Lower levels of human disturbance correspond with longer-term persistence of Endangered Green Peafowl populations

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Summary

Galliformes are one of the most threatened groups of birds in Southeast Asia, with 27% of the species threatened with extinction. Long term population viability and extinction probability studies, at different levels of threat and management, are lacking due to weak life history data. This study aimed to define the long-term viability and extinction risk of two populations of the endangered Green Peafowl, facing different threat and protection levels, using Bayesian Population Viability Analysis (BPVA), which requires less data than traditional methods. The results showed an increasing trend in the Green Peafowl population in HuaiKhaKhaeng Wildlife Sanctuary (western Thailand), with a high protection level and low disturbance, high probability of assuring long-term persistence for the next 100 years; while the population in YokDon National Park (southcentral Vietnam), with a high habitat disturbance level and hunting pressure, is predicted to decline and has a high probability with 99% of extinction by 2097. Also, the BPVA showed minimum viable population (MVP) sizes of 250 and 450 calling males are required for the HuaiKhaKhaeng and YokDon populations respectively, both assuring high probability of long-term

persistence if the minimum numbers of males are available. However, the population size of 219 calling males at YokDon during the 2013 survey is lower than the MVP threshold of 450 calling males, which suggests the species has a low probability of long-term persistence in the area. Despite the limited life history data, BPVA predicted future population trend under site-specific conditions, and the information could be useful for proper management and population restoration.

Keywords: Galliformes, Minimum Viable Population, Bayesian Population Viability Analysis, HuaiKhaKhaeng Wildlife Sanctuary, YokDon National Park

Introduction

Vertebrate diversity has drastically declined over the past decades in tropical regions (Hoffmann et al., 2010). Southeast Asia in particular has a high proportion of species at risk of extinction within the next 50 years (Sodhi et al. 2004, Laurance 2006). This is due primarily to the degradation of natural habitat (Sodhi et al. 2010) and overhunting (Harrison et al. 2016). Birds particularly at risk with about 10% of the 2,696 species are designated as threatened with extinction, including about 27% of the 76 Galliformes species (IUCN 2016). However, there are no empirical data on the extinction probability of the Galliformes species in Southeast Asia (Grainger et al. 2018).

To support conservation and management decisions, it is imperative to determine, quantitatively, the extinction probability of threatened species in the region. In the past, this has been achieved using Population Viability Analysis (PVA), which predicts long-term population survival, extinction risk and associated threats within a specific environment (Boyce 1992, William et al. 2002). PVA analyzes how population growth parameters, such as initial population size, population growth rate, survival rate, productivity and predation rate are affected by environmental factors, such as habitat quality, disturbance level and protection level (Ruggiero et al. 1994). Understanding the variables affecting the survival trend of a population is crucial to defining the actions needed for the species long term management (Brook et al. 2000). Besides providing important details on the probability of extinction, PVA can be used to determine the Minimum Viable Population (MVP), defined as the minimum number of individuals of a species inhabiting a given area needed to guarantee survival of the population over a specific time frame (Shaffer 1981); higher extinction rate is typically observed in small populations in comparison with large ones (Schoener and Spiller 1987). In addition, MVP can be used to estimate the minimum area required for any given carrying capacity.

Although PVAs have potential to provide critical information for conservation planning, some studies have questioned the reliability of PVA due to large uncertainty in model outcomes (Flather et al. 2011). Viability is generally predicted using population models such as those incorporated in the Vortex software (Lindenmayer et al. 1995), that requires multiple parameters (e.g. productivity data, population growth rate and survival rate), however some parameters are not often available, as they require long-term studies (Boyce 1992). Gilpin and Soule (1986) suggested that a study of 12 generations, at least, is required for a robust extinction risk prediction. Unfortunately, most ecological studies are carried out over a three-year period (Tilman 1989, Baskin 1997), providing data that often underestimate the extinction risk (Reed et al. 2003). Generally, the life history of a species is dependent on environmental factors and management strategies (Flather et al. 2011) and therefore, each population within an area ought to be separately considered while performing a PVA analysis. Lack of relevant data has been reported as the main hindrance to viability analysis for Galliformes (Fuller and Garson 2000) and to date, only Bro et al. (2000) and Zhang and Zheng (2007) have conducted PVA studies for Galliformes in Southeast Asia. However, by running PVA in a Bayesian framework, we can develop predictive models using information on observed population abundance, for a period of at least two years, and simulate population information for a given period by random sampling within the range of the observed population abundance data from two observed periods. This approach allows the estimation of a credible range of future population abundance and predicts the probability of a future trend employing only monitoring abundance data.

