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

4  
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16

17 **Abstract:**

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26 permit generally superseded the loss in hunter satisfaction (expressed as willingness-to-pay).  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

30

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

32

33 **1. Introduction**

34 Around the globe, populations of game species cause concern for being either overabundant (e.g.,  
35 moose: Serrouya et al. 2011; deer: Warren 2011) or declining (e.g., grouse: Storch 2007; caribou:  
36 Wittmer et al. 2005). To decide on the right action, managers normally depend on the engagement and  
37 goodwill of hunters. While hunting regulations are instrumental in keeping game populations within  
38 sustainable frames, we also need satisfied hunters in order to maintain hunting as an activity of the  
39 future (Heberlein and Kuentzel 2002; Schroeder et al. 2006). Additionally, hunting revenues may

40 constitute a substantial part of rural economy (Sharp and Wollscheid 2009), and as such presents yet  
41 another reason for managers to take hunter satisfaction into account.

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

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

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

77

78 **2. Materials and methods**

## 79 **2.1. Hunter satisfaction survey**

80 An e-mail invitation to participate in a web-based questionnaire was sent to all grouse hunters ( $N =$   
 81 8,129) registered with the two large public agencies “Norwegian State-owned Land and Forest  
 82 Enterprise” and “The Finnmark Estate” (managing approximately 50% of Norwegian outfields). The  
 83 questionnaire was available from 25/05/2010 to 01/10/2010, with a reminder e-mail sent 09/09/2010.  
 84 Of the invitations sent, 256 bounced due to failed delivery and after eliminating 20 responses that  
 85 were either blank, irrational or foreign, we were left with 3,107 respondents (response rate 40%). We  
 86 also posted open survey invitations on various Norwegian hunting-related web-sites, and got an  
 87 additional 186 respondents (an e-mail filter was used to avoid double participation). Because of the  
 88 low sample size, and because descriptive statistics indicated that the responses did not deviate from  
 89 those in the e-mail survey, all respondents have been pooled in this study.

90 The questionnaire contained 26 main questions, of which 14 were attitudinal and 12 were purely  
 91 descriptive asking for hunter habits and demographic data. The questions ranged from simple closed-  
 92 option tick boxes and balanced 5-point Likert scales to a majority of complex open-ended what-if-  
 93 scenarios. The latter was preferred for questions addressing willingness-to-pay as it has been  
 94 extensively shown that the open-ended answering format may reduce response bias (e.g. Boyle et al.  
 95 1985; Mitchell and Carson 1989; Pollicino and Maddison 2001). However, in some cases we were  
 96 mainly interested in relative changes (e.g., when parameterizing the *shape* of the  $c_{ikl}$  function in  
 97 equation 5), and we then gave a starting value (outlining, e.g., a normal situation worth 1,000 NOK  
 98 for a week’s hunting, and thereafter asking for willingness-to-pay for increased bag sizes). While this  
 99 may have given some slight bias, we believe it is less of a negative influence than what could have  
 100 occurred from a potentially very large spreading of data. Questions that we deemed particularly  
 101 difficult were addressed twice in two different formats (reverse-keying). The survey questions are  
 102 described in more detail in Wam et al. 2013.

103

## 104 **2.2. Hunter typology classification**

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

114

## 115 **2.3. Model framework**

116 Our biosocioeconomic model was developed for the planning of grouse hunting over a fixed period of  
 117 time on a property with only one decision-maker. We thus assume that the property is large enough

118 for cross-border migration of grouse to be negligible. Consequently, we do not address property right  
 119 issues related to such movement, which is generally not a prevalent issue for grouse in Scandinavia  
 120 (dispersal of willow ptarmigan *Lagopus lagopus*, e.g., is approximately 400 m for adults and 4,200 m  
 121 for juveniles, Brøseth et al. 2005). The basic management issue we are addressing is how to best  
 122 allocate a given hunting quota between varying numbers of hunters, considering both landowner  
 123 profit and hunter satisfaction.

