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**Reinforcement is not enough to stabilize the population of an endangered long-distance migrating passerine**

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**Authors contribution**

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**Abstract**

Population viability analysis (PVA) is a valuable tool to guide the reinforcement of endangered bird species. In migrants, demographic data required for population projections are often deficient, making reinforcement outcomes challenging to predict. The globally threatened Aquatic Warbler *Acrocephalus paludicola* is a long-distance migrating passerine that breeds in sedge fen mires in Central Europe and winters in sub-Saharan Africa. Although conservation measures have stopped the decline in the core breeding sites, the westernmost breeding population in Europe (Pomeranian population) is currently threatened with extinction. In this study, we used PVA simulations under different demographic scenarios to determine the most important vital parameters driving the decline and to reveal the duration of releases of juveniles, translocated from the core breeding area needed for a stable population.

Second broods

Number of release years

Habitat restoration

Improvement of survival

**Word limit abstract: 250 / Text: 8000**

**Introduction**

Worldwide, a growing number of vertebrate species are threatened with extinction (**Munstermann et al., 2021**). Anthropogenic pressure and climate change increase habitat loss and fragmentation, which accelerates the risk of population decreases (**Dale, 2001; Lees et al., 2022**). Conservationists are facing the challenge to effectively manage populations and halt ongoing declines (**Bubac et al., 2019; Davis et al., 2023**). For small and isolated populations, providing and maintaining suitable habitat is sometimes not sufficient to increase numbers again (**Dale, 2001; Armstrong and Reynolds, 2011**). Therefore, reinforcement by translocations or captive breeding is an increasingly applied conservation action to assist the population recovery of endangered species (**IUCN/SSC 2013; Bubac et al., 2019**).

Migratory species are more susceptible to population changes than residents and several Afro Palaearctic migrants have declined during the last decades **(Vickery et al., 2014; Lees et al., 2022)**. Nevertheless, only few reinforcement projects have been directed at long-distance migrants (**Pain et al., 2018; Oppel et al., 2021)**. The implementation of effective conservation measures for long-distance migrants has to take into account that their lifecycle includes breeding sites, staging sites during migration and the wintering site, covering different climatic zones and habitats, which in turn are subject to variable threats and alternations (**Vickery et al., 2014; Oppel et al., 2024**). The habitat conditions at the breeding sites are often well studied, but most migrants spend more than 75% of the year at non-breeding sites, where preconditions and parameters affecting survival are poorly understood (**Halupka et al., 2017; Davis et al., 2023**). Carryover effects that influence survival and reproduction will also impact reinforcement outcome (**Finch et al., 2014; Davis et al., 2023**).

To our knowledge, there has been no reinforcement approach for a long-distance migrating passerine so far. Generally, high juvenile mortality and low levels of natal philopatry in long-distance migrating passerines reduce recruitment and may impede the recovery of a population at a given release site (**Weatherhead & Forbes, 1994; Carter et al., 2008; Imlay et al., 2010**). Long durations of releases will be required to observe changes in population size to evaluate reinforcement success (**Carter et al., 2008; Imlay et al., 2010**). Additionally, due to low recapture probabilities in migrating passerines, data on survival and dispersal are often scarce making population development after translocations difficult to predict (**Heinsohn et al., 2022**).

Population viability analysis (PVA) is an important tool to guide the reinforcement of endangered bird species (**Schaub et al., 2009; Armstrong and Reynolds, 2011; Heinsohn et al., 2022**). PVA models simulate temporal changes in population size and estimate extinction probability incorporating demographic stochasticity and can also be used to predict reinforcement outcomes (**Akçakaya and Sjogren-Gulve, 2000; Oppel et al., 2021**). Because these models rely on demographic input data, availability and quality of vital parameters are crucial for estimating future population size (**Coulson et al., 2001**). However, data on survival and reproductive output are often deficient in threatened species (**Heinsohn et al., 2022; Davis et al., 2023**). Especially in long-distance migrants, survival can be expected to be highly variable due to annually changing habitat conditions during migration and wintering (**Ockendon et al., 2014; Halupka et al., 2017**), which further increases uncertainty for future predictions. But even with uncertainties, PVA models can still be useful to compare different management options (**Heinsohn et al., 2022**). Furthermore, the calibration of projections using observed data can be essential to evaluate the validity of demographic assumptions and derived population dynamics (**Badia‐Boher et al., 2024**). In the last decade, PVAs have been increasingly combined with Integrated Population Models (IPMs) (Schaub & Kéry, 2021). IPMs are a modelling framework that uses the shared demographic information between different monitoring datasets from the same population (e.g., mark-recapture, productivity, counts) to provide more precise estimates of demographic estimates and population dynamics (**Schaub & Abadi, 2010**). Merging IPMs and PVAs guarantees 1) a correct propagation of uncertainty from the demographic estimates to the PVA projections, which is fundamental to obtain reliable PVA results (**Chaudhary & Oli, 2002; Reed et al., 2002; Badia-Boher et al., 2024**), and 2) a potential gain in the precision of the projections, thanks to the properties of IPMs.