The Endangered Green Peafowl (*Pavo muticus*) is among the most threatened species in Southeast Asia due to high hunting pressure and habitat destruction (McGowan et al. 1999). The original species distribution covered the whole dry-forest areas (e.g. deciduous, dry dipterocarp, pine forest) in northeast India, Bangladesh, Yunnan (southwest China), Myanmar, Thailand, Laos, Vietnam, Cambodia, peninsular Malaysia and Java, Indonesia (McGowan et al. 1999). However, recent modeling shows a severe decline in range currently scattered into small patches highlighted in six population strongholds, including southern Myanmar; northern, northwestern and western Thailand; and northern and eastern Cambodia (Sukumal et al. in press). Recently several population estimates have been made for some of the strongholds (Sukumal et al. 2015, Nuttall et al. 2016, Loveridge et al. 2017, Sukumal et al. 2017). The loud mating call by males makes detection of Green Peafowl relatively easy compared to other Galliformes species in the region (Suwanrat et al. 2015), making them a good species to investigate the predictive response of ground dwelling birds, especially in dry forest habitat, to different levels of threat and management strategies.

Therefore, the aims of this work were to estimate the long term viability and extinction risk of Green peafowl using only information on the observed population abundance in two years separated by a long interval. We use a Bayesian model to provide estimates of uncertainty as the data we have are limited (the estimates of uncertainty would be narrower in a frequentist model). In addition, we do not have the requisite ecological data (vital rates such as survival, fecundity, and net immigration) to build a more complex model or use stand-alone PVA software (e.g. Vortex). We use two populations of Green Peafowl facing different levels of threat as a case study. Specifically, we 1) estimated the population growth rate at two sites, showing different protection level, where two surveys with count data were conducted at 23 year intervals at a first site and 15 year intervals at a second site (Sukumal et al. 2015, Sukumal et al. 2018) and we projected the results into the future to see for how long the populations will persist in protected areas facing different threats and 2) defined the minimum viable population (MVP) size of Green Peafowl required for a long-term persistence of the species in a given area.

Study area

This study was focused on two sites with different levels of protection and disturbance to the Green Peafowl population. The first site was in HuaiKhaKhaeng Wildlife Sanctuary (HKK), western Thailand (15° 36´ N 99° 19´ E), with increased patrolling and reduced hunting pressure that led to an increase in the population of Green Peafowl between 1992 and 2015 (Sukumal et al. 2017). The HKK is connected to ThungYaiNaresuan Wildlife Sanctuary and this Western Forest Complex is designated as a UNESCO World Heritage Site. It covers a total area of 2,780 km^2 with an altitudinal range of 200 to 1,600 m, an annual temperature range of 8 to 38° C and a mean annual rainfall of 1,375 mm (Simcharoen et al. 2014). The dry season in HKK occurs between November and April, with a mean rainfall of 298 mm; and the wet season occurs between May and October, with a mean rainfall of 1,088 mm. The sanctuary consists of mixed deciduous forest (48%), dry evergreen forest (25%), hill evergreen forest (13%) and dry dipterocarp forest (7%) (Simcharoen et al. 2014). The information on population estimation was derived from two independent surveys during a 23-year period, comprising a historical survey between 1989 and1992 (Simcharoen et al. 1995, McGowan et al. 1999) and a follow-up survey in 2015 (Sukumal et al. 2017).

