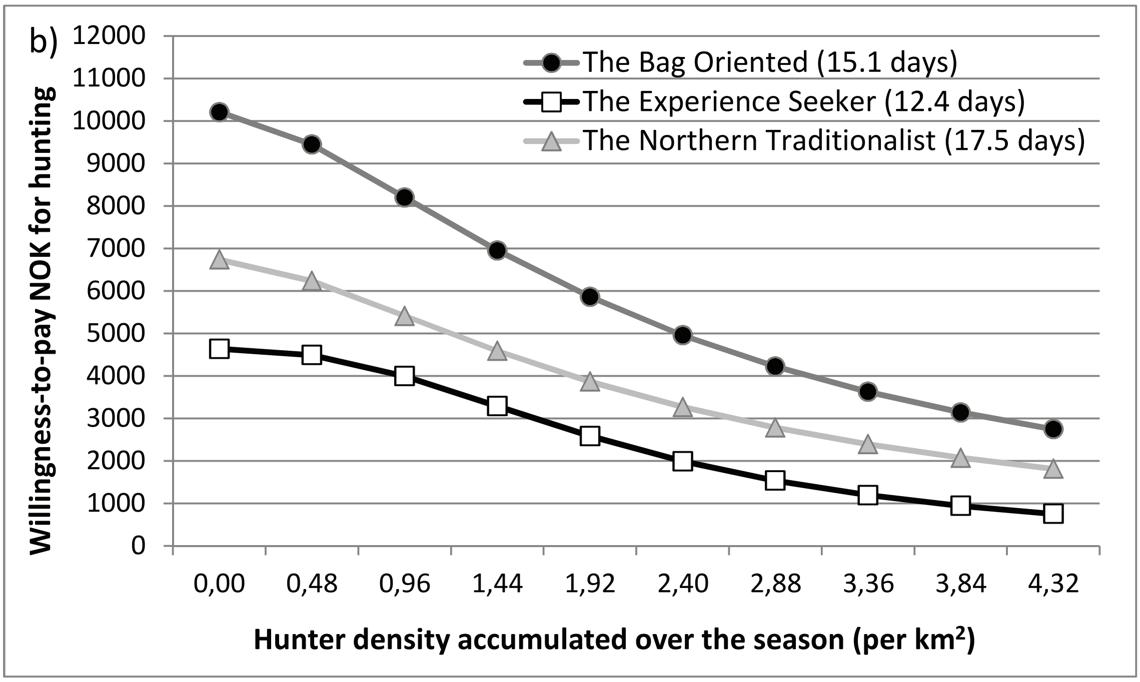

c)
"The Northern Traditionalist"
Regression
95% CI
Willingness-to-pay per bagged bird (NOK)
200
150
100
50
0
0
5
10
15
20
Number of bagged birds per hunter per day



d)
All hunter typologies
Regression
95% CI
Willingness-to-pay for one week's hunting (NOK)
2000
1500
1000
500
0
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1,0
Number of hunter groups seen per day per km2



a)
The Bag Oriented (15.1 days)
The Experience Seeker (12.4 days)
The Northern Traditionalist (17.5 days)
Willingness-to-pay NOK for hunting
3000
2700
2400
2100
1800
1500
1200
900
600
300
0
0,00
0,48
0,96
1,44
1,92
2,40
2,88
3,36
3,84
4,32
Hunter density accumulated over the season (per km²)


b)
The Bag Oriented (15.1 days)
The Experience Seeker (12.4 days)
The Northern Traditionalist (17.5 days)
Willingness-to-pay NOK for hunting
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
0,00
0,48
0,96
1,44
1,92
2,40
2,88
3,36
3,84
4,32
Hunter density accumulated over the season (per km²)