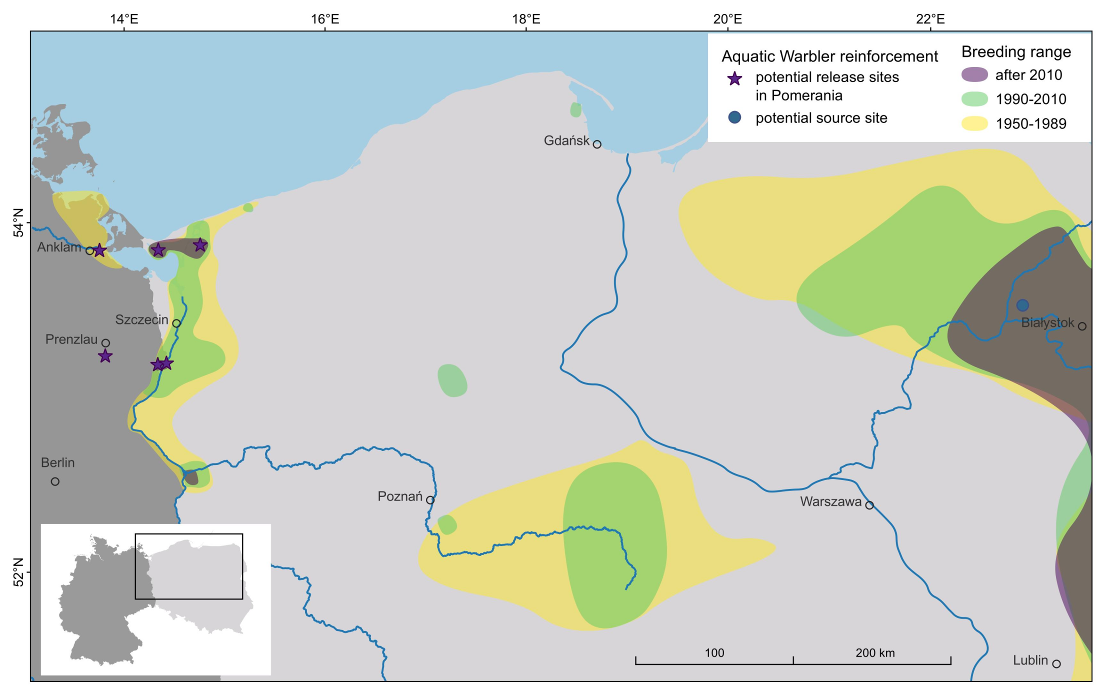
In this study, we used an IPM-PVA to inform the reinforcement of a long-distance migrating bird. The Aquatic Warbler *Acrocephalus paludicola* is a small passerine that breeds in mesotrophic sedge fen mires in Central Europe and winters in sub-Saharan Africa. The species was once widespread and numerous throughout Europe. During the last century, the global population experienced a severe decline (> 90%) caused by habitat loss and degradation due to drainage, peat extraction, conversion to agricultural land and eutrophication (**Flade and Lachmann, 2008; Tanneberger et al., 2011; Briedis and Keiss, 2016**). Today, the Aquatic Warbler is one of the rarest songbirds of continental Europe, classified under the IUCN category “vulnerable” given its small breeding range and continuing threat of habitat loss and population decline (**BirdLife International, 2024**). After the implementation of conservation measures, the decline was halted in the core breeding sites of the species. Only four breeding sites in Belarus, Poland and Ukraine hold 75% of the entire world population of about 11,000 singing males (**Flade et al., 2018).** In peripheral breeding sites, however the decline continues and the westernmost population in Germany and northwestern Poland (hereafter Pomeranian population) is currently threatened with extinction. Recently, a pilot study demonstrated the successful translocation of young Aquatic Warblers prior to their first migration from Belarus to Lithuania (**Morkvėnas et al., 2025**). Following this trial, the first translocation from the core breeding sites started the reinforcement of the Pomeranian population in 2023.

We first try to estimate which demographic parameters may have contributed to the decline of the Pomeranian population of Aquatic Warblers using observed count data. We then used the estimated parameters in a population model to project future population trajectories under different conservation management scenarios, specifically to investigate for how many years releases would be needed to establish a stable population and whether additional conservation measures such as habitat restoration and improvements in survival would be required to achieve population persistence. Our results can inform the reinforcement process of Aquatic Warbler translocations to successfully recover the nearly extinct Pomeranian population and may be useful for the conservation management of other long-distance migrating passerines.

**Material and methods**

**Study population**

The Pomeranian population of the Aquatic Warbler comprises breeding sites in northwestern Poland and northeastern Germany, which are nowadays the westernmost remnants of a once widespread European breeding range (**Flade et al., 2018**). After the successive disappearance of several breeding sites in western Poland, the Pomeranian population is now geographically isolated from core breeding sites in eastern Poland (Fig. 1). Aquatic Warblers show an extraordinary promiscuous breeding system with uniparental brood care by females which attempt to breed twice between May and July (**Schulze-Hagen et al., 1999; Dyrcz et al*.*, 2018**). Females behave very secretive, but males sing continuously during the breeding season from exposed vegetation structures some hours before sunset to attract mates (**Schulze-Hagen et al., 1999; Dyrcz et al., 2018**). Therefore, population size is assessed by counting singing males in this species, which is also a good indicator for the number of nests (**Kubacka et al., 2014**). Counts take place at the end of May and end of June, during the peaks of the first and second breeding attempts. Comprehensive and largely synchronous annual counts were conducted with standardised methodology in Poland in 1993 and 1997 (**Krogulec and Kloskowski, 2003**), and from 2003 onwards in the entire range of the Pomeranian population. In the remaining years only a subset of sites was counted each year. Despite conservation actions, the Pomeranian population strongly declined during the last 30 years (**Flade et al., 2018**). After a pilot study demonstrated the successful translocation of Aquatic Warbler chicks from Belarus to Lithuania (**Morkvėnas et al., 2025**), the reinforcement of the Pomeranian population started with the first translocation from core breeding sites in eastern Poland (Biebrza National Park) to northwestern Poland (Rozwarowo Marshes) in 2023. Further translocations to former and suitable breeding sites within the Pomeranian population range (Fig. 1) are planned during the following years (within a large-scale EU-funded conservation project).



