

## **Appendix S1**

### **Retrospective comparisons of competing demographic models give clarity from ‘messy’ management on a Scottish grouse moor**

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*Ecological Applications*

Table S1. Structure of equation components (annual productivity,  $P_t$ ; summer adult survival,  $S_s^{ad}$ ; and winter adult survival,  $S_w$ ) used in seven nested models predicting post-breeding ( $D_{post}$ ) and pre-breeding ( $D_{pre}$ ) density of red grouse at Langholm Moor during 1992-2019. Description of components included in the baseline model are defined in the text. Baseline model for post-breeding density,  $D_{post}^t = D_{pre}^t S_s^{ad} (1 + P_t)$ , and post-breeding density,  $D_{pre}^t = D_{oct}^{t-1} S_w$ , with  $D_{oct}^t = D_{post}^t \sqrt{S_s^{ad}} - B_t \sqrt[4]{S_s^{ad}}$ . Model name abbreviations: non-protected predator (NPP), hen harrier (HH), and buzzard (BZ).

Model	$P_t$	$S_s^{ad}$	$S_w$
Baseline	$P_{nKTW}^t$	$S_{s,nK}^{ad}$	$S_{w,dd}$
Baseline + habitat	$P_{nKTW}^t$	$S_{s,nK}^{ad}$	$HS_{w,dd}$
Non-protected predator	$P_{nKTW}^t((1 - I_K) + 3.2167 I_K)$	$S_{s,nK}^{ad}(1 - I_K) + S_{s,K}^{ad} I_K$	$S_{w,dd}$
Non-protected predator + habitat	$P_{nKTW}^t((1 - I_K) + 3.2167 I_K)$	$S_{s,nK}^{ad}(1 - I_K) + S_{s,K}^{ad} I_K$	$HS_{w,dd}$
Harrier (NPP + HH)	$P_{nKTW}^t \left( \frac{(1 - I_K) + 3.2167 I_K}{(1 - L_{HH,DF}^P)} \right)$	$\left[ \frac{S_{s,nK}^{ad}(1 - I_K) + S_{s,K}^{ad} I_K}{(1 - L_{HH}^S)} \right]$	$S_{w,dd}$
Buzzard (NPP + HH + BZ)	$P_{nKTW}^t \left( \frac{(1 - I_K) + 3.2167 I_K}{(1 - L_{HH,DF}^P)(1 - 0.039 BZ)} \right)$	$\left[ \frac{S_{s,nK}^{ad}(1 - I_K) + S_{s,K}^{ad} I_K}{(1 - L_{HH}^S)(1 - 0.092 BZ)} \right]$	$S_{w,dd}(1 - 0.088 BZ)$
Buzzard + habitat (NPP + HH + BZ + habitat)	$P_{nKTW}^t \left( \frac{(1 - I_K) + 3.2167 I_K}{(1 - L_{HH,DF}^P)(1 - 0.039 BZ)} \right)$	$\left[ \frac{S_{s,nK}^{ad}(1 - I_K) + S_{s,K}^{ad} I_K}{(1 - L_{HH}^S)(1 - 0.092 BZ)} \right]$	$HS_{w,dd}(1 - 0.088 BZ)$

## **Supplemental Figs. S1-S7**

The large quantity of information already presented in Fig. 4 precluded adding confidence intervals around model predictions as the overlap would have been too great. Here we explode Fig. 4 into seven figures (S1-S7), one for each model. Each figure shows observed and model-specific, predicted densities with 95% confidence intervals for model sets A, B and C.

