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Roe deer (*Capreolus capreolus*) browsing pressure affects yew (*Taxus baccata*) recruitment within nature reserves in Norway

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Abstract

Grazing and browsing by large herbivores is known to affect patterns of biodiversity. Still much remains to be done to assess the specific role of browsing on single, red listed plant species. In Norway, the yew (*Taxus baccata*) is a threatened species and several nature reserves have been established. We show, that within two nature reserves between 1988 and 2003, yew recruitment was strongly dependent on variation in roe deer (*Capreolus capreolus*) browsing pressure. Our study emphasized that establishing nature reserves for yew is not enough to conserve this species unless control over browsing roe deer population is also taken. We argue that roe deer, being the most abundant large herbivore in Europe, may have a larger effect on conservation than currently realized.

Keywords: Conservation; Grazing impact; Herbivory; Management; Trophic interactions

1. Introduction

It is well known that grazing and browsing by large herbivores affect patterns of biodiversity (Olff and Ritchie, 1998; Austrheim and Eriksson, 2001). However, few studies have considered the effect of grazing and browsing on single and threatened Red-List species, though notable exceptions occur (e.g., Augustine and Frelich, 1998). Yew (*Taxus baccata*) is a late successional species (Thomas and Polwart, 2003), and in Norway, is an endangered species, and several protected areas have been established to conserve it (Svalastog and Høiland, 1991). Despite this, poor recruitment of yew has been observed in these reserves (Svalastog and Høiland, 1991). Previously, focus on yew regeneration has been related to insect herbivory on seeds (Hulme, 1996). Despite being a highly toxic plant for many species (Jordan, 1964; Schulte, 1975), including some species of large herbivores (Knowles, 1949; Lowe et al., 1970), severe browsing of yew by roe deer (*Capreolus capreolus*) has been reported in Norway (Mysterud and Østbye, 1995). Moreover, yew has declined drastically on the Åland archipelago (between Sweden and Finland) since roe deer were introduced (Hæggström, 1990), and in Fennoscandia, roe deer browsing has been suggested as a factor limiting northward expansion of yew (Ståhl, 1988). However, quantification of demographic data on yew under periods of variable browsing pressure are lacking.

To assess the role of roe deer browsing, we present data on recruitment of young yew, a key to success for conserving this species, during periods of high and low roe deer density. We test the hypothesis that roe deer browsing reduces yew recruitment, and that yew recruitment therefore should be greater in periods of low roe deer abundance. Only roe deer browse yew, except where there is some moose (*Alces alces*) browsing in very severe winters (Mysterud and Østbye, 1995). This is in contrast to the Pacific yew (*Taxus brevifolia*), which is browsed frequently by moose (Pierce and Peek, 1984).

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2. Methods

2.1. Study area

The study area is located in the Lier valley in southern Norway (between 59°52′–59°58′N and 10°14′–10°20E). Most of the area is forested and situated within the boreo-nemoral region (Abrahamsen et al., 1977). Vegetation is varied and dominated by Norwegian spruce (*Picea abies*) mixed with Scots pine (*Pinus sylvestris*) on the drier and poorer locations. Along the bottom of the valley there is especially rich ground where deciduous forest predominates, but is fragmented by cultivated fields. In the deciduous forest species like hoary alder (*Alnus incana*) and bird cherry (*Prunus padus*) predominate mixed with elm (*Ulmus glabra*) and lime (*Tilia cordata*) at the richest locations. Where the soil is calcium-rich there are the greatest densities of yew in Norway (Svalastog and Høiland, 1991). The roe deer population is partly seasonally migratory between highland and lowlands (Mysterud, 1999); during the winter most of the population are in the lowlands feeding on agricultural crops as well as wild plants (Kjøstvedt et al., 1998; Mysterud et al., 1999). A sudden drop in roe deer density occurred in our study area during the unusually severe winter of 1993/94. An impression of the level in density decline is evident from looking at harvest statistics; harvest of roe deer in one surveyed area halved from 26 to 14 deer roe deer autumns of 1993 and 1994, respectively, despite a similar quota and hunter effort (E. Østbye, unpubl. data). Harvest dropped from 169 (1993) to 108 (1994) within the Lier municipality. Locally this gave areas with an almost total absence of roe deer (based on evidence from snow tracking; E. Østbye, unpubl. data).