**Fig. 1.** Breeding range decline of the Aquatic Warbler in Germany and Poland and location of potential release sites for the reinforcement of the Pomeranian population.

**Demographic parameters to inform population model**

Because the Pomeranian population is very small and has been decreasing for decades, very few data on the survival and fecundity of Aquatic warblers exist from this population. To construct a population model and project future population trajectories, we therefore had to adopt demographic parameters from closely related populations in Poland. These studied populations nest in similar habitat, at similar latitude, follow the same migratory flyway, and are likely connected by dispersing individuals (Kubacka et al. 2024), hence we consider it reasonable that survival and fecundity of these populations could also be realized in a restored Pomeranian population.

The breeding system of Aquatic Warblers was classified as polygynous (**Schulze-Hagen et al., 1999**). The majority of broods are fathered by more than one male, and females mate with several partners during the breeding season (**Dyrcz et al., 2018**). Males defend no exclusive territories and no pair bonds are formed (**Schulze-Hagen et al., 1999**). Therefore, we assume that all males and all females of a population (except for fledglings) attempt to reproduce every year (Tab. 1). Clutch size varies between 3 and 6 eggs with a median of 5 eggs (**Dyrcz and Zdunek, 1993b; Schulze-Hagen et al., 1999**). Breeding success is generally > 60% and the average number of fledglings per brood is 3.5 ± 1.8 (**Dyrcz and Zdunek, 1993b ; Kubacka et al., 2014**). Under optimal conditions up to 50% of the females initiate a second brood (**Dyrcz and Zdunek, 1993b; Schulze-Hagen et al., 1999**), and the number of fledglings was smaller in second broods (1.8 –3.7 fledglings) than in first broods (2.3 – 4.0 fledglings, **Kubacka et al., 2014**). Sex ratio at birth is balanced (49% males, **Dyrcz et al., 2004**), while adult sex ratio in the breeding population is assumed to be slightly male biased (56% males, **Dyrcz and Zdunek, 1993a**). Population assessments in the Aquatic Warbler are based on counts of singing males (**Krogulec and Kloskowski, 2003**), and we assumed that the number of males counted represented 56% of the total population size.

Annual survival for adults (males: 0.67, 95% confidence interval: 0.54–0.79; females: 0.42, 0.29.0–0.56) was obtained from a mark-recapture analysis of 279 Aquatic Warblers (149 males, 130 females) ringed between 1987 and 1995 in Biebrza Marshes in Poland (**Dyrcz and Zdunek, 1993a; Dyrcz and Chylarecki, 2018**). The lower estimates for females are probably attributed to a lower detection probability because of a more secretive behaviour, but may also be caused by lower site fidelity and higher dispersal probability (**Bellebaum, 2018; Dyrcz and Chylarecki, 2018**). Data to estimate first year survival were available from juveniles translocated from Zvanets (Belarus) to Zuvintas Biosphere Reserve (Lithuania) in 2018 and 2019 (**Morkvėnas et al., 2025**), and first-year survival was therefore directly estimated in our model (see below).

Carrying capacity is difficult to derive, because breeding densities are highly variable throughout the range and are possibly lower in small and isolated sites. In high quality habitats breeding density can be high, on average 9.6 (1.8-21.5) singing males per 10 ha and on average 6.0 (0.0-18.0) nests per 10 ha (**Kubacka et al., 2014**). In Pomerania, however, these densities of singing males have never been reached, and we therefore used a density of 1.5 males and 1.2 nests (breeding females) per 10 ha to calculate carrying capacity, which represents the average singing male densities of former Pomeranian breeding sites (**Tanneberger et al., 2018**).

**Population model structure and estimation of growth rate**

We estimated demographic parameters of the Aquatic Warbler using an integrated population model structured like similar models for other *Acrocephalus* warblers (Saether et al. 2004). The population model was constructed with two age classes, juveniles and adults, and assumed that all females started breeding at the age of one year, and that a certain proportion of adult birds were males (this proportion followed a normal distribution with a mean of 0.56 and a standard deviation of 0.01). We used a Leslie matrix to describe the transition probabilities of juveniles and adults from one year to the next and estimated those transition probabilities with the parameters for survival and productivity of breeders. We assumed that annual survival during the first year of life (juvenile survival) was different from annual survival for birds that were older than one year (adult survival).

Annual fecundity was decomposed into a process determined by the number of successful broods and the fledged brood size. We assumed that in the past, intensive agricultural management and early mowing of breeding habitats did not permit raising two broods, so second broods were only possible in hypothetical scenarios of the past or in future management scenarios. The proportion of birds raising two broods was assumed to follow a normal distribution with a mean of 0.25 and standard deviation of 0.07. The number of fledglings per first brood was assumed to follow a normal distribution with a mean of 3.15 and a standard deviation of 0.16, while the number of fledglings per second brood followed a normal distribution with a mean of 2.75 and a standard deviation of 0.2.