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

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

140

$$141 \quad \vec{G}_{t+1,k} = \vec{G}_{tk} - \vec{S}_{tk} - \vec{M}_{tk} + \mathbf{G} \cdot \vec{G}_{tk} \quad (1)$$

142

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

146

$$147 \quad \mathbf{G} = \begin{bmatrix} r_{11} & 0 & \cdots & 0 \\ 0 & r_{21} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & r_{ij} \end{bmatrix} \quad (2)$$

148

149 where  $r_{ij}$  is the discrete recruitment rate (number of juveniles observed per adult). Although not  
 150 included here,  $\mathbf{G}$  can easily be expanded to include movement of birds across zones, which may be  
 151 relevant to other hunting regulations such as the use of refugee areas. Basically, what is available as  
 152 hunting quotas ( $q_{tk}$ ) are  $r_k \cdot G_{tk}$ . Naturally, the number of shot birds can never exceed the hunting

153 quotas, and because we were not interested in temporal population effects in this study, we assume  
 154 that the quotas are fully utilized ( $s_{tk} = q_{tk}$ ). However, as grouse hunting is more or less additive to  
 155 other causes of death (Pedersen et al. 2004; Pöysä et al. 2004; Sandercock et al. 2011), the available  
 156 quotas is delimited with a compensation factor:

$$157$$

$$158 \quad q_{tk} = c \cdot (r_{tk} \cdot G_{tk}), \quad c = [0, 1] \quad (3)$$

159

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

$$168$$

$$169 \quad \pi = \sum_{t=1}^T \sum_{k=1}^K \sum_{l=1}^L [p_{tkl} \cdot h_{tkl} - fc_t - hc_{tk} \cdot h_{tkl}] \quad (4)$$

170

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

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

$$185$$

$$186 \quad p_{tkl} = d_{tkl} \cdot (a_{tkl} + b_{tkl}) / c_{tkl} \quad (5)$$

187

188 where  $d_{tkl}$  denotes the number of days each hunter normally hunts per season,  $a_{tkl}$  is what they on  
 189 average spend on on-site accommodation (offered by and paid to the landowner),  $b_{tkl}$  is a function  
 190 reflecting the hunters’ willingness-to-pay for the number of birds they bag per day, and  $c_{tkl}$  is a

191 function reflecting the effect of crowding. Overall, the price function mimics a classic Beverton-Holt  
 192 curve (Beverton and Holt 1957), so that the price obtained per sold permit approaches a lower limit  
 193 when the number of hunters increases.

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

197

$$198 \quad b_{tkl} = \left[ \delta_l \cdot \left( q_{tk} / \sum_{l=1}^L (d_{tkl} \cdot h_{tkl}) \right)^2 + \lambda_l \cdot q_{tk} / \sum_{l=1}^L (d_{tkl} \cdot h_{tkl}) + \gamma_l \right] \cdot q_{tk} / \sum_{l=1}^L (d_{tkl} \cdot h_{tkl}), \quad q/dh = [0.5, 20] \quad (6)$$

199

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

204 In the function regulating the effect of crowding:

205

$$206 \quad c_{tkl} = 1 + \alpha_l \cdot (o_k \cdot h_{tkl} / km_k^2)^{\beta_l}, \quad h / km^2 = \langle 0, 5 \rangle, \quad \beta > 0 \quad (7)$$

207

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

214

#### 215 **2.4. Model parameterization**

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

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

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

237 In the survey, crowding was addressed by stipulating hunter encounters (0-1, 4-6 and 10+ groups  
 238 of hunters seen per day). When transforming these into hunter densities we assumed a terrain size of  
 239 10 km<sup>2</sup> (making 0.05, 0.50 and 1.00+ hunters seen per day and km<sup>2</sup>). The relationship between hunter  
 240 densities and hunter encounters is likely to vary considerably from terrain to terrain. We estimated  
 241 ours from 1) the empirical finding that Norwegian ptarmigan hunters walk an average of 16.2 km/day  
 242 (Brøseth and Pedersen 2000); and 2) the assumption that average visibility in the terrain is 300 m  
 243 (thus, the average hunter overlooking an area of 9.7 km<sup>2</sup>). Typical hunting intensities in Scandinavia  
 244 are 1-4 hunting days/km<sup>2</sup> (Hörnell-Willebrand 2005). Divided by the average number of ptarmigan  
 245 hunting days for Norwegian grouse hunters (15 days per hunter per season, this study), these figures  
 246 correspond to 0.07-0.27 hunters/km<sup>2</sup> accumulated over the season. If all hunters hunt at the same time  
 247 and are 100% observable to each other (no spatial or temporal distribution), hunter encounters per km<sup>2</sup>  
 248 would correspond to the actual number of hunters per km<sup>2</sup>. However, that is normally not the case,  
 249 and therefore we included an observability factor  $o_k$  in equation 5 (section 2.3).