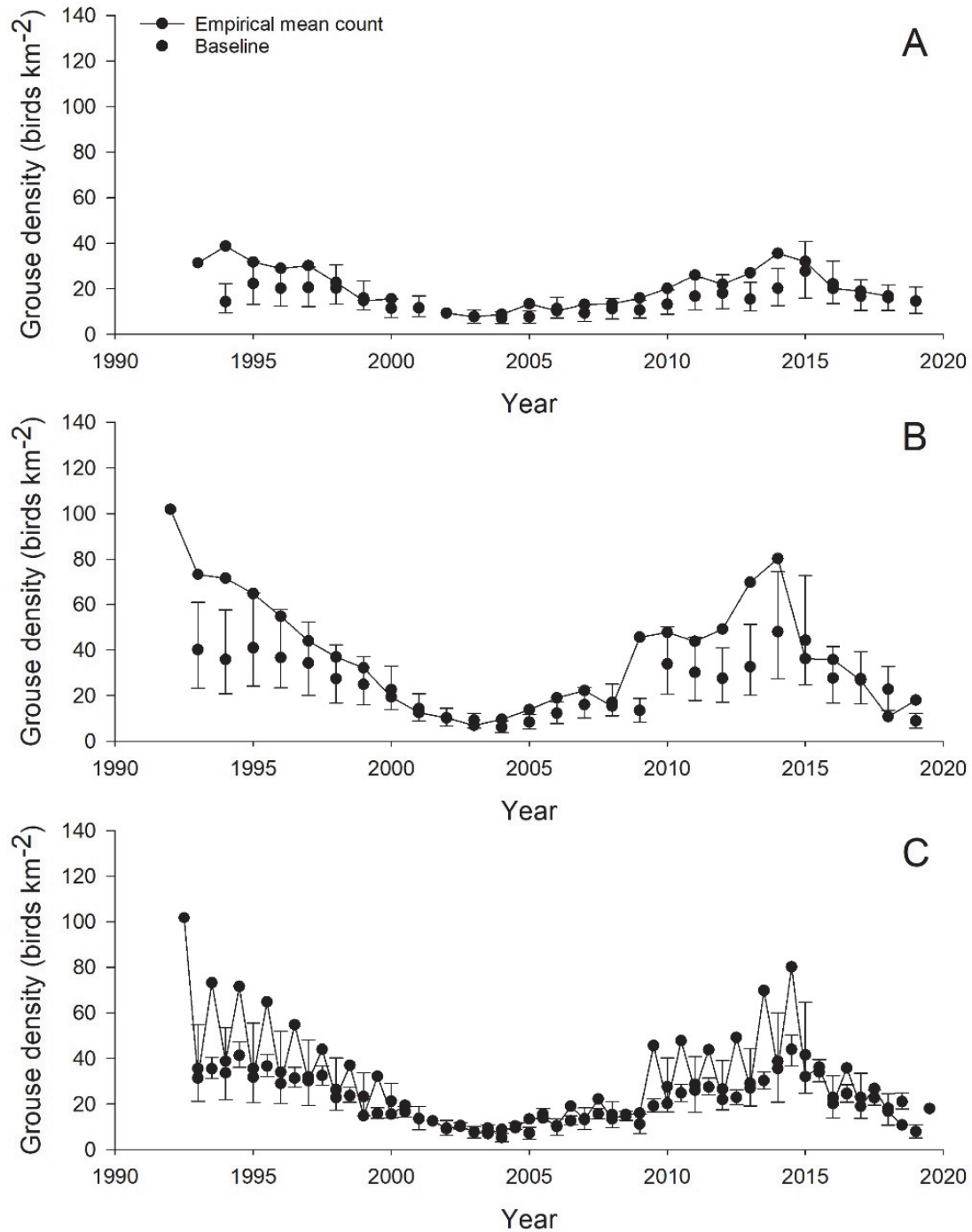


Fig. S1. Observed and predicted densities of red grouse at Langholm Moor in southwest Scotland during 1992-2019 from the baseline model in three model sets: (A) models assessed annually pre-breeding, (B) models assessed annually post-breeding, (C) models assessed seasonally both pre- and post-breeding. Model predictions are means from 500 stochastic simulations and are shown with the observed mean density for each year. Error bars show 95% bounds of simulated values. No pre-breeding density estimates were available for 1992, 2001 or 2019.