To estimate survival probabilities from individual capture-recapture data we used a Cormack-Jolly-Seber open population live recapture model based on 99 individually marked birds released in Lithuania in 2018 and 2019 and recaptured every year until 2022. This recapture model assumed annually varying survival and recapture probabilities, and that the probability to recapture males was greater than for females. We used informative priors for juvenile (normal: 0.32±0.025) and adult (normal: 0.42±0.03) survival probability, and vague priors for sex-specific recapture probabilities (uniform 0.05-0.75).

The state process was linked to survey data of singing males from 2003 – 2022 and assumed that only males were counted with some observation error based on a Poisson distribution. We calculated the population growth rate as the geometric mean of the annual changes in total population size (N *t+1* / N *t*). To include the effects of density dependence and habitat limitations, we assumed that during the 1990s the area of occupancy was 2965 ha for the Pomeranian population (Flade et al. 2018), and thus permitted an upper population size of 356 females (density of 1.2 females / 10 ha \* 2965 ha). If the projected number of adult females exceeded the carrying capacity *K* of the available habitat, then only *K* adult females were permitted to reproduce, while the remaining females were assumed to roam and omit breeding, but they were not removed from the population.

We fitted the integrated population model using a Bayesian approach to combine the joint likelihood with prior probability distributions of the parameters to draw inferences about all demographic parameters (Kéry and Schaub 2012; Schaub et al. 2010; Schaub et al. 2007). We ran four Markov chains with 75,000 iterations each and discarded the first 25,000 iterations. From the remaining iterations we only used every fifth iteration for inference, and we tested for convergence using the Gelman-Rubin diagnostic (Brooks and Gelman 1998); all estimated parameters had values of R-hat < 1.002. To calculate the posterior distributions of the parameters of interest, we used Markov chain Monte Carlo methods in JAGS v. 4.3.0 called from R via the jagsUI package (Plummer, 2017; Kellner, 2016).

**Reinforcement and management scenarios**

To address our main question which management scenario may result in a stable population of Aquatic Warblers in Pomerania, we explored several plausible scenarios that considered changes in survival, productivity, extent of habitat and the duration of reinforcement.

After fitting the model to the past observation data from 2003 to 2022, we explored 3 alternative (hypothetical) scenarios for the past, how the population could have developed in the past if (1) mowing regimes had been changed in 2003 to allow second broods; (2) if survival had been improved by 5% from 2003 onwards, and (3) if both mowing regimes and survival had been improved simultaneously in 2003.

We then explored 36 different scenarios that combined the following combinations of reinforcement and other management.

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Based on experience from pilot translocations of Aquatic Warblers, 10 nests (~50 chicks) per year are logistically feasible and appear to be inconsequential for the source site (**Morkvėnas et al., 2025**). Hence, our projected future scenarios were based on 50 released individuals per year, and only explored different durations of reinforcement (5, 10 and 15 years). Three scenarios considered the different duration of reinforcement with unlimited habitat but agricultural use similar to the past, when early mowing prevented second broods. All other scenarios assumed that conservation management prevented early mowing and that female Aquatic Warblers had the opportunity to raise two broods per year.

We identified six potential release sites within the range of the Pomeranian population (Fig. 1), and assumed that each release site provides 200 ha of suitable habitat, which could be increased to 400 ha by habitat restoration. We therefore explored four different scenarios of habitat availability, namely one or six release sites, either with or without habitat restoration, resulting in available habitat of 200, 400, 1200 or 2400 ha. This available habitat corresponded to assumed carrying capacities of 24, 48, 144, or 288 adult females, respectively. Combining those four habitat availabilities with the three reinforcement durations resulted in a total of 12 future scenarios where habitat was constrained and six scenarios (described above) where habitat was unconstrained. All of these 18 scenarios were projected either with constant survival probability or an improved survival of 5% for both adults and juveniles to reflect ongoing conservation efforts on breeding grounds and along the flyway.

