birds

Article

Long-Term Trends of Hazel Grouse (*Tetrastes bonasia*) in the Bohemian Forest (Šumava), Czech Republic, 1972–2019

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Simple Summary: In this paper, the long-term dynamics of a Central European Hazel Grouse population in the Bohemian Forest (Czech Republic) were investigated. The fluctuating population was stable for more than 30 years, until 2006, and then showed a declining trend. Possible reasons for the decline include increasing forestry: heavy, noisy machines, clear cutting in large areas, the extension of transport lines, and the removal of pioneer trees. The disturbance of this shy bird by growing tourist activities and predation are also discussed. Management recommendations to improve the situation for the red-listed umbrella species embrace the extension of the core zone of the national park, and a reduction in the intensity of forestry in favor of mixed forests with pioneer trees that provide winter food for the species.

Abstract: The population dynamics of Hazel Grouse were studied by presence/absence recording at stationary sites along fixed routes (110 km) in the central part of Šumava (Bohemian Forest, Czech Republic) from 1972 to 2019. The 100 km^2 study area covered altitudes between 600 m (Rejštejn) and 1253 m above sea level (Mt. Sokol). Our database contained indices of Hazel Grouse occupancy: positive sites/visited sites for a yearly increasing number of Hazel Grouse occurrence sites ($n = 134$) for 48 years. We used a loglinear Poisson regression method to analyze the long-term population trend for Hazel Grouse in the study area. In the period from 1972 to 2006 we found a stable Hazel Grouse population ($p = 0.83$). From 2006–2007 to 2019, the population index dropped (-3.8% per year, $p < 0.05$). This decline is assumed to be influenced by habitat loss due to succession, resulting in older, more open forest stands, by strongly increasing forestry and windstorm "Kyrill", followed by clear cutting, bark beetle damage, and the removal of pioneer trees in spruce plantations, which diminished buds and catkins, the dominant winter food of Hazel Grouse. The influence of disturbance by increasing tourist activities and/or predation is also discussed. Our results could help to optimize the conservation efforts for Hazel Grouse in the Bohemian Forest.

Keywords: Hazel Grouse; Bohemian Forest; long-term monitoring; population trend; TRIM

1. Introduction

The Hazel Grouse (*Tetrastes bonasia*) is a cryptically colored, medium-sized forest bird, adapted to multi-layered and old-growth forests with gaps and spots of dense, young forest succession [1–6]. The IUCN (International Union for Conservation of Nature) Red List of Threatened Species designated the current situation of Hazel Grouse as "least concern" [7]. In Europe, the species' status was "lower risk" (near threatened) [8] and the EU Birds Directive (2009/147/EC) listed the Hazel Grouse in its Annex I. In the National Red Data books of some Central and Southern European countries, the species is recorded as "vulnerable" (e.g., in Czechia [9]) or "endangered" (e.g., in Germany [10]), and hunting is forbidden. The European Breeding Bird Atlas-2 documents the large and almost continuous distribution range of the species [11] across the boreal forests, with the highest occurrence probabilities and abundances in Southern Finland and Russia, where suitable habitats of

coniferous and mixed forests prevail throughout large, unfragmented areas. There are few areal changes in the core range from Finland, through the Baltic States, and towards Belarus and Russia. However, in the more fragmented range in Central and Western Europe, a high number of squares where the species was not confirmed indicate substantial range losses. In France, the Hazel Grouse had already vanished from areas outside the Jura Mountains and the Alps before the 1990s. In Switzerland, the species disappeared from the eastern part of the Jura and is only preserved in the less-fragmented regions of the western Jura and the Alps [11].

Except for the Alps, the Bohemian Forest is the largest area occupied by Hazel Grouse in Central Europe [12–14]. After World War 2, farmers left this region and forest succession began on abandoned fields and meadows, comprising huge areas. In addition to the natural regeneration of pioneer trees in all suitable habitats, spruce (*Picea abies*) was planted, mostly in small plots, forming mosaics with the high density of forest edges throughout the whole region. Before 1950, the density of Hazel Grouse in the spruce-dominated landscape was low. The increase in the amount of young, mixed forests was accompanied by a pronounced increase in Hazel Grouse numbers [13,15–17].

Long-term field studies provide valuable data about animal populations. In practice, these types of data often contain many missing values. Simple comparisons of numbers or occupancy ratios between years may thus yield population and trend estimates that are different from the true population state [18]. In this study, we therefore calculated the population trends for Hazel Grouse in the Bohemian Forest by applying a loglinear Poisson regression method to the full set of Hazel Grouse sites over a 48-year period. We therefore report on the longest Hazel Grouse monitoring period in Central Europe. The aims of our study were: (1) to track the dynamics of a formerly expanding Hazel Grouse population in Central Europe by long-term monitoring; (2) to seek possible reasons for the trends; (3) to provide basic knowledge for conservation [13,19,20]. The Hazel Grouse in the study area were extremely shy, in contrast to Fennoscandia or Siberia (for a review, see [2]). Therefore, in addition to habitat loss through forestry, we focused on possible disturbance due to tourism. The influence of weather on the investigated population was discussed in a previous study [16] and habitat parameters that explain the presence of Hazel Grouse in the study area were described by Ludwig and Klaus [21].

2. Methods

2.1. Study Area

Hazel Grouse were monitored from 1972 to 2019 in the central part (district Klatovy, Czech Republic) of the Bohemian Forest (Šumava in Czech, Bayerischer-Böhmerwald in German). Our 100 km² study area (Figure 1) covered altitudes between 600 m (Rejštejn) and 1253 m asl. (Mt. Antigl/Sokol, near Horska Kvilda). The Bohemian Forest is an extensive 120 km long mountain along the border between the Czech Republic, Germany, and Austria. It is one of the geologically oldest mountain ranges in Central Europe.