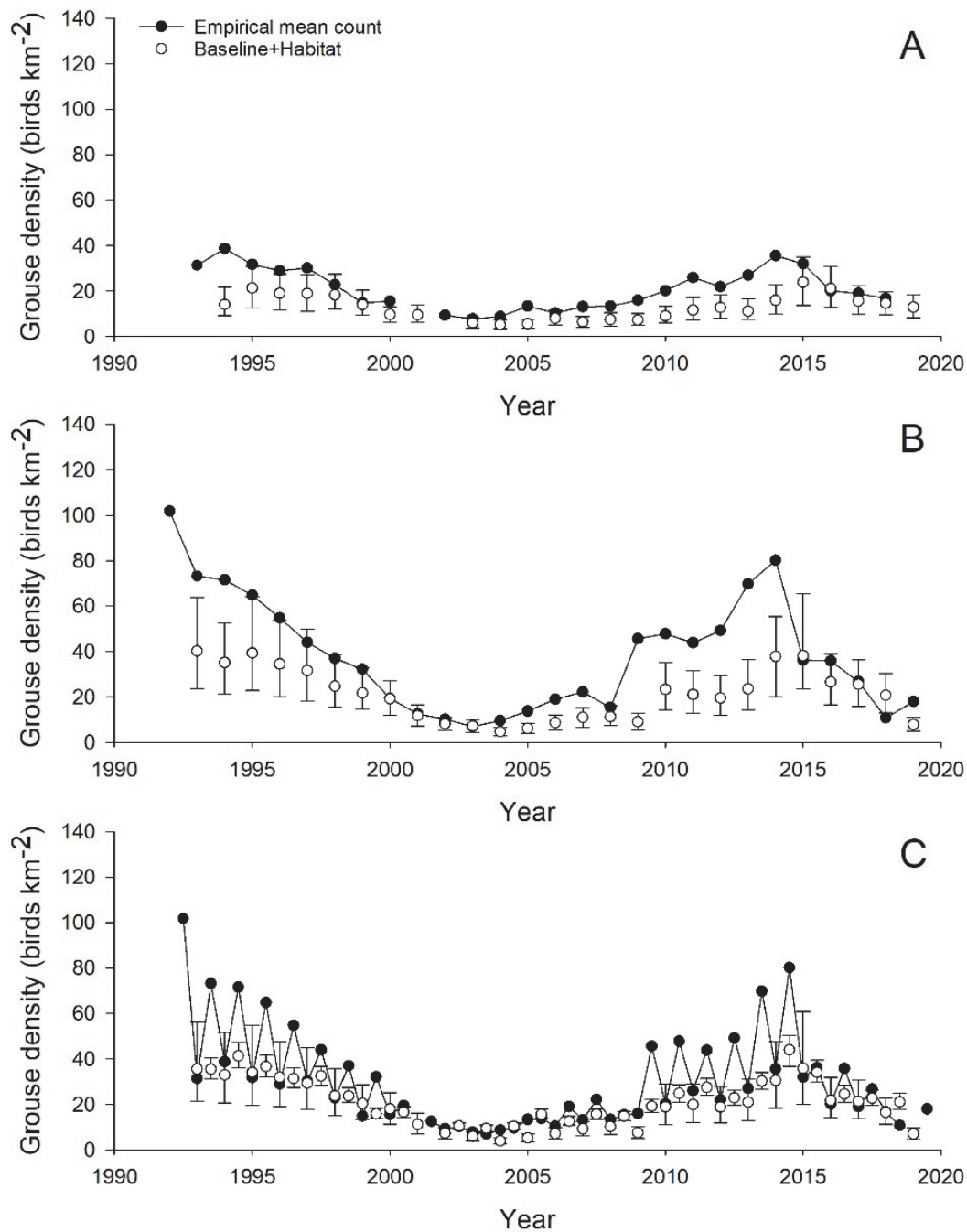


Fig. S2. Observed and predicted densities of red grouse at Langholm Moor in southwest Scotland during 1992-2019 from the baseline + habitat model in three model sets: (A) models assessed annually pre-breeding, (B) models assessed annually post-breeding, (C) models assessed seasonally both pre- and post-breeding. Model predictions are means from 500 stochastic simulations and are shown with the observed mean density for each year. Error bars show 95% bounds of simulated values. No pre-breeding density estimates were available for 1992, 2001 or 2019.