The second site was in YokDon National Park (YDN), southcentral Vietnam (12° 47´ - 13° 00´N, 107° 29´ - 107° 50´E), with a high level of habitat disturbance and hunting pressure that led to a drastic decline in the Green Peafowl population between 1998 and 2013 (Sukumal et al. 2015). The YDN is located in DakLak Province, which borders Cambodia and has a total area of 1,155 km^2, mainly dominated by dry deciduous forest (75% of total area). The area is relatively flat with an elevation of about 200m and high spots of up to 474m (Sterling et al. 2006). This area comprises the majority of suitable habitat for Vietnam's remaining Green Peafowl population (Brickle 2002). However, a recent survey in 2013 reported a much reduced Green Peafowl population in YDN (Sukumal et al. 2015), compared to the population number in 1998 (Brickle et al. 1998).

Methods

Population monitoring data

The estimation of the Green Peafowl population number in HKK was based on two historical datasets on recorded calling males, comprising 256 (Simcharoen et al. 1995) and 225-300 calling males (McGowan et al.1999); and the dataset from a follow-up survey, comprising 434 calling males with a range of 373 to 512 (95% Confidence Interval estimated using DISTANCE) (Sukumal et al. 2017). These datasets were used to model the population abundance over the last hundred years. For YDN, a historical dataset comprising an estimated 475 calling males, ranging from 391 to 559 (Brickle et al. 1998) and an estimated 219 calling males, ranging between 101 and 479 calling males, from a recent survey (Sukumal et al. 2015) were used as input for the model.

BPVA framework

The analysis was conducted using a Bayesian state-space model. We analyzed the population datasets for HKK with a high level of protection and low level of disturbance (Sukumal et al. 2017), and YDN with an observed high disturbance level (Sukumal et al. 2015) to illustrate the potential differences in extinction probability. We chose a state-space approach to account for both sampling and demographic uncertainty. Ideally, one would incorporate monitoring data over a longer time period, but such data is unavailable for Green Peafowl. Hence, for the simulation procedure, a constant rate of growth was assumed throughout the projected time series. The initial population size was inputted in range from 0 to the initial population estimate. We used estimated historical population number at each site as a maximum initial population size in the analysis. The population estimates from the historical and recent surveys were used to calculate annual population abundances in HKK, from 1992 to 2015, and in YDN, between 1998 and 2013. These annual population abundances were used to estimate average population growth rates and the average population growth rate values were then used to estimate the future population abundance trend over the next 100 years (1992-2092 for HKK, and 1998-2098 for YDN). We ran BPVA under the assumption of exponential growth rate when no constraints were applied because the estimation of carrying capacity (k) is highly uncertain, especially for a species that has been hunted unsustainably, resulting in a sparse population distribution across the entire range.

Data analysis

Posterior distribution of parameters was conducted using Markov chain Monte Carlo (MCMC) simulations in the program JAGS, implemented using the R (R Development Core Team 2014) package "R2jags" (Su and Masanao 2015). The analysis was run using three independent chains for 50,000 iterations after a burn-in of 10,000 iterations.

MVP was determined following BPVA approach (Saunders et al. 2018) whereby each population number was inputted in a loop procedure as the mean of recent population sizes. Next, the lowest population number that showed a stable or increase future population trend after 50 years was used to simulate the population abundance.

Results

Population viability at different disturbance levels

In HKK (western Thailand), with a high level of protection and low disturbance, the Green Peafowl population size was stable over the study period, as evidenced by the BPVA estimated population abundance of 209 (credible interval or CI predicted by model = 26-255) and 261 (CI = -49 – 411) calling males in 1992 and 2015 respectively, with an overlapping CI. If the current protection and disturbance levels in the area remains, the population size will increase to 1,516 calling males (CI = 896-2,081) by 2091 (Figure 1).

In contrast, the population size in YDN (southcentral Vietnam), with a high level of habitat disturbance and hunting pressure, drastically declined between 1998 and 2013. The estimated population abundance, along with the corresponding CI in 1998 and 2013 were 458 (CI = 410-474) and 111 (CI = 33-165) calling males, respectively. If the status quo remains going forward, without any conservation or management improvement, the species has a 63% chance of going extinct, based on our model, as evidenced by the estimated population size of 0.95 (CI = 0.17-3.93) in 2052 (Figure 2).