In 1991, the National Park "Šumava" (Bohemian Forest—68,064 ha) was founded and 68% of the visited sites became part of this reserve. In contrast to the IUCN rules, timber harvesting continued with increasing intensity in the whole study area. Before 1990, the existence of the "iron curtain" led to the development of a broad band of military training areas along the border between Western Germany and Czechoslovakia. Therefore, the study area was forcibly placed outside of the restricted areas [22] and outside of the core zone, without logging, which mainly comprised peat bogs and made up only 13% of the national park area. In 2008 and 2020, the core zone was enlarged to 22% and 27% of the national park area, respectively. The whole study area is part of the EU-Natura 2000 network (Special Protected Area). Only 1.47 human inhabitants per 100 ha live permanently in Šumava National Park, but 770,000 visitors (in total for the whole national park) were counted [23].
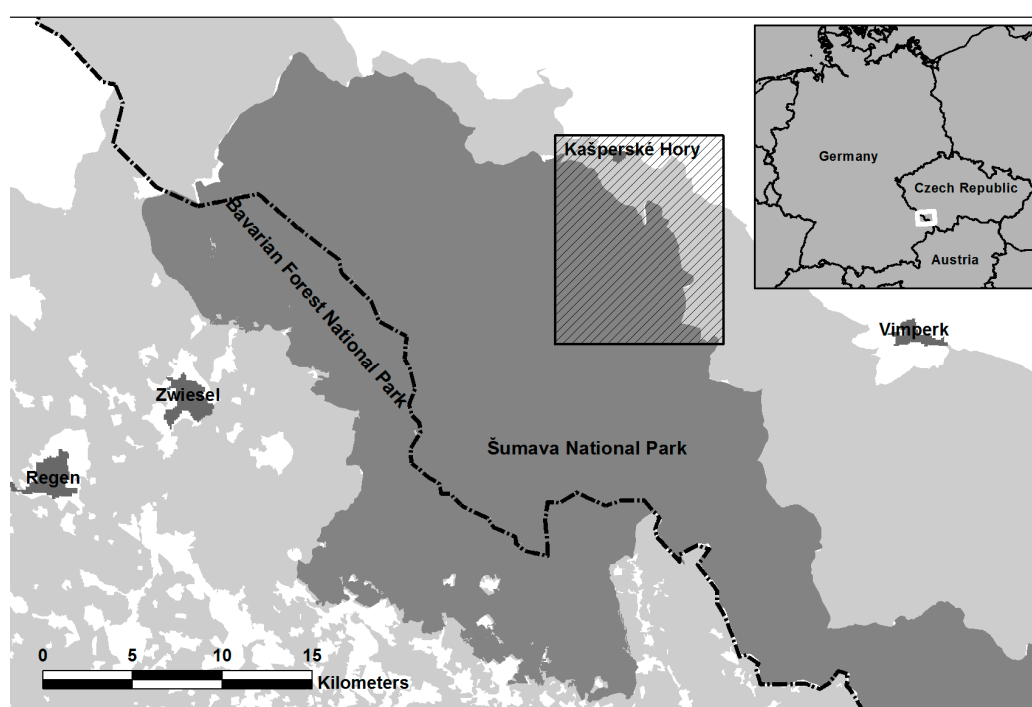
Figure 1. Location of the study area (hatched rectangle) in the central part of the Bohemian Forest, including the small town of Kašperské Hory at its northern edge. Dark grey areas show the Šumava (north of the national border) and Bavarian Forest National Parks (south of the national border); light grey areas indicate Bohemian Forest Landscape Reserves (north of the national border) and Bavarian Forest Nature Park (south of the national border). The white box on the inset map (upper right) depicts the position of the national parks along the German–Czech Republic border.

The spruce-dominated study area was designated so as to represent all typical vegetation zones. It includes four main forest types that provide Hazel Grouse habitats. Along an altitudinal gradient, there are valleys with alder (*Alnus glutinosa*) as the dominating deciduous tree (about 600–700 m asl.), lower slopes with birch *(Betula pendula)* and hazel (*Corylus avellana*) as potential winter food (about 700–900 m asl.), as well as montane mixed forests with spruce, beech (*Fagus sylvatica*) and fir (*Abies alba*) at 900–1100 m asl., and mountain spruce forests where single rowans (*Sorbus aucuparia*) provide food in winter (above 1100 m asl.).

Potential mammalian predators that have an impact on Hazel Grouse are the red fox (*Vulpes vulpes*), the pine marten (*Martes martes*), the lynx (*Lynx lynx*), the badger (*Meles meles*), and various raptors: the Northern Goshawk (*Accipiter gentilis*), the Sparrow Hawk (*Accipiter nisus*), the Eagle Owl (*Bubo bubo*), and the Ural Owl (*Strix uralensis)*. The wild boar (*Sus scrofa*), whose population has been increasing since 1980, may predate nests and grouse chicks [24–27].

2.2. Detection of Hazel Grouse Occupancy

Here, we use the term "Hazel Grouse site" or "site" instead of "territory", because most of the indications of Hazel Grouse presence were found by indirect evidence and not by territorial activities of the birds responding to playback of the territorial song. All sites where Hazel Grouse had been found at least once since 1972 were assigned unique numbers (1–134) and were mapped. An increasingly varied number of sites (4–14 at the beginning and 23–70 sites since 1981, mean: 41.8 sites/year) were examined yearly (exceptions: 1974, 1977/78, 1993, and 2016–18) until 2019, along fixed routes (110 km in total [11,13,20]). The maximum number of visitations per site was 38 years (mean: 12.6 years/site). The detection of Hazel Grouse included indirect signs (dust-bathing places, droppings, feathers and tracks) and testing the reactions of males to whistling, following the methods described by Wiesner et al. [28] and Swenson [29]. Sites were visited during daylight hours. The time

spent at a site varied between 10 and 30 min, depending on the direct response of Hazel Grouse to playback and/or the time taken to search for indirect signs.