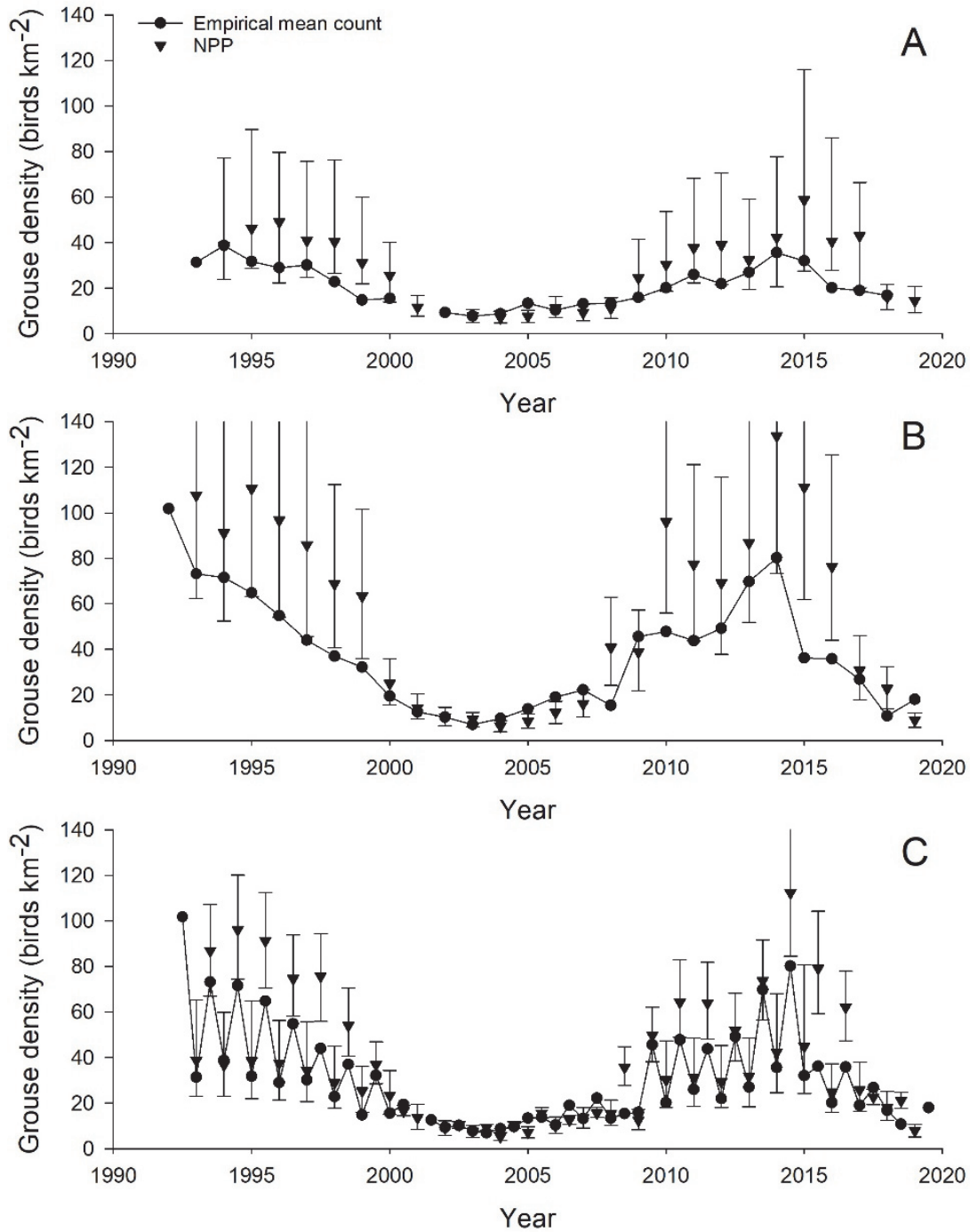


Fig. S3. Observed and predicted densities of red grouse at Langholm Moor in southwest Scotland during 1992-2019 from the non-protected predator (NPP) model in three model sets: (A) models assessed annually pre-breeding, (B) models assessed annually post-breeding, (C) models assessed seasonally both pre- and post-breeding. Model predictions are means from 500 stochastic simulations and are shown with the observed mean density for each year. Error bars show 95% bounds of simulated values. No pre-breeding density estimates were available for 1992, 2001 or 2019.