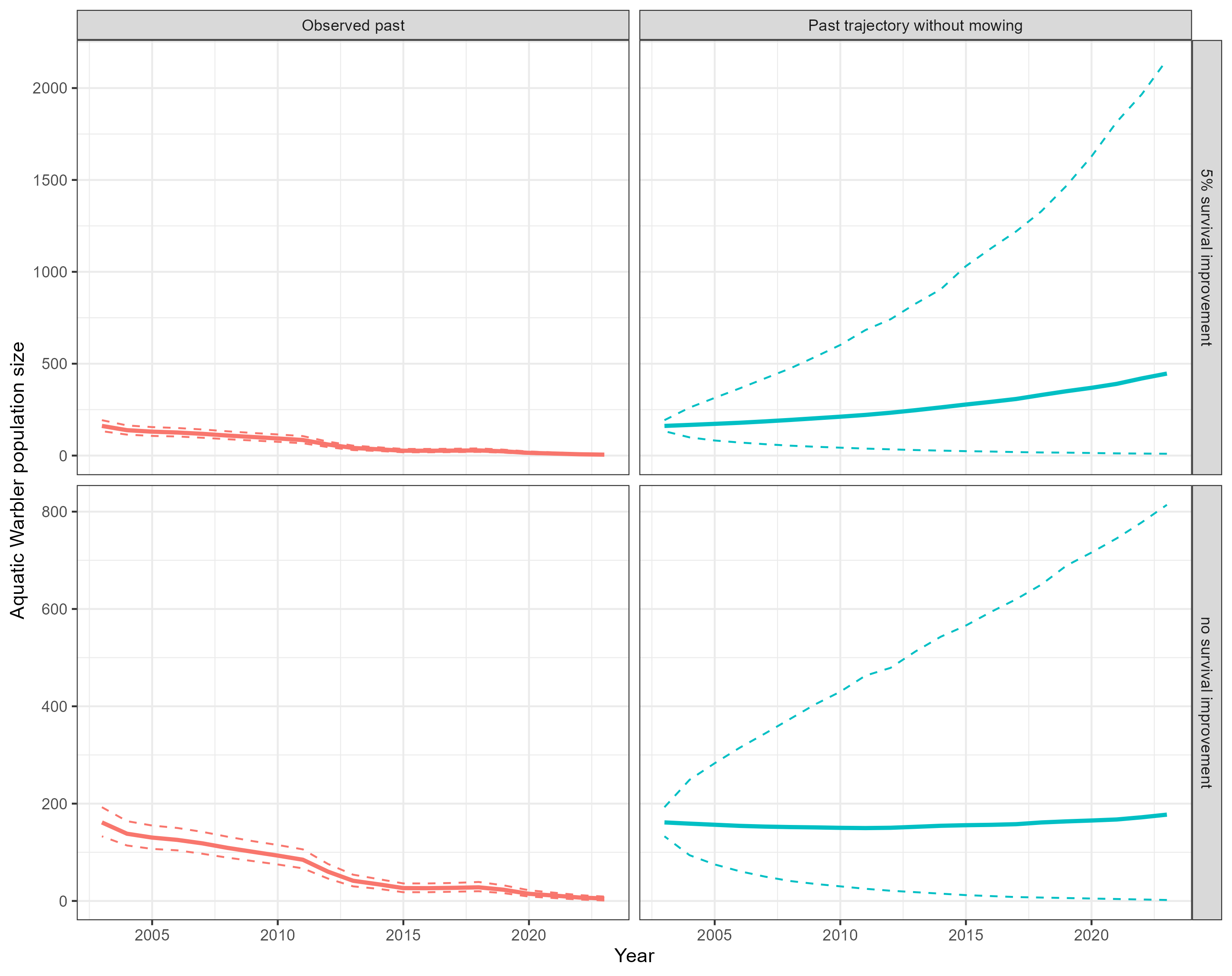
To examine which of the 36 combinations of reinforcement and management would result in a stable or increasing population trend, we projected the population size estimated by the integrated population model 20 years into the future while accounting for the uncertainty in demographic parameters ([Schaub & Abadi 2011](#_ENREF_66" \o "Schaub, 2011 #3871); [Kéry & Schaub 2012](#_ENREF_37" \o "Kéry, 2012 #3705); [Oppel](#_ENREF_52" \o "Oppel, 2014 #2927) *[et al.](#_ENREF_52" \o "Oppel, 2014 #2927)* [2022](#_ENREF_52" \o "Oppel, 2014 #2927)). For each scenario of reinforcement and survival improvement - including a ‘do nothing’ scenario of no reinforcement and no survival improvement - we calculated the future population growth rate as the geometric mean population growth rate from 2023 – 2043. We present this population growth rate to assess at which combination of reinforcement and survival improvement the population would stabilize (growth rate ≥ 1). We also present the probability of extinction calculated as the proportion of population simulations under each scenario where the total number of birds of breeding age was <2 in the year 2043.

**Results**

**Population development 1993 – 2023**

After 250 and 262 singing males were counted in 1993 and 1997, respectively, the Pomeranian population was substantially smaller in 2003 (89 singing males) and experienced a slow but continuous decrease with only one singing male recorded in 2023 (Fig. 2).

When assuming that different management had started in 2003 (prevention of mowing), allowing some Aquatic Warblers to raise a second brood every year, the population could have remained stable over the last 20 years (mean growth rate XX; Fig. 2d). If survival had been increased by 5% starting in 2003, the population decline would have been slightly slower than observed, but the population would not have remained stable (mean growth rate: xx, Fig. 2a).