All the positive sites had adequate habitat quality, as indicated by the presence of Hazel Grouse over several years, based on habitat descriptions in the literature [2,3,5], and our own measurements [13]. The proportion of occupied sites was estimated after the break-up of broods in October. All data on density are indices rather than direct counts. The index of the density of occupied sites in a given year was defined as the proportion between the number of occupied sites and the number of sites investigated for the presence of Hazel Grouse. At every Hazel Grouse site, negative factors (obvious damage caused by forestry resulting from activities in the present year, the presence of humans seen during the control of each site, and habitat loss by ongoing succession) were recorded simply as presence/absence data during two periods: (1) 2007–2011 and (2) 2012–2015 and 2019. All field data were collected by one of the authors (S.K.) without changing the collection method over the whole study period.

2.3. Statistical Methods

Our database contained presence counts of Hazel Grouse signs at $n = 134$ sites over 48 years (1972–2019), with the above-mentioned data gaps. We used R [30] and TRIM (Trends and Indices in Monitoring Data), implemented in the rtrim package [31], to analyze the long-term Hazel Grouse population trend. Using loglinear Poisson regression, the method can estimate the trends of animal populations based on typically incomplete count data, as was the case with our 134 Hazel Grouse sites. Year and site effects as independent factors, as well as missing species counts in the dependent variable, are taken into account to determine annual indices, trends, and their standard errors [18]. In addition, the method considers overdispersion, i.e., the deviation of the variance from the mean of the Poisson distribution, as well as serial autocorrelation, i.e., the time dependence of a count on its predecessors [32]. We deployed TRIM model type 2, because, in addition to site effects, it also allows linearly changing trends to best describe the increases and decreases in the population. We included binary covariates to test for trend differences inside and outside the national park and between altitudes of 900 m and above.

For a simple comparison of the mean numbers of monitored sites affected by forestry, tourism, or habitat loss due to succession during periods (1) and (2) (see above), we applied Welch's two-sample t-test, a variant of the paired t-test, assuming unequal variances. We also tested the time series of visitor numbers (2004–2019, obtained from the administration of Šumava National Park) in four places as predictors of the index values from our best model using a generalized linear model (GLM).

3. Results

3.1. Population Trend

The first model with a constant trend was not significantly different from a loglinear Poisson model (chi-square = 614.6, df = 1575, $p = 1.0$, AIC = −2299.43) and thus achieved a good fit. Over the entire period, from 1972 to 2019, the model showed a slight population decrease. The average decrease was 0.6% per year and was close to significant ($p = 0.06$). The population may therefore be interpreted as stable over the whole study period (Table 1).

Table 1. Coefficients for the model of the Hazel Grouse population with constant trend (second row) and with changing trend (lower two rows) for the Hazel Grouse population. Trend coefficients are given in additive (add) and multiplicative notation (mul) with their standard errors (se). Multiplication of additive coefficients with 100% provides yearly changes for the period. The same is achieved by subtracting one from the multiplicative coefficients.

From	Upto	Add	Se Add	Mul	Se Mul	*p*	Meaning
1972	2019	−0.0061	0.0032	0.9940	0.0032	0.0622	Stable
1972	2006	−0.0008	0.0049	0.9992	0.0049	0.8782	Stable
2006	2019	−0.0376	0.0126	0.9631	0.0121	0.0113	Decrease (*p* < 0.05)

In the next step, we tested for significant trend changes. The stepwise selection of changepoints was not possible due to data constraints. Therefore, we sequentially tested all years as potential changepoints and chose the best model based on the lowest Akaike Information Criterion (AIC) and Wald test for the significance of changes in the slope. This resulted in an improved version of the model (ΔAIC = 5.56), predicting a stable population until 2006 ($p = 0.63$) and a population decrease of −3.8% per year ($p < 0.02$) for the last 13 years (Table 1).

Inclusion of a covariate neither resulted in significantly different trends for sites below or above 900 m, nor did it for sites within and outside the national park ($p > 0.4$).

The simple occupancy index (proportion occupied/investigated sites each year) exaggerated the ups and downs of the modeled trend curve (Figure 2). It also tended to overestimate the declining population after the changepoint (2006). However, while the trend index displays change in the population relative to the first year, the occupancy index must be interpreted as the proportion of sites occupied by Hazel Grouse. Our results therefore suggested that Hazel Grouse occupancy in our study area fluctuated between 50 and 80%.
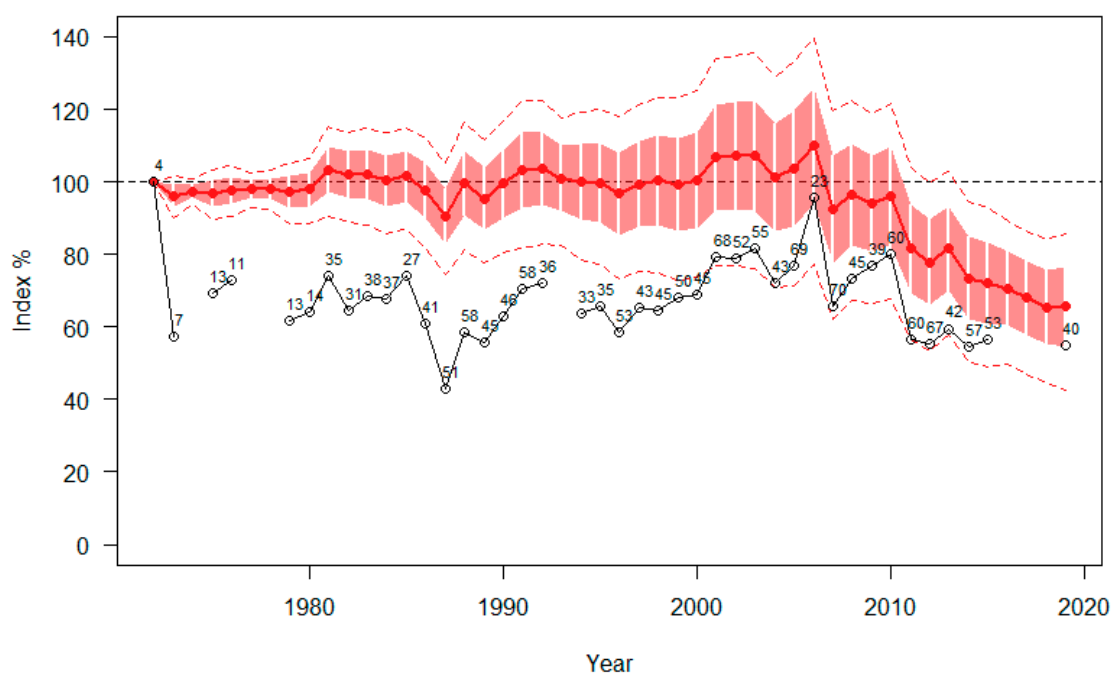