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

252

## 253 **2.5. Model optimization**

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

264

## 265 **3. Results**

### 266 **3.1. Hunter typologies**



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

277

### 278 **3.2. Hunter satisfaction (willingness-to-pay)**

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

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

293

### 294 **3.3. Model optimization scenarios**

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

301

#### 302 **3.3.1. The effect of property size and running costs**

303 The size of the property as well as the fixed administrative costs naturally affected the overall profit,  
 304 but singly had no bearing on the hunter densities and achieved bag sizes. If we adjusted the fixed  
 305 administrative costs proportionally to the property size, their effect diminished completely. The hunter

306 densities were more strongly affected by the administrative cost per sold permit. Increasing this cost  
 307 not only reduced the overall profit (e.g., raising the cost from 50 to 250 NOK lowered the overall  
 308 profit from 391 to 312 NOK/km<sup>2</sup>), but also reduced the hunter density, as the drop in income per  
 309 permit was partly counteracted by simultaneously reducing the crowding effect (hence, gaining a  
 310 higher income per permit). However, the hunter density was not reduced until a certain threshold was  
 311 passed, at which the cost increment exceeded the drop in income. Because the gain of having one less  
 312 hunter was only about 30 NOK/permit (base scenario, varying with typology), this threshold was  
 313 quite high (occurring at a permit cost of 603 NOK, base scenario). With a different hunting quota, the  
 314 threshold shifted, as this also affected the gain per permit when adjusting the hunter density.

315

### 316 *3.3.2. The effect of hunting days, accommodation and bag size*

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

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

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

333 The minimum daily bag size was one of the most influential factors in the model. If omitted, the  
 334 hunter density more than doubled (from 0.40 to 0.88 hunters per km<sup>2</sup>). The income per permit then  
 335 dropped and its source shifted: more of it came from payment for accommodation (62-70%,  
 336 depending on typology) rather than bagged birds. In the base scenario, accommodation contributed  
 337 47-53% of the total income per permit. Conversely, if the minimum daily bag size was raised, the  
 338 hunter density was correspondingly reduced (to, e.g., 0.10/km<sup>2</sup> if given a bag limit of two birds per  
 339 day, a typical situation in Norway). The hunters would then pay on average 270 NOK/day, which is  
 340 substantially higher than in the base scenario (110 NOK/day), but still a little lower than what is the  
 341 current market situation in Norway (302 NOK/day, Table 1). Selling less permits thus created a  
 342 substantial gain in hunter satisfaction, as indicated by the income per permit.

343

### 344 *3.3.3. The effect of typology mixes and crowding*

345 The income per permit for “The Bag Oriented” was 10% higher than for the “The Experience Seeker”  
346 and 31% higher than for the “The Northern Traditionalist”. Altering the proportional distribution of  
347 hunter typologies affected the daily bag size and the overall profit, but not the hunter density. Having  
348 100% “The Bag Oriented” generated an overall profit that was 17% higher than having 100% “The  
349 Experience Seeker” and 60% higher than having 100% “The Northern Traditionalist”.

350 The effect of crowding had a strong influence on the hunter density. Reducing the observability  
351 factor made room for more hunters without lowering the hunters’ willingness-to-pay (fewer of the  
352 hunters would actually be seen by others). However, due to the minimum daily bag size, the hunter  
353 density was not affected other than for quite extreme values (the threshold being 83% observability in  
354 the base scenario). Consequently, observability had a rather weak effect on the income per permit  
355 (and the overall profit). For example, reducing it to 25% raised the income per permit from 1,656 to  
356 1,820 NOK, while increasing it to 75% made the income per permit drop to 1,452 NOK.

357

#### 358 **4. Discussion**

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

369

##### 370 **4.1. Model framework**

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

378 Nevertheless, inclusion of season is a temporal aspect that could possibly be a valuable expansion  
379 of our model. Some parts of the hunting season are more favourable to grouse hunters than others: of  
380 the annual hunting days reported in our survey, 52% occurred in September, 29% in October, 11% in  
381 November-January and 8% in February-March. Likewise, the willingness-to-pay declined with  
382 season. The decline is likely caused by a combination of gradually fewer birds left to hunt;  
383 increasingly inclement weather; and fulfilment of the hunting desire. Skonhøft and Gudding (2010),

384 for example, included season in their bioeconomic model for ptarmigan hunting, with ‘days’ as the  
 385 unit of time. Unfortunately, for our purpose of study we lack empirical data on the relationship  
 386 between hunting effort and harvest, which we expect to vary with season (Kastdalen 1992; Hörnell-  
 387 Willebrand 2005). The inclusion of season must therefore be put on hold until someone establish  
 388 reliable CPUE (catch per unit of effort) data for Scandinavian grouse hunting.