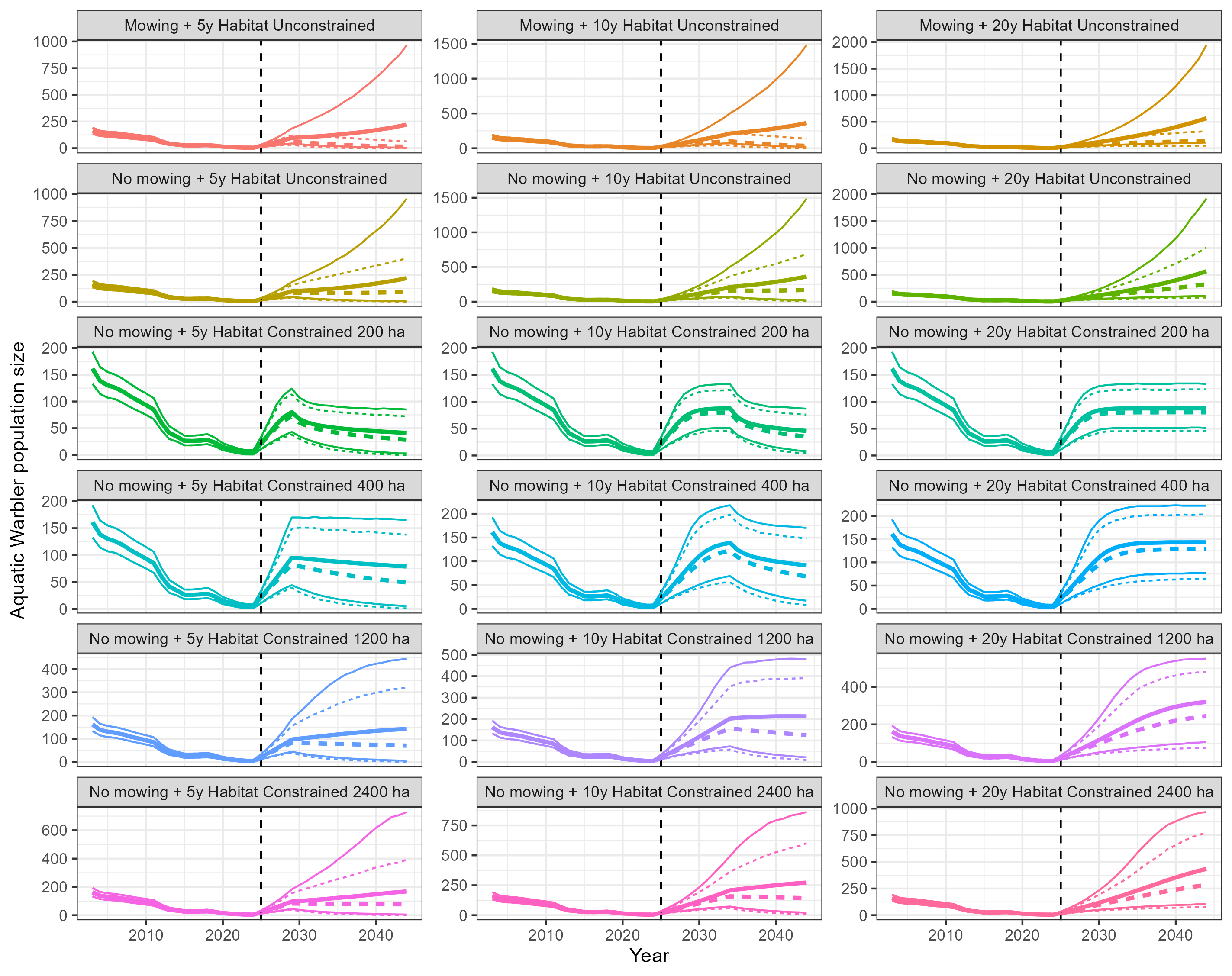


**Fig. 2**: Actual (c) and hypothetical (a,b,d) population development (mean size ± 95% CI) of the Pomeranian population of Aquatic Warblers between 2003-2023 simulated for scenarios that assumed no mowing (and therefore second broods) and a 5% improvement in annual survival probability.

**Reinforcement and management scenarios**

Our future population projections indicated that survival and habitat availability are key limiting factors for the persistence of the Aquatic Warbler population in Pomerania, while the duration of reinforcement only modulated the time when a stable population may be reached (Fig. 3). Scenarios with ongoing mowing (thus preventing second broods) and the same survival probability that we estimated for the past population trend, would not be able to retain a population regardless of the amount of available habitat or the duration of reinforcement (Fig. 3). Scenarios with improved survival and no mowing would facilitate a recovery of the population, and reinforcement could be stopped within <5 years if only 200 ha of habitat were available, or continued for 20 years if 2400 ha of habitat were available.

Without an improvement in survival, populations may decline after reinforcement stops even if Aquatic Warblers can raise two broods per year (Fig. 3). However, all of these projections are surrounded by very large uncertainty and only perpetual reinforcement and unlimited habitat resulted in an extinction probability of 0.



**Fig. 3. Posterior probability density for the population growth rate for the scenarios xx**

**Scenarios from Fig. 2: (1) no second broods, (7) second broods, habitat 200 ha, (13) second broods, habitat 1200 ha, (32) second broods, habitat 1200 ha, improved survival**