2.2. Yew data – recruitment and browsing pressure

We counted the number of yews (categorized in 10 cm height intervals) in 6 transects, each 250 m long and 50 m wide. Two transects were established in 1988 within one nature reserve, and the rest were established in 1991. The other transects were situated close to the first nature reserve, and one of them was within another reserve. Transects were put in areas where yew were fairly abundant, and the mean distance between transects was 800 m. All transects were re-checked in 1996 and all but one in 2003. The number of recruited yews was defined as those below 50 cm height. While these are mainly young yews, some 10–15 year old yews of only 20 cm height were also present (aged by counting tree rings), as their growth was depressed by severe browsing (E. Østbye, unpubl. data). In the last period (after 1995), no such trees were seen.

Browsing pressure on yew was estimated in 1988 (two transects), 1990–1994, 1996 and 2003. We have previously reported the browsing pressure until 1994 (Mysterud and Østbye, 1995). For each yew tree, we counted the number of browsing signs on the plants. A "browsing sign" is one bite by the animal on the tree, being evident as a fresh cut on the twigs. For each transect and year, browsing pressure was given as a percentage of trees with more than 10 browsing signs (denoted heavy browsing). During the high-density period for roe deer, winter browsing could be extremely severe removing a large part of the biomass (Mysterud and Østbye, 1995).

2.3. Statistical analyses

We used an ANCOVA model with (ln) number of "recruited yews" (<50 cm high) as the response variable, with year as a continuous covariate and "transect" as a categorical factor. A similar model was used for browsing pressure. As browsing pressure was reported as a percentage, we used an arcsin(sqrt) transformation to avoid heteroscedasticity. The AIC was used when comparing models (Burnham and Anderson, 1998). The model with the lowest AIC value is considered to be the most parsimonious model, i.e., the best compromise between explaining most of the variation and simultaneously using as few parameters as possible. As repeated sampling of the same transect may be seen as pseudoreplication, we also ran a linear mixed-models with "transect" as a random factor to account for non-independency of observations. All statistical analyses was performed in S-Plus (Venables and Ripley, 1994).

3. Results

There was a marked increase in the number of recruited yews from 1988/91 to 2003 (Fig. 1(a), Table 1), although with a significant variation in recruitment between transects ($F = 8.132$, $P = 0.001$). Adding the interaction term between year and transect resulted in a model (AIC = 8.166) that was less parsimonious than the one excluding this term (AIC = 6.428). The effect of "year" remained significant when entering "transect" as a random factor in a linear mixed-model (mean = 0.108, SE = 0.022, $T = 4.859$, $P < 0.001$). The number of yew recruits was negatively correlated with the roe deer browsing pressure (mean = −1.030, SE = 0.334, $T = -3.082$, $P = 0.010$).

There was a significant decrease in browsing pressure over time (Fig. 1(b), Table 1); reducing to zero heavily browsed trees in all transects after 1995. There was variation in browsing between transects ($F = 2.084$, $P = 0.089$). Adding the interaction term between year and transect resulted in a model (AIC = 10.621) that was less parsimonious than the one excluding this term (AIC = 9.283). A model using a categorical year term

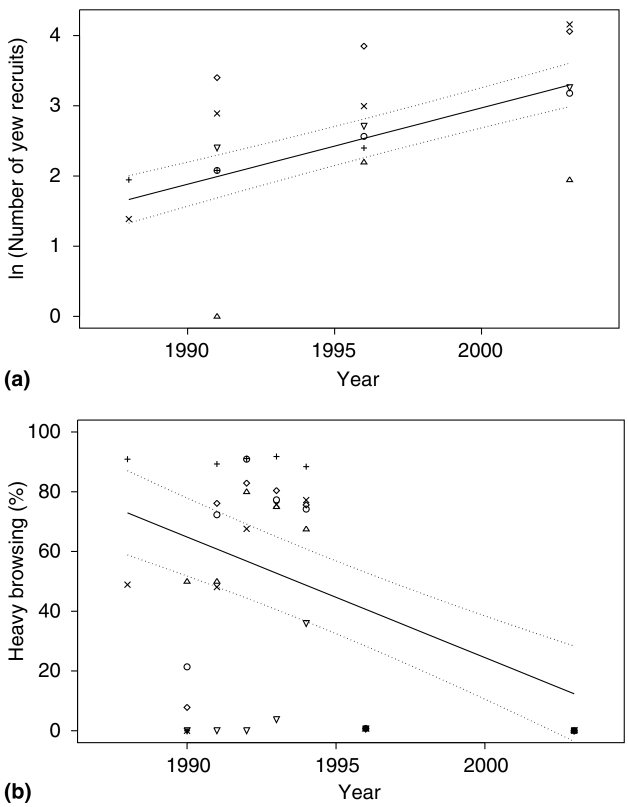

Fig. 1. The temporal development of: (a) the (ln) number of recruited yews and (b) roe deer browsing pressure within and adjacent to two nature reserves for yew in Norway from 1988 to 2003. Dotted lines indicate 95% c.i. Different symbols indicate each of the 6 transects. Note that the analysis of browsing was also performed on transformed values, and that year entered as "before" or "after" 1995 (roe deer population crash) provided a much better fit than the linear trend used for presentation.