Figure 2. Index curve (bold red line, relative abundance, 1972 = 100%) of the Hazel Grouse population in the Bohemian Forest from 1972 to 2019 (red bar = standard error) and its 95% confidence limits (dashed red lines) based on the best loglinear Poisson regression model with the year 2006 as a changepoint. Black lines and circles show a simple occupancy index, calculated as the proportion between positive sites and visited sites (lower curve). The number of visited sites per year is indicated by small numbers (see Methods for details).

3.2. Negative Impact of Forestry and Disturbance by Tourism on Hazel Grouse

Habitat damage by industrial forestry increased from an average of 5.6 monitored sites per year by a factor of 1.3 to 7.4 monitored sites per year (Welch's two sample *t*-test: $t = -1.57$, df = 7.82, $p = 0.15$) from 2007–2011 to 2012–15/19. After the strong windstorm "Kyrill" in 2007, there was also an increase in negative factors in 2007–2011, as compared with the previous period. The negative impact of clear cutting and the creation of monocultures of spruce were at least partially additiv within the two periods because the damaged habitat sites did not recover by the end of the study period. Therefore, we summarized the negative events for both periods, resulting in a combined factor of 2.3.

Disturbance by tourist activities increased by a factor 2.5 from 1.6 sites to 4.0 sites per year between the two periods (Welch's two sample *t*-test: $t = -1.98$, df = 4.97, $p = 0.10$). The Hazel Grouse trend indices from our best model were negatively linked to increasing visitor numbers counted at "Kašperské Hory" ($p < 0.0001$, AIC = 106, Figure 3), from which most tourists entered the study area. Visitor numbers at this place explained 85% of the deviance in the Hazel Grouse trend. They more than doubled during the period of 2004–2019 from 15,000 to more than 30,000 visitors per year (Figure 3).
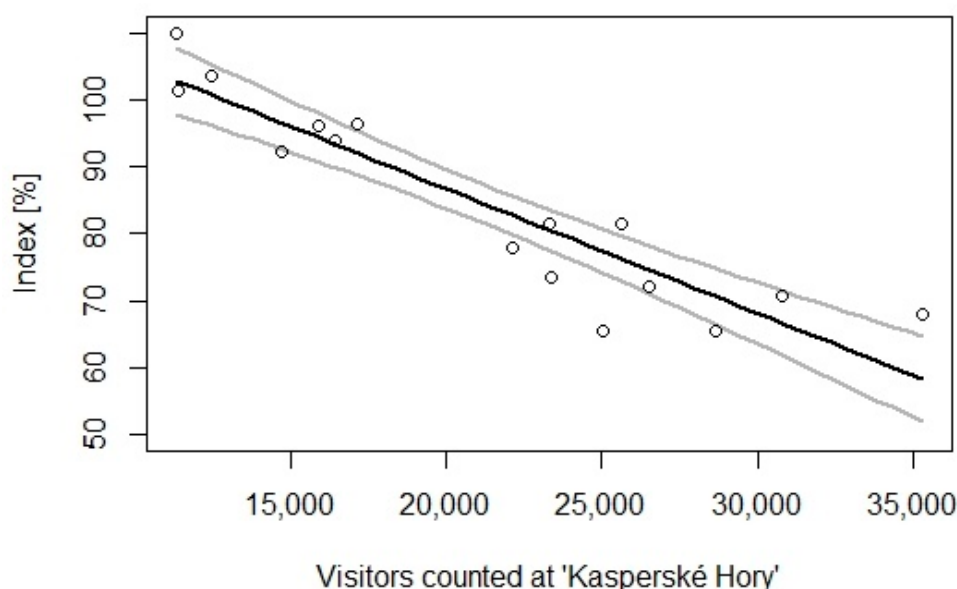
Figure 3. Association between the modeled relative Hazel Grouse abundance index (% relative to the studies starting year 1972, c.f. Figure 2) and the number of visitors counted at "Kašperské Hory" over 16 years (2004–2019). Visitor numbers were provided by the administration of Šumava National Park.

We tested the same relationship, including visitor numbers, from three other places that were located farther away from the study area and found a significant negative correlation between the Hazel Grouse trend index and visitor numbers in only one other place ("Březník"). However, the model performed much worse (AIC = 115, $p > 0.05$, $D^2 = 56\%$) than the one with visitor numbers from "Kašperské Hory".

In even-aged plantations, habitat loss in some Hazel Grouse sites was driven by the succession from young to mature forest stands, with reduced cover in mature stands. Habitat loss affected, on average, 1.6 sites per year during the period from 2007 to 2011 and 3.2 sites during the following five years (Welch's two sample *t*-test: $t = -1.91$, df = 7.50, $p = 0.09$). Given that this effect is also cumulative, a threefold increase in sites unsuitable to Hazel Grouse may be considered.

4. Discussion

Šumava National Park is a special case in Central Europe, because it is a rare example of a stable Hazel Grouse population over 35 years of study, as shown by our results and earlier work [16]. Another case was reported in the Southern French Alps [4,33–35].