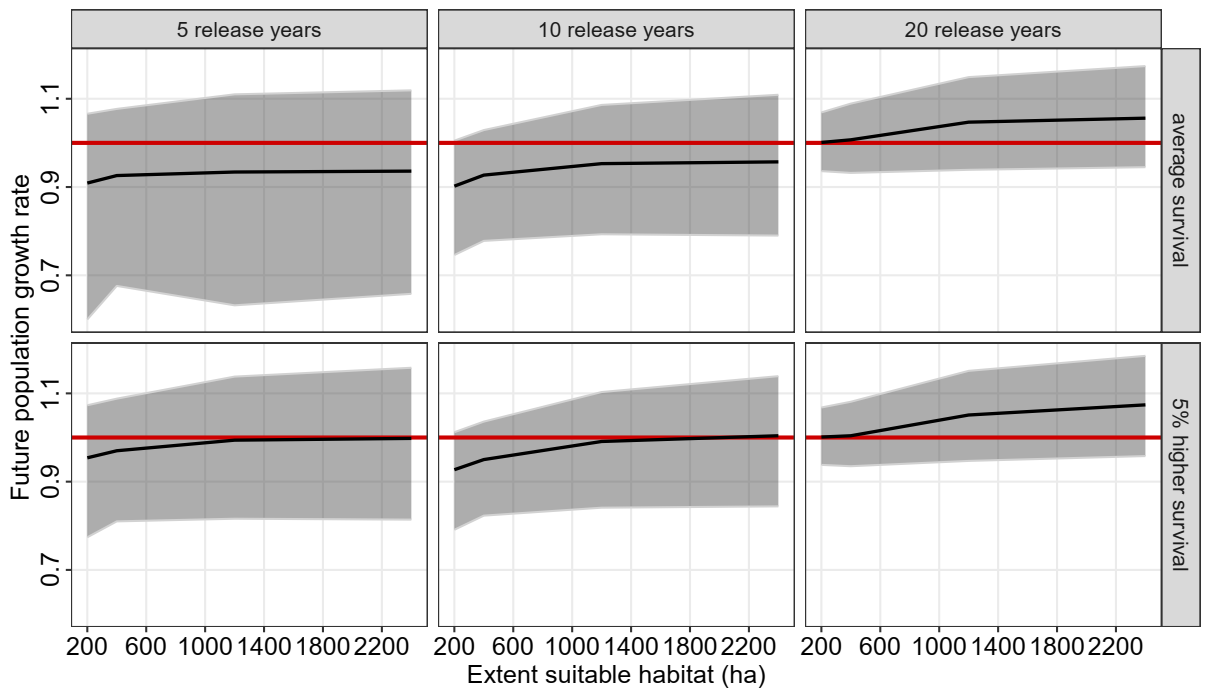


Fig. 4. Population growth rate of the reinforced Pomeranian population of Aquatic Warblers in relation to available breeding habitat (with a limit of 0.12 breeding females per ha) shown for different numbers of release years and for average and improved survival, assuming that mowing is managed so that Aquatic Warblers can raise two broods per year.

**Discussion**

We show that the Pomeranian population of Aquatic Warblers disappeared due to a combination of low productivity and insufficient survival, and that a reduction in mowing intensity that would have allowed second broods, and slightly higher survival may have been sufficient to retain the population. We further show that reinforcement alone will be insufficient unless the amount of available habitat is increased, and conservation measures are taken to increase survival and productivity by allowing second broods.

In the context of the current extinction crisis, population reinforcements appear critical to prevent and mitigate local or global species extinctions (**IUCN/SSC 2013; Bubac et al., 2019; Munstermann et al., 2021**). However, our results indicate that reinforcement alone is insufficient to restore a viable population of the Aquatic Warbler in Pomerania.

One aim of this study was to explore which demographic parameters contributed to the observed decline of the Pomeranian population of Aquatic Warblers during the last 30 years. Although ongoing habitat loss until 2003 has certainly contributed to the decrease of the population (**Flade et al., 2018**), large-scale drainage and increased land use intensity on fen mires drastically reduced available habitat (**Tanneberger et al., 2011**). Our population model suggests that the low numbers of Aquatic Warblers after 2003 can be partially attributed to a reduction in the proportion of second broods (Fig. 2). The majority of females are assumed to move to other breeding sites for the second brood (**Dyrcz and Zdunek, 1993b; Schulze-Hagen et al., 1999**). Ongoing habitat loss increased habitat fragmentation which may have limited movements between breeding sites. Additionally, mowing during the breeding season before July reduced the possibility for second breeding attempts and possibly also increased female mortality to some extent which also contributed to a negative population growth rate (Fig. 2).

Under the current conditions, the Pomeranian population of Aquatic Warblers is likely to go extinct immediately. In 2023, only one singing male was recorded. Despite conservation measures (e.g. postponed mowing on breeding sites) implemented after 2008, the population would require an increase in the annual survival probability to persist. However, our model can only estimate apparent survival probability, which is affected by emigration. In small fragmented populations, for a species that is known to disperse widely among other suitable patches of habitat, it is entirely possible that our estimates of apparent survival probability are biased low by chronic emigration. Larger, and more contiguous habitat patches would facilitate a greater retention or even immigration rate of individuals, thus leading to an improved apparent annual survival probability. We are therefore somewhat optimistic that the 5% increase in apparent annual survival probability could be achieved without massive conservation investments along the entire flyway.

**Reinforcement and management scenarios**

Our study implies that reinforcement and habitat restoration without improvements in survival rates may not be sufficient to stabilize the Pomeranian population of Aquatic Warblers. Whereas in long-lived species, population growth is mainly determined by adult survival (**Schaub et al., 2009; Davis et al., 2023**), in short-lived species, such as most of long-distance migrating passerines, population growth is mainly attributed to recruitment (**Dale, 2001; Border et al., 2017**). Reproductive output is determined by the number of fledglings per brood and is linked to the proportion of second broods. The average fledged brood size and the proportion of second broods is unknown for the Pomeranian population and may be lower than in the core breeding sites. However, our results clearly show that intensive farming practices that reduce the opportunity to raise a second brood may be a key contributing factor to the decline of Aquatic Warbler populations.