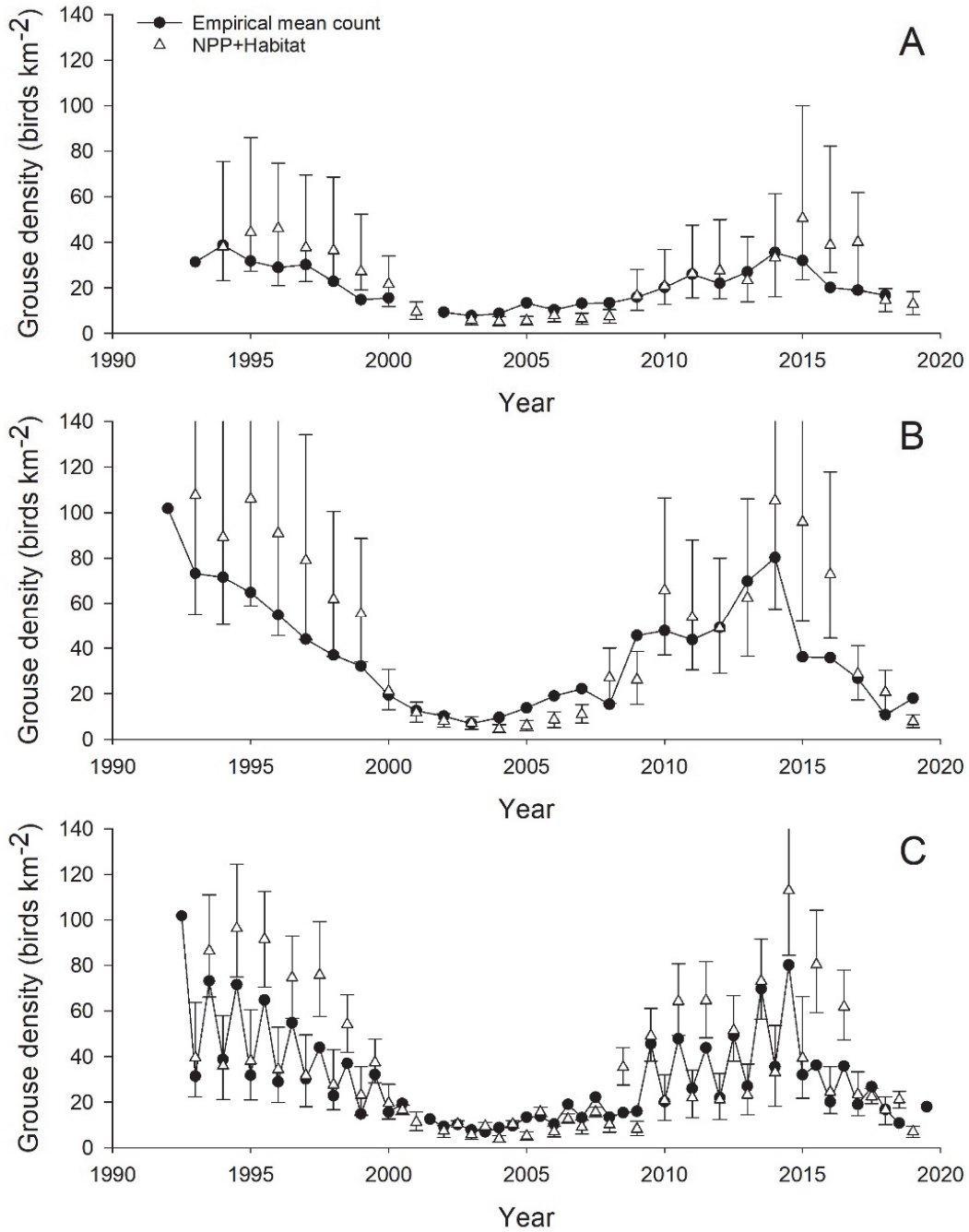


Fig. S4. Observed and predicted densities of red grouse at Langholm Moor in southwest Scotland during 1992-2019 from the non-protected predator + habitat (NPP + habitat) model in three model sets: (A) models assessed annually pre-breeding, (B) models assessed annually post-breeding, (C) models assessed seasonally both pre- and post-breeding. Model predictions are means from 500 stochastic simulations and are shown with the observed mean density for each year. Error bars show 95% bounds of simulated values. No pre-breeding density estimates were available for 1992, 2001 or 2019.