Our density index of site occupancy suggested fluctuations in Hazel Grouse occupancy between 50 and 80%. It is most probable that these fluctuations reflected not only patterns due to varying site numbers and thus different detection probabilities and habitat quality at sites, but also turnover in the occupancy of Hazel Grouse territories. The metapopulation dynamics of Hazel Grouse [36], with assessments of colonization and extinction probabilities, were beyond the scope of this study. However, the field data were well suited to estimate long-term trends. With the applied loglinear Poisson regression, which considers missing values, overdispersion and serial autocorrelation, we are confident that we captured trend estimates that come close to the true overall dynamics of the Hazel Grouse population in the Bohemian Forest. Using models that make assumptions about the structure of the counts, it was possible not only to obtain better population indices, but also to include estimates about their precision. Model fit, as assessed by chi-square tests, revealed no deviation from the assumed Poisson distribution. Another feature that increased the credibility of our trend estimates was that detection probability was not influenced by different observation skills, because field work was carried out by one of the authors (S.K.).

The modeled index curve shows irregular fluctuations in Hazel Grouse density. However, there is no indication of the cyclicity found in the long-term census data on Hazel Grouse in Russia and Fennoscandia [37–41]. Helle et al. [42] and Ranta et al. [43] reported cyclic fluctuations of grouse populations in Finland with 5–7-year cycle length.

From 2006/2007 to present, the Hazel Grouse trend and occupancy indices in our study area dropped obviously. This decline could possibly be driven by several factors. In accordance with the literature (see [2,8] for a review), habitat loss due to natural succession, which led to older and more open forest stands, and increasing logging activity (more pronounced after windstorm "Kyrill" in 2007) most likely played a major role. Timber harvest took place in the whole study area over the entire timespan, which might explain why we did not find any trend differences between sites inside and outside the national park. Profit-based clear felling, which increased after windstorm "Kyrill", and bark beetle calamities, resulted in the loss of several sites. In spruce plantations, the removal of pioneer trees, the preferred winter food of Hazel Grouse, was another habitat deterioration factor. In parts of the study area, increasing densities of red deer (*Cervus elaphus*), damaging deciduous trees and bilberry (*Vaccinium myrtillus*) may have had further detrimental effects on habitat quality [44,45] because Hazel Grouse prefer these plants as ground cover and for food year-round [21,46].

There are only a few recent studies on the habitat choice of Hazel Grouse in Central Europe. Based on data from the nearby Bavarian Forest National Park, Müller et al. [47] showed that habitat heterogeneity, stand structure, the presence of pioneer trees like rowan and willow, the root plates of fallen trees, and borderlines are important habitat features for Hazel Grouse. In the northern Carpathians (Southern Poland), the most important factors were the presence of bilberry, the gap structure, and the presence of pioneer trees [48]. In the Swiss Alps, Hazel Grouse preferred spruce stands with high portions of tall rowans, forest edges, and dense shrub layers [49]. Our earlier studies in the Bohemian Forest showed that the probability of occupancy by Hazel Grouse for a given habitat site increased with growing number of tree species. The probability of occurrence culminated in young age-class forests between 20 and 40 years. Stands > 50 years old lost habitat quality due to a lack of ground cover. In contrast, multi-layered old-growth forests were also used by Hazel Grouse [13]. Ludwig and Klaus [21] found that site occupancy by Hazel Grouse in the Bohemian Forest was high in dense spruce forests characterized by short sighting distances (>20 m). This increased sharply with small proportions of deciduous trees (5–10%) in conifer-dominated forests. Other elements positively associated with Hazel Grouse site occupancy were the presence of anthills and fallen logs, well developed herb

cover, and high bilberry cover. The Hazel Grouse, as a poor disperser, is sensitive to habitat fragmentation [34,50–52], the latter being promoted by recent clear cutting activities in our study area. Rolstad and Wegge [53] and Haakana et al. [54] reported forest grouse habitat loss by clear felling in Norway and Finland, which also resulted in the fragmentation of Hazel Grouse habitats [51].

Many studies from Fennoscandia presented evidence that predators like Goshawk [55–57] control grouse populations. Moreover, red fox and pine marten are effective predators of grouse [58,59]. Although predation was outside the aim of our study, indirect evidence from hunting bags [16] indicate that an increase in opportunistic predators and wild boar occurred in central Europe during from 1970 to the 1990s, when the Hazel Grouse population in the study area was stable. Šťastný et al. [60] documented no increase in the Goshawk population between 1973 and 1989 in Czechoslovakia. Therefore, the continuous decline since 2006 does not seem to be supported by an increase in predator densities, although an increase in predation in more fragmented habitats cannot be excluded. According to Kauhala and Helle [61], predator numbers also were of minor importance when determining the trends in grouse populations in Finland.

Disturbance is assumed to have profound negative impacts on vigilant grouse species [62], but its effects are difficult to assess at the population level [63]. Disturbance can occur at different levels: individual stress and escape behavior, as well as the blocking of suitable habitats and reduced survival or reproduction [64]. Noise caused by forest machines and people could mask the Hazel Grouse's silent intraspecific communication, such as warning calls and communication between females and their chicks [6] and thus have long-term population effects. Our data document the increasing attractiveness of Šumava National Park to tourists, such as hikers, skiers, and mountain bikers, resulting in increasing disturbance pressure. Increasing visitor numbers, counted from 2004 to 2019 at the main entrance, were strongly and negatively correlated with the Hazel Grouse trend index in our study area. Though causation cannot be inferred due to simple temporal correlation and a spatial sample size of $n = 1$, the high significance of the relationship made it likely that increasing leisure and tourist activities contributed to the blocking of habitats [65] and thus to the observed negative population trend. This was supported by the less and non-significant relationships of the Hazel Grouse trend index with tourist numbers from three tourist stations that were located inside the national park but outside of our study area. Only "Kašperské Hory" was part of our study area and, as such, delivered the main influx of visitors to the studied Hazel Grouse sites.

The effects of climate change on Hazel Grouse was not a focus of our study. Nevertheless, the increase in bark beetle damage to spruce plantations due to higher mean temperatures and less precipitation was obviously one reason for the fast growth in forest activities. From a long-term perspective, habitats can improve after a bark beetle attack, as pioneer trees in young, mixed forests can develop in the openings. The explosion of bark beetles, resulting in dead wood, natural rejuvenation, and the enrichment of structures in the Šumava and Bavarian National Parks, was reported to favor an increase in both the capercaillie (*Tetrao urogallus*) and Hazel Grouse population [19,66].