389

#### 390 **4.2. Model parameterization**

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

401 All survey data asking respondents to evaluate imaginary situations are subject to deliberate or  
 402 unintentional cognitive bias (Liljas and Blumenschein 2000). One traditional way to mitigate such  
 403 bias is to repeat the same question with a different phrasing, which we did in our survey. While the  
 404 actual gain from applying such follow-up questioning may be less than aspired (Herriges and Shogren  
 405 1996), at least it serves to elucidate the scope of the bias. Our survey data had one noticeable  
 406 discrepancy revealed by follow-up questioning: when asked directly *at what bag sizes* the willingness-  
 407 to-pay per bird would level out, the hunters stated an average of six birds per day. When asked *how*  
 408 *much* they would pay per bird given various bag sizes, however, their prices still slightly increased (or  
 409 decreased) when going from 8-10 to 15-20 birds. This also illustrates how question formulation may  
 410 shape the response. By stipulating three levels of bag size, we made the respondents automatically  
 411 consider the second alternative to be of intermediate value.

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

421

#### 422 **4.3. Applied relevance and conclusion**

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

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

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

443

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448

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- 572

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

	“The Experience Seeker”	“The Bag Oriented”	“The Northern Traditionalist”
Percent of respondents	43%	32%	25%
Place of living <sup>a</sup>			
Southern Norway	61%	60%	45%
Northern Norway	39%	40%	55%
Personal gross income (per year)	507 <sup>b</sup> NOK	498 <sup>b</sup> NOK	470 <sup>b</sup> 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 <sup>b</sup>			
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 <sup>c</sup>			
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 <i>not</i> satisfying)	1,426 NOK	1,259 NOK	1,240 NOK
If seeing 5-6 hunters (bag <i>not</i> satisfying)	789 (-45%)	678 (-46%)	688 (-45%)
*Willingness-to-pay per bagged bird <sup>d</sup>			
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%)

<sup>a</sup> Northern region = Nordland, Troms and Finnmark. Southern region = remaining counties.

<sup>b</sup> 1-5 scale, where 1=acceptable and 5=not acceptable. Percentages refer to going from the lowest to the two higher densities.

<sup>c</sup> Percentages refer to going from the lower to the higher hunter density for a given bag satisfaction.

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

579 **Table 2.** Model goodness-of-fit for estimated willingness-to-pay for ptarmigan hunting as a function  
 580 of bag size and crowding, respectively, among three hunter typologies : “The Experienced Seeker”  
 581 (ES), “The Bag Oriented” (BO) and “The Northern Traditionalist” (NT). Based on a survey conducted  
 582 in Norway 2010 ( $N=3,293$  respondents).  
 583

Model	$F_{dfe}$	$r^2$ <sup>a</sup>	$p$ -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 <sub>2,868</sub>	0.172	<0.001
	BO: $86.0 + 3.03 \cdot x$	184 <sub>1,177</sub>	0.135	<0.001
	NT: $59.0 + 0.51 \cdot x$	7.8 <sub>1,775</sub>	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 <sub>2,867</sub>	0.186	<0.001
	BO: $75.1 + 7.36 \cdot x - 0.28 \cdot x^2$	106 <sub>1,176</sub>	0.151	<0.001
	NT: $57.8 + 0.91 \cdot x - 0.02 \cdot x^2$	4 <sub>1,774</sub>	0.004	0.018
	Michaelis Menten $y = \beta_1 \cdot x / (\beta_1 + x)$			
ES: $45.3 \cdot x / (-1.07 + x)$	45 <sub>2,867</sub>	0.175	<0.001	
BO: $140 \cdot x / (1.17 + x)$	1 <sub>1,176</sub>	0.152	0.397	
NT: $67.7 \cdot x / (0.28 + x)$	1 <sub>1,774</sub>	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 <sub>2,092</sub>	0.268	<0.001
	BO: $2,009 - 1,548 \cdot x$	494 <sub>1,445</sub>	0.255	<0.001
	NT: $1,840 - 1,409 \cdot x$	387 <sub>1,210</sub>	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 <sub>2,091</sub>	0.276	<0.001
	BO: $2,173 - 2,805 \cdot x + 1,144 \cdot x^2$	260 <sub>1,444</sub>	0.264	<0.001
	NT: $1,961 - 2,333 \cdot x + 840 \cdot x^2$	200 <sub>1,209</sub>	0.248	<0.001
	Sigmoid function <sup>a</sup> $y = \beta_1 / (1 + \beta_2 \cdot x^{\beta_3})$			
ES: $2,093 / (1 + 4.3 \cdot x^{2.2})$	12 <sub>2,091</sub>	0.276	<0.001	
BO: $2,048 / (1 + 2.4 \cdot x^{1.4})$	5 <sub>1,444</sub>	0.168	0.032	
NT: $1,833 / (1 + 2.2 \cdot x^{1.5})$	6 <sub>1,209</sub>	0.171	0.015	

<sup>a</sup> Note that the  $r^2$  value may not be fully comparable between linear and nonlinear regression models (Cameron and Windmeijer 1997).