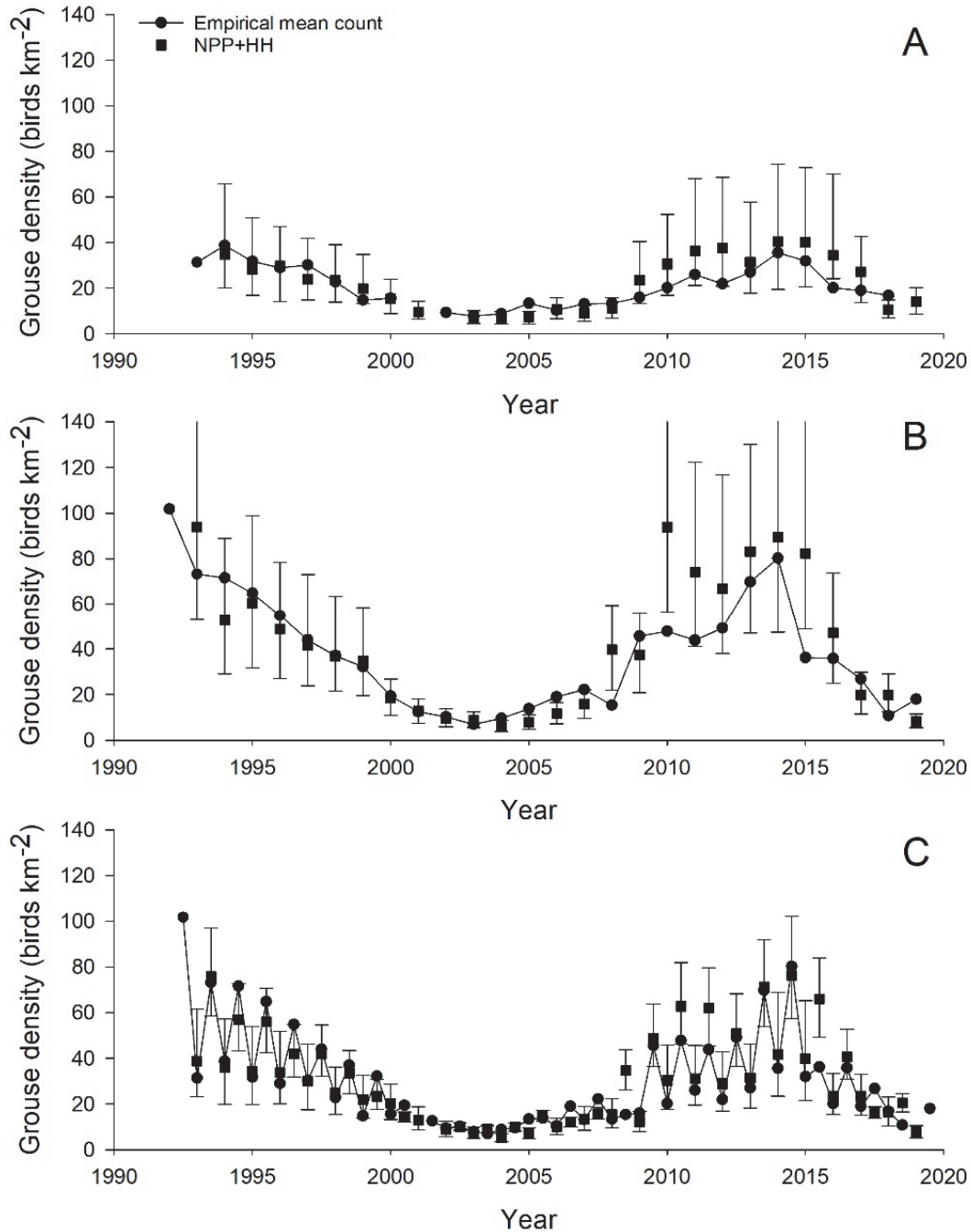


Fig. S5. Observed and predicted densities of red grouse at Langholm Moor in southwest Scotland during 1992-2019 from the non-protected predator + hen harrier (NPP + HH) model in three model sets: (A) models assessed annually pre-breeding, (B) models assessed annually post-breeding, (C) models assessed seasonally both pre- and post-breeding. Model predictions are means from 500 stochastic simulations and are shown with the observed mean density for each year. Error bars show 95% bounds of simulated values. No pre-breeding density estimates were available for 1992, 2001 or 2019.