5. Conclusions

In this study, the long-term dynamics of a central European Hazel Grouse population was investigated. The results could be used for EU-directed reports on the target and annexed species of the Natura 2000 network. The fluctuating population was stable for more than 30 years, until 2006. The possible reasons for the decline since 2006 are complex. The increasing impact of industrial forestry (heavy, noisy machines, clear cutting in large areas, the extension of transport lines, frequent thinning operations, and the removal of pioneer trees), disturbance by increasing tourist activities and predation were all discussed. Management recommendations include the extension of the core zone of the national park, and a reduction in the intensity of forestry in favor of mixed mountain forests, as well as the protection of pioneer trees. The results of this and earlier studies were forwarded to the

administration of the Šumava National Park, and sent by the Galliformes Specialist Group of the IUCN's Species Survival Commission to the administration of the national park and to the Ministry of Environment of the Czech Republic in order to improve the management activities for Hazel Grouse [13,19,20].

References

1. Scherzinger, W. Rauhfuß-Hühner. In *Nationalpark Bayerischer Wald*; Bayer. Staatsministerium: München, Germany, 1976; Volume 2, p. 71.
2. Bergmann, H.H.; Klaus, S.; Müller, F.; Scherzinger, W.; Swenson, J.E.; Wiesner, J. *Die Haselhühner*; Westarp Wissenschaften: Magdeburg, Germany, 1996; ISBN 3-89432-499-6.
3. Pynnönen, A. Beitrage zur Kenntnis der Lebensweise des Haselhuhns, *Tetrastes bonasia* (L.). *Riistatiet. Julk. Pap. Game Res.* **1954**, *12*, 1–90.
4. Montadert, M.; Leonard, P. Survival in an expanding hazel grouse *Bonasa bonasia* population in the southeastern French Alps. *Wildl. Biol.* **2003**, *9*, 357–364. [CrossRef]
5. Swenson, J.E. The ecology of Hazel Grouse and management of its habitat. *Naturschutzreport* **1995**, *10*, 227–238.
6. Klaus, S.; Bergmann, H.-H. *Auerhühner & Co.—Heimliche Vögel in Wilder Natur*; Aula Verlag: Wiebelsheim, German, 2020; ISBN 978-3-89104-835-1.
7. BirdLife International *Bonasa bonasia*. IUCN Red List Threat. *Species*. Available online: https://www.iucn.org/resources/conservation-tools/iucn-red-list-threatened-species (accessed on 16 March 2021).
8. Storch, I. *Grouse: Status Survey and Conservation Action Plan 2006–2010*; World Pheasant Association & IUCN and Fordingbridge, UK: Gland, Switzerland, 2007; ISBN 978-2-8317-1009-9.
9. Šťastný, K.; Bejček, V.; Němec, M. Červený seznam ptáků České republiky. In *Červený Seznam Ohrožených Druhů České Republiky. (Red list of Birds, in Czech.)*; Chobot, N.M., Ed.; Příroda Praha: Prague, Czech Republic, 2017; Volume 34, pp. 107–154.
10. Grüneberg, C.; Bauer, H.-G.; Haupt, H.; Hüppop, O.; Ryslavy, T.; Südbeck, P. Rote Liste der Brutvögel Deutschlands. *Ber. Vogelschutz* **2015**, *52*, 19–67.
11. Zbinden, N.; Klaus, S.; Keller, V. *Bonasa bonasia*-Hazel Grouse. In *European Breeding Bird Atlas 2. Distribution, Abundance and Change*; Keller, V., Herrando, S., Voříšek, P., Franch, M., Kipson, M., Milanesi, P., Martí, D., Anton, M., Klvaňová, A., Kalyakin, M.V., et al., Eds.; European Bird Census Council & Lynx Edicions: Barcelona, Spain, 2020; pp. 86–87. ISBN 978-84-16728-38-1.
12. Klaus, S. Effects of forestry on grouse populations: Case studies from the Thuringian and Bohemian Forests, Central Europe. *Ornis Scand.* **1991**, *22*, 218–223. [CrossRef]
13. Klaus, S. Hazel grouse in the Bohemian Forest: Results of a 24-year-long study. *Silva Gabreta* **1996**, *1*, 209–220.
14. Klaus, S.; Martens, J.; Andreev, A.; Sun, Y.H. *Bonasa bonasia* (Linnaeus, 1758) Haselhuhn. In *Atlas der Verbreitung Palaearktischer Vögel, 20. Jg., Nr. 6*; Martens, J., Eck, S., Sun, Y.-H., Eds.; Erwin-Stresemann-Gesellschaft für Paläarktische Faunistik e.V.: Berlin, Germany, 2003; p. 15.
15. Kučera, L. Verbreitung und Populationsdichte von Auerhuhn (*Tetrao urogallus*), Birkhuhn (*Lyrurus tetrix*) und Haselhuhn (*Tetrastes bonasia*) im westlichen Teil von Šumava (CSSR). *Ornithol. Mitt.* **1975**, *27*, 160–169.
16. Klaus, S. A 33-year Study of Hazel Grouse *Bonasa bonasia* in the Bohemian Forest, Šumava, Czech Republic: Effects of Weather on Density in Autumn. *Wildl. Biol.* **2007**, *13*, 105–108. [CrossRef]

17. Klaus, S.; Ludwig, T. Ökologie, Verhalten und Schutz des Haselhuhns *Bonasa bonasia* im Böhmerwald (Šumava, Tschechien). In Proceedings of the Symposium Raufußhühner des Landesjagdverbandes Bayern—Bayerischer Jagdverband e.V. und der Bayerischen Akademie für Jagd und Natur; Schriftenreihe des Landesjagdverbandes Bayern e.V., Band 22: Freyung, Germany, 2016; pp. 45–54.

18. Ter Braak, C.J.F.; van Strien, A.J.; Meijer, R.; Verstrael, T.J. Analysis of monitoring data with many missing values: Which method? In *Proceedings 12th International Conference of IBCC and EOAC*; Statistics Netherlands: Noordwijkerhout, The Netherlands, 1994; pp. 663–673.