585 **Table 3.** Parameter sensitivity in a biosocioeconomic model for optimizing the number of ptarmigan  
 586 hunting permits, with an objective function to maximize annual landowner profit. Only one parameter  
 587 was re-scaled at a time. The numbers below shaded areas are the model output (same as those given in  
 588 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 <sup>2</sup>	10	50	250	1,000
		0.40; 9 (0.6); 1,657; -1,862	0.40; 9 (0.6); 1,656; 139	0.40; 9 (0.6); 1,657; 539	0.40; 9 (0.6); 1,657; 614
$f_c$ (fixed administrative cost)	25,000 NOK	0	2,500	50,000	100,000
		0.40; 9 (0.6); 1,656; 639	0.40; 9 (0.6); 1,656; 614	0.40; 9 (0.6); 1,656; 139	0.40; 9 (0.6); 1,656; -361
$hc_{ik}$ (costs added per permit)	50 NOK	0	25	250	1,000
		0.40; 9 (0.6); 1,656; 411	0.40; 9 (0.6); 1,656; 400	0.40; 9 (0.6); 1,656; 312	0.12; 29 (2.0); 3,552; 59
$a_{ikl}$ (accommodation per day)	see Table 1	0	-50%	+100%	+500%
		0.39; 9 (0.6); 906; 84	0.40; 9 (0.6); 1,149; 189	0.40; 9 (0.6); 2,679; 799	0.40; 9 (0.6); 6,773; 2,437
$d_{ikl}$ (number of days hunted)	see Table 1	-75%	-50%	+50%	+100%
		0.36; 10 (2.7); 1,004; 90	0.66; 5 (0.7); 758; 212	0.27; 13 (0.7); 2,660; 444	0.20; 18 (0.6); 3,632; 468
$q_{ik}$ (total hunting quota)	3.5 birds/km <sup>2</sup>	0.5	1.5	7.5	15.0
		0.06; 9 (0.6); 1,888; -143	0.17; 9 (0.6); 1,837; 57	0.68; 11 (0.8); 1,506; 735	0.41; 36 (2.5); 3,664; 1,241
Minimum bag/hunter/day	0.50	0.00	1.00	2.00	5.00
		0.88; 4 (0.28); 927; 514	0.20; 18 (1.2); 2,519; 243	0.10; 35 (2.4); 4,056; 152	0.04; 88 (6.0); 8,452; 95
$o_k$ (observability)	50%	0%	25%	75%	100%
		0.40; 9 (0.6); 1,896; 487	0.40; 9 (0.6); 1,820; 457	0.40; 9 (0.6); 1,452; 310	0.35; 10 (0.7); 1,420; 228
Density dependent effects	see Fig. 1 and 2	No bag effect <sup>a</sup>	No bag/crowd <sup>a</sup>	No bag/crowd <sup>b</sup>	
		0.40; 9 (0.6); 1,661; 393	0.40; 9 (0.6); 1,903; 489	3.50; 1.0 (0.1); 1,264; 3.976	
% hunter typologies <sup>c</sup>	see Table 1	100; 0; 0	0; 100; 0	0; 0; 100	
		0.40; 9 (0.7); 1,668; 397	0.40; 9 (0.6); 1,839; 464	0.40; 9 (0.5); 1,402; 290	
<b>Number of hunters/km<sup>2</sup></b>	0.40				
<b>Bag size/hunter (per day)</b>	9 (0.6)				
<b>Gross income per permit</b>	1,656 NOK				
<b>Overall profit per km<sup>2</sup></b>	391 NOK				

<sup>a</sup> 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).

<sup>b</sup> As for footnote<sup>a</sup>, but in addition, leaving out the lower limit on daily bag size.

<sup>c</sup> "The Experience Seeker", "The Bag Oriented" and "The Northern Traditionalist", respectively.

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

594

595 **Figure 2.** Norwegian grouse hunters' total willingness-to-pay for their normal number of ptarmigan  
596 hunting days throughout the season in relation to crowding, given they obtain **(a)** low yields (1  
597 ptarmigan/day); and **(b)** higher yields (5 ptarmigans/day), and assuming an hunter observability of  
598 25% (i.e. every fourth hunter is actually seen by others). Based on a survey conducted in 2010 with  
599  $N=3,293$  respondents.

600

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