Minimum Viable Population (MVP)

In HKK, the smallest population number that could maintain long-term population survival (i.e. MVP) for 76 years from last survey, i.e. from 2016 to 2091, or for the 100-year period between 1992 and 2091, is 250 ±124 (SD) calling males, assuming the current protection and disturbance levels, comparable to conditions in 1992, are maintained going forward. However, this number is lower than the estimated initial historical population size of 256 calling males (Simcharoen et al. 1995) (Figure 3).

In contrast, for YDN, the smallest initial population size that could maintain a long-term population survival (i.e. MVP) for 84 years from last survey (i.e. from 2014 to 2097) is 450 ±145 calling males (Figure 4). This number lies within the initial historical population range of 391 to 559 (Brickle et al. 1998) and is higher than the recent population estimate of 219 calling males, indicating that Green Peafowl population is currently at a level of population size that does not appear to be sustainable, given demographic influences in the region.

Discussion

We conducted our analysis employing only data on population abundance from two timeframes at two different sites, with different protection and disturbance levels, to simulate the historical, recent and future (next 100 years) population trends. Results from the HuaiKhaKhaeng Wildlife Sanctuary, which has a high level of protection and low disturbance, suggest a positive Green Peafowl population growth, assuring long-term population persistence for the next 70 years. An MVP size of 250 calling males was determined to guarantee the species long-term persistence in the area. In contrast, the Green Peafowl population in YokDon National Park, suffering high habitat disturbance and hunting pressure, drastically declined and our analysis predicts the population has a 63% chance of going extinct in the year 2052, in the absence of intervention measures. Our model estimated that a population level of 450 calling males were the lowest level at which a stable population was predicted under the assumptions of our model, which included an assumption of exponential growth. However, the latest survey, in 2013, showed the population number is lower than this MVP, and we infer this to be strong evidence that the species may be at risk of local extinction.

Using population abundance information with BPVA

Our ecological knowledge of Green peafowl is still limited in terms of life history parameters such as annual productivity despite the availability of efficient methods that increase their detection probability, compared to other forest Galliformes species (Suwanrat et al. 2015). In the absence of the life history data, the state-space modelling approach allowed us to simulate the current and future population abundance of the species using historical monitoring data. However, because we lacked empirical productivity and survival information, our model's outputs were characterized by high uncertainty (i.e. wide Credible Interval of posterior abundance). Therefore, we recommend the integration of life history information, when available, to improve the precision of the analysis.

Given the difficulty in obtaining life history data, our basic model is a promising tool for conservation planning.

Population viability analysis has been scarcely applied to study Galliformes species, especially in Southeast Asia. For the whole Asia region, only one case study that collected the long-term life history data (from 1982 to 2004) of Cabot's Tragopan (*Tragopan caboti*) in Wuyanling, south-east China, and VORTEX was used in the study to estimate population viability (Zhang and Zheng 2007). VORTEX requires substantial life history information (e.g. population growth rate, survival rate) for conducting PVA. Nevertheless, by integrating the limited data on population abundance with Bayesian approach, reliable prediction of the future viability of the population, and appropriate management actions could be recommended.

Conservation and management implication

As expected, the two protected areas show a marked difference in the disturbance and protection levels. HuiKhaKhaeng has a high level of protection with minimum disturbances. The effective patrolling system covering the entire area has resulted in a reduction of hunting pressure. Moreover the sanctuary has reduced human activities due to the prohibition of settlement within the area. The good management in HuaiKhaKhaeng Wildlife Sanctuary has reportedly led to an increase in population of various endangered species, e.g. Tiger (*Panthera tigris*) (Duangchantrasiri et al. 2016), Banteng (*Bos javanicus*) and Green Peafowl (Sukumal et al. 2017). If the current management system is maintained, the population levels of Green Peafowl have high probability of being maintained for the next 70 years. However, monitoring of Green Peafowl population abundance should be conducted every 5 years, which is the age of sexual maturity for males (Madge and McGowan 2002). To assure long-term persistence of the Green Peafowl population in the site managers should aim to maintain at least 250 calling males. By contrast, YokDon is characterized by high habitat disturbance and hunting pressure. Overgrazing by domestic cattle and bushfire have led to the deterioration of vegetation cover, resulting in the loss of foraging and nesting sites for Green Peafowl. These disturbances, in addition to a high hunting pressure, contributed to the drastic decline in Green Peafowl population in the area (Sukumal et al. 2015). A study conducted in 2013 revealed the counted population of Green Peafowl in YokDon was below the level predicted by the model as the one needed to sustain it in the long term following the current growth rate, indicating that the population may be at risk of local extinction. Measures such as restriction of human activities and effective patrolling are crucial to improving the Green Peafowl population. YokDon is strategically important for the survival of the species in Southeast Asia as it is connected to Mundulkiri Protected Forest at eastern part of Cambodia, which is home to a large population of Green Peafowl (Sukumal et al. in press).