Table 1
Parameter estimates and test statistics for the models analyzing variation in (a) yew recruitment and (b) browsing pressure on yew by roe deer during the period 1988–2003 within nature reserves in Norway

Parameter	l.s. mean	SE	T	P
(a) Yew recruitment				
Intercept	−214.375	44.864	−4.778	<0.001
Year	0.109	0.0224	4.841	<0.001
Transect (2 vs. 1)	−0.180	0.390	−0.463	0.652
Transect (3 vs. 1)	−1.407	0.390	−3.606	0.004
Transect (4 vs. 1)	−0.103	0.406	−0.254	0.804
Transect (5 vs. 1)	0.305	0.368	0.830	0.423
Transect (6 vs. 1)	0.983	0.390	2.518	0.027
(b) Browsing pressure				
Intercept	117.790	30.713	3.835	<0.001
Year	−0.059	0.015	−3.831	<0.001
Transect (2 vs. 1)	0.579	0.226	2.558	0.015
Transect (3 vs. 1)	0.550	0.226	2.433	0.020
Transect (4 vs. 1)	0.620	0.219	2.826	0.008
Transect (5 vs. 1)	0.415	0.219	1.890	0.067
Transect (6 vs. 1)	0.547	0.226	2.417	0.021

(before/after 1995) gave a much improved fit (AIC = 69.242 vs. 47.668; $r^2 = 0.412$ vs. 0.631). The effect of "year" remained significant when entering "transect" as a random factor in a linear mixed-model (mean = −0.766, SE = 0.114, $T = -6.742$, $P < 0.001$).

4. Discussion

Roe deer have expanded greatly in both distribution and abundance during the last few decades and are now the most abundant cervid in Europe (Andersen et al., 1998). Nevertheless, little is known on how roe deer browsing affects the conservation of threatened plant species, and biodiversity in general. Focus has been on how roe deer browsing affects the more common plant species (but see Ballon and Maizeret, 1990; Cibien et al., 1988) and usually trees of forestry interest (Guthörl, 1994; König and Baumann, 1990; review in Putman, 1992). Interestingly the North-American "ecological equivalent" to roe deer is the white-tailed deer (*Odocoileus virginianus*), which is considered a keystone herbivore (Waller and Alverson, 1997; Williams et al., 2000), known to locally extirpate sensitive forbs (e.g., *Trillium* spp., Augustine and Frelich, 1998), and prevent *Thuja occidentalis* forest regeneration (Cornett et al., 2000). Similar effects are likely to occur with roe deer browsing, and here yew showed retarded recruitment due to heavy browsing. Roe deer have fairly small home ranges in Lier, Norway (Mysterud, 1999), and browsing pressure varied considerably at a local scale (between transects) depending on local deer activity and alternative food sources (Mysterud and Østbye, 1995).

The drop in roe deer density in our study area was due mainly to the unusually severe winter 1993/94. The persistent low density in the following years was partly due to an increasing number of the European lynx (*Lynx lynx*) (Andersen, 2003). Lynx have a much more marked effect on roe deer population dynamics when roe deer density is fairly low (Solberg et al., 2003). Roe deer populations recovered in many areas after the severe winter, but not in this area where deer predation was often observed and concurrent studies of radio-collared lynx were being done. Our study, therefore, has implications for assessing trophic cascades of large carnivores (e.g. Post et al., 1999; Ripple et al., 2001). By allowing the lynx populations to increase, it helped keep roe deer browsing pressure in the nature reserves at a much lower level leading to successful yew recruitment, thus also providing a case in which large carnivore conservation goes hand in hand with another conservation objective.

In the UK, roe deer browsing was not considered a major threat to conservation in a questionnaire of managers (Putman and Moore, 1998). Based on the evidence presented here, we suggest that more detailed empirical studies are needed before conclusions can be made regarding how the currently dense roe deer populations affect conservation issues in Europe. Further, when establishing nature reserves in Norway it is not enough just to prevent logging, it is essential also to control herbivores.

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