First year survival used in this study was only assessed recently based on a small data set of marked juveniles of the pilot translocation study. Differences in return rates between years, ranging between 14% and more than 30% for first year males (**Morkvėnas et al., 2025**) suggest that first year apparent survival is highly variable in Aquatic Warblers. Mortality in migrants is highly affected by conditions on wintering grounds and during migration and therefore annually variable. In Sedge Warblers, survival and population changes are significantly related to rainfall at the wintering site (**Peach et al., 1991; Ockendon et al., 2014**). Higher survival in Common Reed Warblers *Acrocephalus scirpaceus* was associated with more precipitation at the stopover sites in Spain and Morocco (**Halupka et al., 2017**). Aquatic Warblers are insectivores and accumulate fat deposits for migration (**Kerbiriou et al., 2010**). Because they need refuelling en route, they highly rely on food availability at stopover sites (**Kerbiriou et al., 2010;** **Vickery et al., 2014**).Carryover effects may translate adverse conditions during non-breeding periods in lower reproduction in the subsequent year (**Finch et al., 2014**). We were not able to relate population changes of the Pomeranian population to rainfall at wintering or stopover sites, suggesting that negative habitat effects at both breeding and non-breeding sites have contributed to the decline.

Female apparent annual adult survival probability is extremely difficult to quantify due to the low detection probability of females owing to their secretive behaviour (**Schulze-Hagen et al., 1999; Dyrcz et al., 2018**). Breeding site fidelity is probably rather low in Aquatic Warblers and permanent dispersal may contribute to the low apparent survival estimates for females (Kubacka et al. 2024). Natal dispersal, which is also usually female-biased in most passerine species (**Dale, 2001**) may additionally reduce the recruitment at a given breeding site. A first year return rate of 10% for females to the release site, observed in the pilot Aquatic Warbler translocation study (**Morkvėnas et al., 2025**) is in line with return rates reported for other migrant passerines (**Grinkevich et al., 2009; Border et al., 2017**). After the first release, first year return rate of males was remarkable high (>30%), followed by a substantial population increase (**Morkvėnas et al., 2025**), indicating that at least in years with high first year survival, high population growth can be expected, possibly enough to compensate for years with lower first year survival. However, the strong fluctuations in population size in Lithuania suggest that local population growth probably depends on immigration from other breeding sites (**Border et al., 2017**). Apparent survival rates used in this study account for detection, but not for permanent emigration from the study site. Movements between breeding sites are hardly understood in Aquatic Warblers so far, but must be sufficient to maintain constant gene flow (Kubacka et al. 2024).

**Conclusions**

Our study provides the first population viability analysis for the Aquatic Warbler. We conclude that high effort will be needed to reinforce the westernmost and geographically isolated Pomeranian population of the Aquatic Warbler.

Based on our PVA, the most effective management would be a improvement in survival. In a migratory species, however, main causes for mortality are found outside the breeding area (**Ockendon et al., 2014; Davis et al., 2023**). Therefore, conservation actions for Aquatic Warblers should also address wintering grounds and stopover sites. Although initial studies revealed migration patterns of Aquatic Warblers (**Salewski et al., 2019; Flade et al., 2023**), further identification of migration routes and threats is important to inform conservation actions. Simultaneous conservation actions along the whole flyway may increase the success of population recovery in migrants than measures implemented at single breeding sites (**Davis et al., 2023; Oppel et al., 2024**).

Since habitat loss has been a key factor for the previous decline of Aquatic Warblers, improving and increasing breeding habitats within the Pomeranian population will also be one of the critical factors for a successful reinforcement (**Bubac et al., 2019**). Habitat restoration and maintenance to provide > 1000 ha of suitable breeding habitat are likely required to maintain a stable population (Fig. 4).

Due to the remaining uncertainties in the demographic data we highly recommend long-term monitoring of the development of the reinforced Pomeranian population to validate survival and reproduction rates and to update the PVA when more data are available (**Akçakaya and Sjogren-Gulve, 2000**). Furthermore, more effort should be made to understand the intra-seasonal movements of the species and the importance of the connection with core breeding sites. If local populations depend on immigration to compensate for variations in recruitment and mortality (**Border et al., 2017**) it will be almost impossible to maintain an isolated population of Aquatic Warblers at the margin of the breeding range.

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**Table 1.** Demographic parameters of the Aquatic Warbler included in the population viability analysis of the Pomeranian population conducted with VORTEX.

|  |  |  |  |
| --- | --- | --- | --- |
| **Parameter** | **Details** | **Value** | **Source** |
| Reproductive system |  | polygynous | Schulze-Hagen et al. 1999 |
| Max. no broods per year |  | 2 | Dyrcz & Zdunek 1993b, Schulze-Hagen et al. 1999 |
| Sex ratio at birth (% males) |  | 50 | Dyrcz et al. 2004 |
| Proportion of males in breeding pool (%) | no pair bonds, no territories | 100 | Schulze-Hagen et al. 1999 |
| Proportion of females breeding (%) | females breed every year | 100 | Schulze-Hagen et al. 1999 |
| Number fledglings per brood | First brood  Second brood | 3.2 (2.3-4.0)  2.9 (1.8-3.7) | Kubacka et al. 2014 |
| Proportion of second broods (%) |  | 25 (0-50) | Dyrcz & Zdunek 1993b, Schulze-Hagen et al. 1999 |
| First year survival (%) |  | 30 (20-44) | *Morkvėnas et al* |
| Annual survival adults (%) | Females | 42 (29-56) | Dyrcz & Chylarecki 2018 |
| Annual survival adults (%) | Males | 67 (54-78) | Dyrcz & Chylarecki 2018 |
| Adult sex ratio (% males) |  | 56 | Dyrcz & Zdunek 1993a |
| Available habitat | Before / after restoration | 200-1200 / 400-2400 |  |
| Males density | 0.15 males / ha | 30-360 | Tanneberger et al. 2018 |
| Breeding density | 0.12 nest / ha | 24-288 |  |