Generally, native wildlife populations are facing different threat levels and management strategies are urgently required to ensure their survival. Understanding how a population responds to site-specific conditions is key to setting up proper management plans for effective population restoration. Our results clearly show that protection level affects long term survival of species, we can see that with improved protection populations tend to increase, while with absence or reduce protection population decrease. Therefore, projecting future protection level, when those data are available, should be included when performing viability analysis. Information on population abundance can be useful to investigate the population viability and predict plausible future population trend. Considering the relative ease of detecting calling males during the breeding season, Green Peafowl could be used as indicator species to investigate the response of ground-dwelling birds to human-induced threats in their dry forest habitat. Information on population abundance could be integrated with BPVA to predict future population trends under site-specific conditions. Moreover, we expect that this analysis can be applied to other species where only population abundance and not life history information is available. The BPVA can also be applied to a broader scale for determining suitable management strategies especially for highly threatened species.

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Figures

Figure 1. Predicted population size from 1992 to 2091 (blue line, year 1-100) of Green Peafowl in HuaiKhaKhaeng Wildlife Sanctuary from a simulation model of population growth. Red shading represents 95% credible intervals (CI).

Figure 2. Predicted population size from 1998 to 2097 (blue line, year 1-100) of Green Peafowl in YokDon National Park from a simulation model of population growth. Red shading represents 95% credible intervals (CI).

Figure 3. Predicted population size from 1992 to 2091 (blue line, year 1-100) of Green Peafowl in HuaiKhaKhaeng Wildlife Sanctuary, by inputting 256 calling males of historical datasets at population abundance in 1992 and inputting the mean number of 250 ±124 (SD) calling males at population abundance in 2015. Red shading represents 95% credible intervals (CI).

Figure 4. Predicted population size from 1998 to 2097 (blue line, year 1-100) of Green Peafowl in YokDon National Park, by inputting 475 calling males of historical datasets at population abundance in 1998 and inputting the mean number of 450 ±145 calling males at population abundance in 2013. Red shading represents 95% credible intervals (CI).