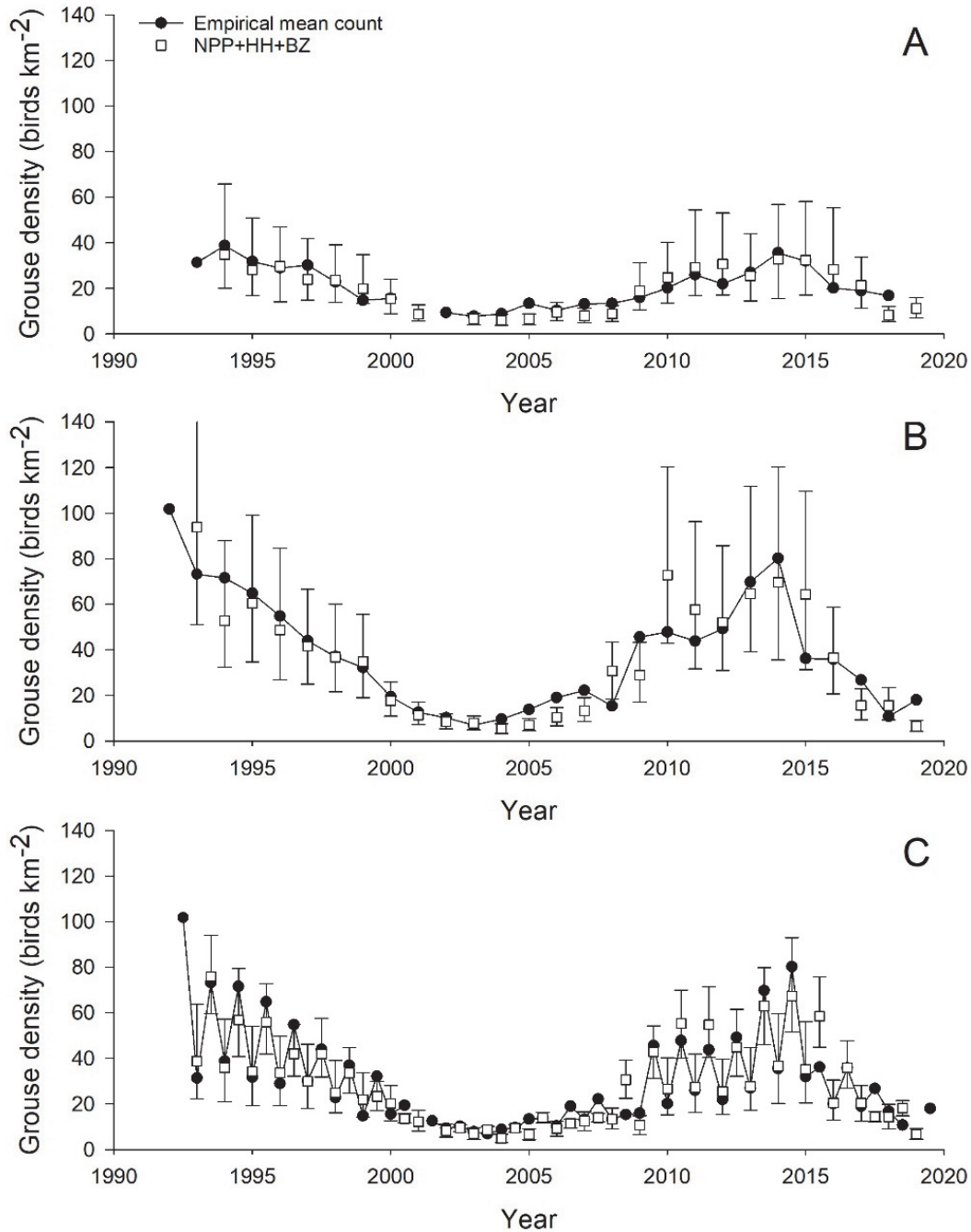


Fig. S6. Observed and predicted densities of red grouse at Langholm Moor in southwest Scotland during 1992-2019 from the non-protected predator + hen harrier + buzzard (NPP + HH + BZ) model in three model sets: (A) models assessed annually pre-breeding, (B) models assessed annually post-breeding, (C) models assessed seasonally both pre- and post-breeding. Model predictions are means from 500 stochastic simulations and are shown with the observed mean density for each year. Error bars show 95% bounds of simulated values. No pre-breeding density estimates were available for 1992, 2001 or 2019.