19. Klaus, S. Forest grouse and wilderness—Survival without management impacts. In *Proceedings of the Europe's wild Heart*; Conference Report; Bavarian Forest National Park & Šumava National Park: Vimperk, Czech Republic; Grafenau, Germany, 2009; pp. 35–37.

20. Klaus, S. Situation of the hazel grouse *Tetrastes bonasia* in the National Park Šumava and in the Šumava Landscape Reserve—Activities of the Galliforme Specialist Group of IUCN. *Grouse News Newsl. Grouse Spec. Gr.* **2014**, *48*, 7–8.

21. Ludwig, T.; Klaus, S. Habitat selection in the post-breeding period by Hazel Grouse *Tetrastes bonasia* in the Bohemian Forest. *J. Ornithol.* **2017**, *158*, 101–112. [CrossRef]

22. Klaus, S. Haselhühnerforschung im Böhmerwald. *Nationalpark* **1998**, *3*, 51–55.

23. "Biosphärenreservat Šumava". Available online: https://de.wikipedia.org/w/index.php?title=Biosphärenreservat_Šumava&oldid=207209923 (accessed on 8 February 2021).

24. Klaus, S.; Berger, D.; Huhn, J. Capercaillie *Tetrao urogallus* decline and emissions from the iron industry. *Wildl. Biol.* **1997**, *3*, 131–136. [CrossRef]

25. Cukor, J.; Linda, R.; Andersen, O.; Eriksen, L.F.; Vacek, Z.; Riegert, J.; Šálek, M. Evaluation of spatio-temporal patterns of predation risk to forest grouse nests in the central European mountain regions. *Animals* **2021**, *11*, 316. [CrossRef]

26. Klaus, S. Predation among capercaillie in a reserve in Thuringia. In Proceedings of the 3rd International Grouse Symposium; Lovel, T., Hudson, P., Eds.; World Pheasant Association: New York, NY, USA, 1984; pp. 334–346.

27. Kämmerle, J.-L.; Storch, I. Predation, predator control and grouse populations: A review. *Wildl. Biol.* **2019**, *2019*, 1–12. [CrossRef]

28. Wiesner, J.; Bergmann, H.H.; Klaus, S.; Müller, F. Siedlungsdichte und Habitatstruktur des Haselhuhns (*Bonasa bonasia*) im Waldgebiet von Bialowieza (Polen). *J. Ornithol.* **1977**, *118*, 1–20. [CrossRef]

29. Swenson, J.E. Evaluation of a density index for territorial male Hazel Grouse *Bonasa bonasia* in spring and autumn. *Ornis Fenn.* **1991**, *68*, 57–65.

30. R Core Team. *R: A Language and Environment for Statistical Computing*; R Foundation for Statistical Computing: Vienna, Austria, 2019.

31. Bogaart, A.P.; Van Der Loo, M.; Pannekoek, J. Rtrim: Trends and Indices for Monitoring Data. R Packag. Version 2016, 1.0.1. Available online: https://cran.r-project.org/package=rtrim (accessed on 16 March 2021).

32. Pannekoek, J.; Van Strien, A. *TRIM 3 Manual (TRends and Indices for Monitoring Data)*; CBS Statistics Netherlands: Dutch, The Netherlands, 2005.

33. Montadert, M.; Leonhard, P. Natal dispersal affects population dynamics of Hazel Grouse in heterogenous landscapes. In *Ecology, Conservation, and Management of Grouse*; Sandercock, B.K., Martin, K., Segelbacher, G., Eds.; University of California: London, UK, 2011; pp. 89–103.

34. Montadert, M.; Klaus, S. Hazel grouse in open landscapes. *Grouse News* **2011**, *41*, 13–22.

35. Montadert, M. Fonctionnement Démographique et Sélection de L'habitat D'une Population en Phase D'expansion Géographique. Cas de la Gélinotte des Bois Dans les Alpes du Sud, France. Ph.D. Thesis, Université de Franche-Comté, Besançon, France, 2005.

36. Sahlsten, J.; Wickström, F.; Höglund, J. Hazel grouse *Bonasa bonasia* population dynamics in a fragmented landscape: A metapopulation approach. *Wildl. Biol.* **2010**, *16*, 35–46. [CrossRef]

37. Siivonen, L. The Problem of the Short-Term Fluctuations in Numbers of Tetraonids in Europe. *Pap. Game Res.* **1957**, *19*, 1–44.

38. Semenov-Tjan-Shanskij, O.I. Ökologie der Birkhuhnvögel. *Tr. Laplandskogo Gosudarvstveno Zapov.* **1960**, *5*, 1–318, (In Russian, Translated into German).

39. Lindström, J.; Ranta, E.; Lindén, H.; Lindstrom, J.; Linden, H. Large-Scale Synchrony in the Dynamics of Capercaillie, Black Grouse and Hazel Grouse Populations in Finland. *Oikos* **1996**, *76*, 221. [CrossRef]

40. Lindstrom, J.; Ranta, E.; Linden, M.; Linden, H. Reproductive Output, Population Structure and Cyclic Dynamics in Capercaillie, Black Grouse and Hazel Grouse. *J. Avian Biol.* **1997**, *28*, 1. [CrossRef]

41. Helle, P.; Lindén, H. Changes in Finnish grouse populations during the past half-century. *Suom. Riista* **2015**, 56–66.

42. Helle, P.; Belkin, V.; Bljudnik, L.; Danilov, P.; Jakimov, A. Changes in grouse populations in Finland and Russian Karelia during recent decades. *Suom. Riista* **2003**, *49*, 32–43.

43. Ranta, E.; Helle, P.; Lindén, H. Forty years of grouse monitoring in Finland. *Suom. Riista* **2004**, *50*, 128–136.