Figure 1

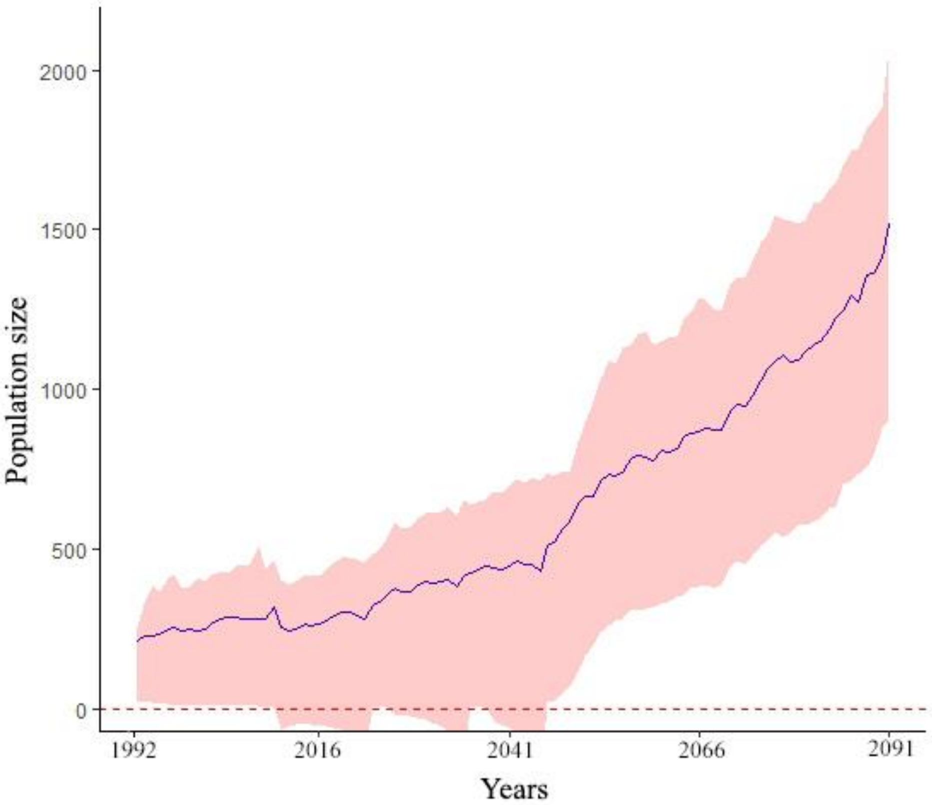
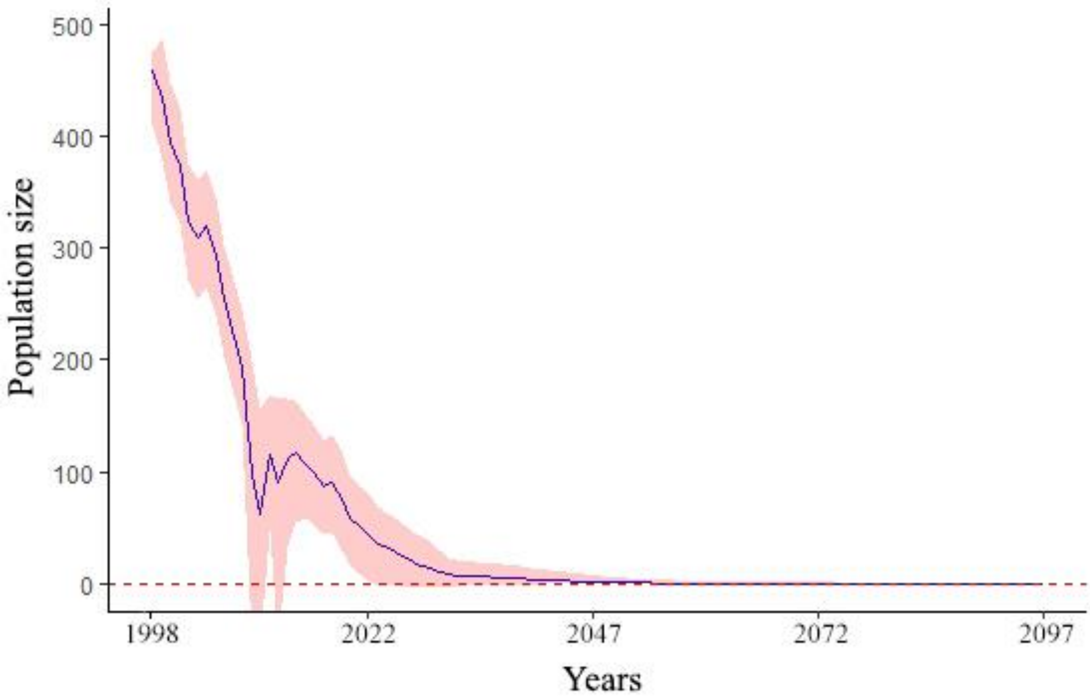