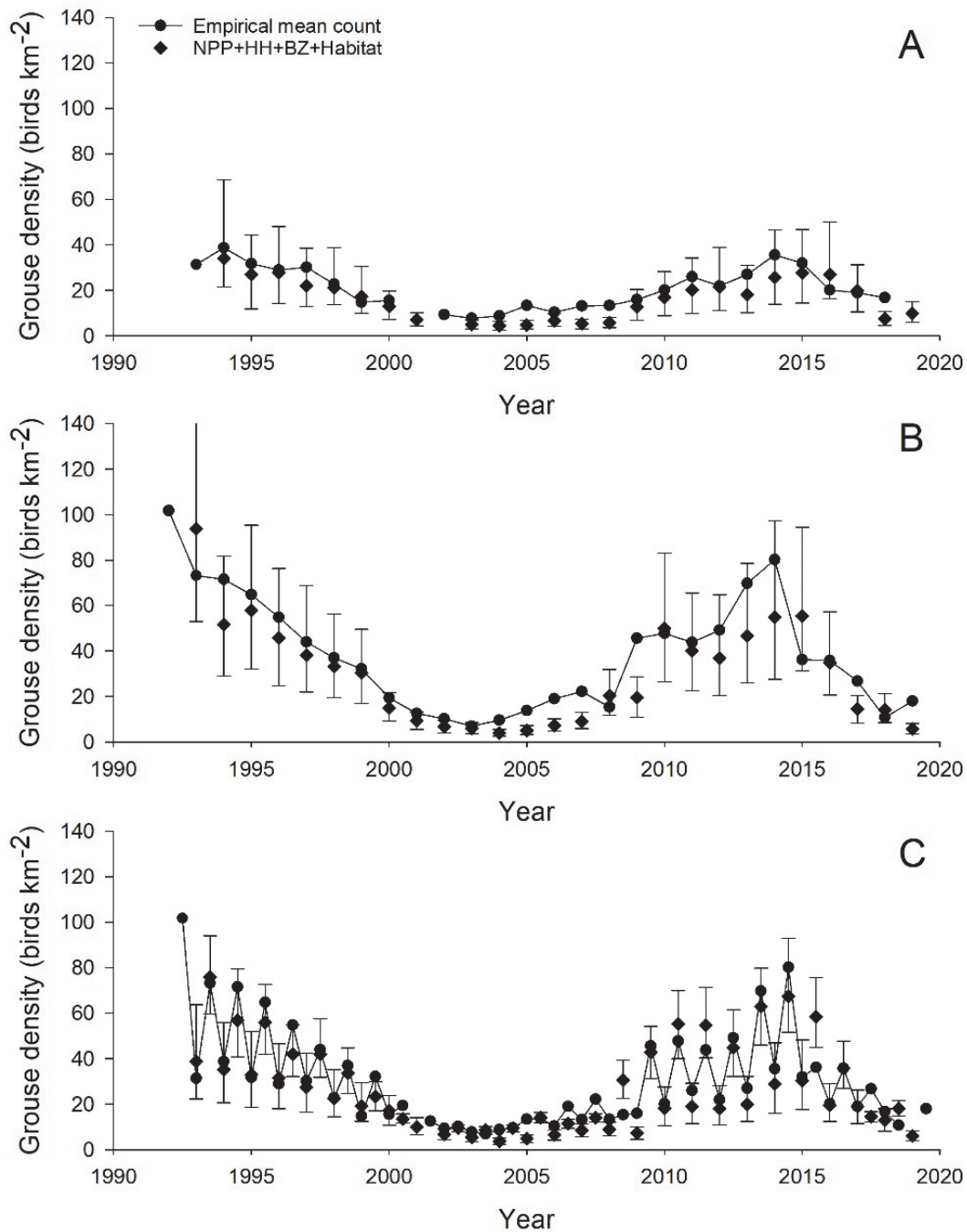


Fig. S7. Observed and predicted densities of red grouse at Langholm Moor in southwest Scotland during 1992-2019 from the non-protected predator + hen harrier + buzzard + habitat (NPP + HH + BZ + habitat) model in three model sets: (A) models assessed annually pre-breeding, (B) models assessed annually post-breeding, (C) models assessed seasonally both pre- and post-breeding. Model predictions are means from 500 stochastic simulations and are shown with the observed mean density for each year. Error bars show 95% bounds of simulated values. No pre-breeding density estimates were available for 1992, 2001 or 2019.