44. Baines, D.; Moss, R.; Dugan, D. Capercaillie breeding success in relation to forest habitat and predator abundance. *J. Appl. Ecol.* **2004**, *41*, 59–71. [CrossRef]

45. Sim, I.M.W.; Eaton, M.A.; Setchfield, R.P.; Warren, P.K.; Lindley, P. Abundance of male Black Grouse Tetrao tetrix in Britain in 2005, and change since 1995–1996. *Bird Study* **2008**, *55*, 304–313. [CrossRef]

46. Huhta, E.; Helle, P.; Nivala, V.; Nikula, A. The effect of human-modified landscape structure on forest grouse broods in two landscape types. *Ecosphere* **2017**, *8*, e01950. [CrossRef]

47. Müller, D.; Schröder, B.; Müller, J. Modelling habitat selection of the cryptic Hazel Grouse *Bonasa bonasia* in a montane forest. *J. Ornithol.* **2009**, *150*, 717–732. [CrossRef]

48. Kajtoch, Ł.; Żmihorski, M.; Bonczar, Z. Hazel Grouse occurrence in fragmented forests: Habitat quantity and configuration is more important than quality. *Eur. J. For. Res.* **2012**, *131*, 1783–1795. [CrossRef]

49. Schäublin, S.; Bollmann, K. Winter habitat selection and conservation of Hazel Grouse (*Bonasa bonasia*) in mountain forests. *J. Ornithol.* **2011**, *152*, 179–192. [CrossRef]

50. Swenson, J.E. Is the hazel grouse a poor disperser? In Proceedings of the 20th Congress of the International Union of Game Biologists, Gödöllö, Hungary, 21–26 August 1991; pp. 347–352.

51. Åberg, J.; Swenson, J.E.; Angelstam, P. The habitat requirements of hazel grouse (*Bonasa bonasia*) in managed boreal forest and applicability of forest stand descriptions as a tool to identify suitable patches. *For. Ecol. Manag.* **2003**, *175*, 437–444. [CrossRef]

52. Klaus, S.; Sewitz, A. Ecology and conservation of Hazel grouse *Bonasa bonasia* in the Bohemian Forest (Šumava, Czech Republic). In Proceedings of the International Conference Tetraonids at the Break of the Millenium (Tetřevovití—Tetraonidae na Přelomu Tisíciletí), Ceske Budejovice, Czech Republic, 24–26 March 2000; pp. 138–146.

53. Rolstad, J.; Wegge, P. Effects of logging on capercaillie (*Tetrao urogallus*) leks. *Scand. J. For. Res.* **1989**, *4*, 129–135. [CrossRef]

54. Haakana, H.; Huhta, E.; Hirvelä, H.; Packalen, T. Trade-offs between wood production and forest grouse habitats in two regions with distinctive landscapes. *For. Ecosyst.* **2020**, *7*, 21. [CrossRef]

55. Lindén, H.; Wikman, M. Goshawk predation on hazel grouse. *Suom. Riista* **1987**, *34*, 96–106.

56. Tornberg, R. Pattern of goshawk Accipiter gentilis predation on four forest grouse species in northern Finland. *Wildl. Biol.* **2001**, *7*, 245–256. [CrossRef]

57. Tornberg, R.; Lindén, A.; Byholm, P.; Ranta, E.; Valkama, J.; Helle, P.; Lindén, H. Coupling in goshawk and grouse population dynamics in Finland. *Oecologia* **2013**, *171*, 863–872. [CrossRef]

58. Marcstrom, V.; Kenward, R.; Engren, E. The impact of predation on boreal tetraonids during vole cycles: An experimental study. *J. Anim. Ecol.* **1988**, *57*, 859–872. [CrossRef]

59. Lindström, E.R.; Andrén, H.; Angelstam, P.; Cederlund, G.; Hörnfeldt, B.; Jäderberg, L.; Lemnell, P.-A.; Martinsson, B.; Sköld, K.; Swenson, J.E. Disease Reveals the Predator: Sarcoptic Mange, Red Fox Predation, and Prey Populations. *Ecology* **1994**, *75*, 1042–1049. [CrossRef]

60. Šťastný, K.; Bejček, V.; Hudec, K. *Atlas Hnizdniho Rozšiřeni Ptaku v Česke Republice 1985–1989 (Atlas of Breeding Birds, in Czech)*; Jinočany H & H: Jihlava, Czech Republic, 1996.

61. Kauhala, K.; Helle, P. The impact of predator abundance on grouse populations in Finland—A study based on wildlife monitoring counts. *Ornis Fenn.* **2002**, *79*, 14–25.

62. Ukkola, M.; Helle, P.; Huhta, E.; Jokimäki, J.; Kaisanlahti-Jokimäki, M.L. The impacts of ski resorts on wildlife in northern Finland. In *Arctic Centre Reports: Environment, Local Society and Sustainable Tourism*; Jokimäki, J., Kaisanlahti-Jokimäki, M.L., Tuulentie, S., Laine, K., Uusitalo, M., Eds.; Painatuskeskus: Rovaniemi, Finland, 2007; Volume 50, pp. 31–41.

63. Storch, I. Human disturbance of grouse—Why and when? *Wildl. Biol.* **2013**, *19*, 390–403. [CrossRef]

64. Le Corre, N.; Gélinaud, G.; Brigand, L. Bird disturbance on conservation sites in Brittany (France): The standpoint of geographers. *J. Coast. Conserv.* **2009**, *13*, 109–118. [CrossRef]

65. Moss, R.; Leckie, F.; Biggins, A.; Poole, T.; Baines, D.; Kortland, K. Impacts of Human Disturbance on Capercaillie *Tetrao urogallus* Distribution and Demography in Scottish Woodland. *Wildl. Biol.* **2014**, *20*, 1–18. [CrossRef]

66. Kortmann, M.; Heurich, M.; Latifi, H.; Rösner, S.; Seidl, R.; Müller, J.; Thorn, S. Forest structure following natural disturbances and early succession provides habitat for two avian flagship species, capercaillie (*Tetrao urogallus*) and hazel grouse (*Tetrastes bonasia*). *Biol. Conserv.* **2018**, *226*, 81–91. [CrossRef]