Figure 2



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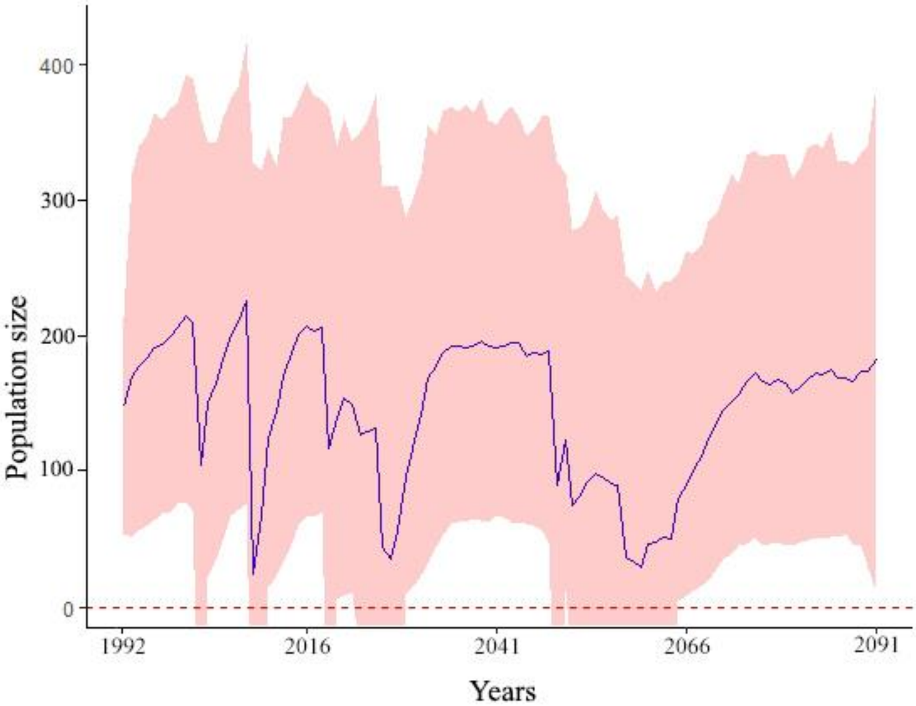
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Population size
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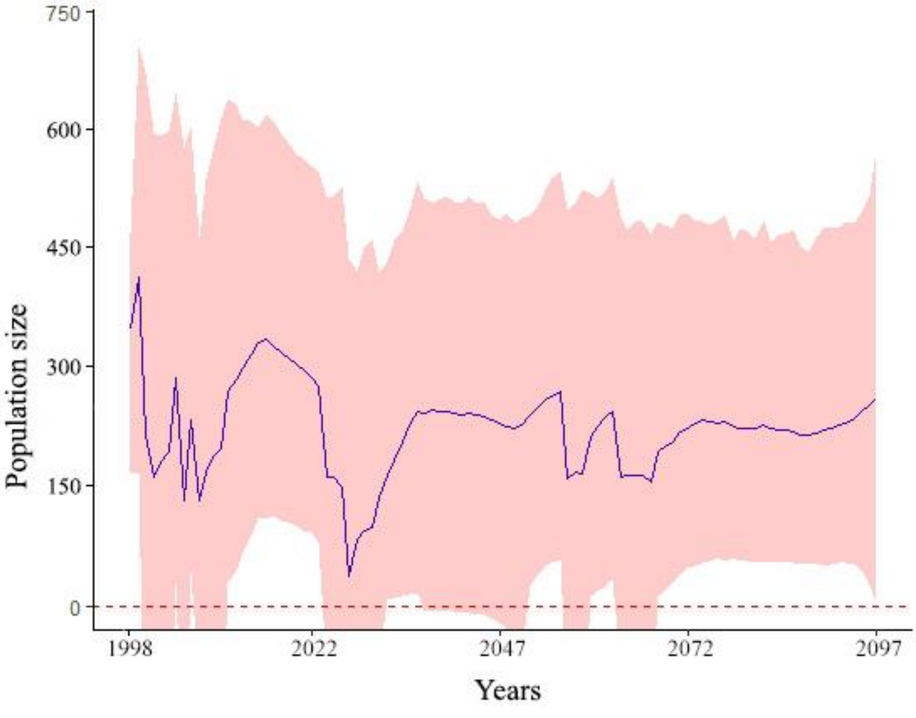
Figure 4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