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ORIGINAL ARTICLE

Survival of wild and farmed-released mallards: the Swedish example

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Abstract

More than three million farmed mallards are released annually for hunting purposes in Europe. The ecological impact of these releases depends on how many birds survive to join the wild breeding population. We estimated annual survival in farmed-released and wild-caught Swedish mallards, using mark-recapture data. In 2011–2018, we ringed 13,533 farmed ducklings before release (26.5% recovered). Most recoveries were birds shot at the release site, while only about 4% were found >3 km away. In 2002–2018, 19,820 wild mallards were ringed in Sweden, yielding 1369 (6.9%) recoveries. Like in farmed-released birds, most recoveries were by hunting, but 91.1% of recovered wild mallards were >3 km away from the ringing site. Annual survival rate in farmed-released mallards (ringed as pulli) was 0.02. In wild mallards (ringed as fledged or fully grown), annual survival was lower in females (0.64) than in males (0.71). At two sites in 2018, farmed ducklings were released in two batches 3 weeks apart to study the effect of early versus late release date, while controlling for body condition (BCI). Ducklings released early had a higher BCI and were recovered earlier (lower longevity) than those released late. Individual BCI and longevity were not correlated in recovered ducklings. Based on our estimate of annual survival in farmed-released mallards, a substantial number, i.e., 5000 (95% CI, 3040–6960), join the wild population annually. Despite being fed, a large proportion of released ducklings does not survive until the hunting season. Early releases may maximize pre-hunting survival. Repeated releases may prolong hunting opportunities and increase hunting bags.

Keywords Body condition index · Captive reared · Hunting · Restocking · Ringing · Recoveries

Introduction

The mallard (*Anas platyrhynchos*) is a model species in waterfowl ecology, zoonotic research, wetland conservation, and wildlife management. It is also the world's most numerous and widely distributed dabbling duck, whose global population is estimated at 20 million individuals (Wetlands International 2020). It provides a host of ecosystem services (Green and Elmberg 2014) and it is one of the most harvested game species worldwide. In the European Union alone, there are more than 6.4 million registered hunters (Hirschfeld et al. 2019), which together bag more than 4.5 million mallards annually (Hirschfeld and Heyd 2005).

The long-standing popularity of waterfowl hunting provides an important base for massive management programs in the northern hemisphere. These efforts amount to huge monetary values and largely focus on habitat conservation and restoration, as well as on cooperative schemes over larger areas to monitor recruitment and harvest (U.S. Fish and Wildlife Service 2016). However, there is also a long tradition of supplementing huntable populations by releasing mallards reared in captivity (hereafter called "farmed") into the wild, at or near sites where they are later hunted (Leopold 1933; Söderquist 2015).

Already in the first half of the 20th century, such local population restocking became a common practice in North America (Brakhage 1953; Lincoln 1934). After studying the fate of released mallards, the practice was deemed expensive and non-efficient on this continent due to low survival, reduced migratory propensity of surviving released birds, and

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in the end a low contribution to the hunting bag (Brakhage 1953; Errington and Albert 1936; Lincoln 1934). Despite the subsequent general abandonment of mallard restocking in most of North America, it has become, and still remains, a common practice in Europe. For example, in France, 1.4 million farmed mallards are released annually (Mondain-Monval and Girard 2000); in Denmark, the corresponding number is 400,000 (Noer et al. 2008); and in Sweden, more than 250,000 (Söderquist 2015). Altogether, more than 3 million farmed mallards are released in Europe each year for restocking or hunting purposes (Champagnon et al. 2013). This number can be compared to a total breeding population of about 4.5 million pairs in Europe (Delany and Scott 2006), which inevitably raises the question of how introductions affect the wild mallard population.

The early studies by Lincoln (1934) and Errington and Albert (1936) based on ringing of farmed versus wild mallards showed that only about 1.5% of the former were reported back, compared to about 12% of the latter. In addition, post-release dispersal of farmed mallards in these studies was limited compared to that of wild mallards. Low pre-hunting survival of farmed mallards has later been confirmed in several studies in North America (Brakhage 1953; Dunn et al. 1995; Soutiere 1989) as well as in Europe (Fog 1964, 1965; Fransson and Pettersson 2001). Interestingly, the difference in survival between wild and farmed mallards may not primarily be a result of higher hunting pressure on the latter, as research has demonstrated that their survival is lower also in the absence of hunting (Champagnon et al. 2011).

Further concerns have been added to the issue of restocking practices of mallards. Due to crowded conditions and high numbers of immuno-naïve individuals, mallard farms have been implicated as problematic from viewpoints of veterinary medicine and zoonotic disease (Markwell and Shortridge 1982). Moreover, mallard breeding stock in farms is often not of native provenance. Release of such birds thus creates a risk of eroding local genotypic adaptation by introgression into local wild populations by birds that survive the hunt (Champagnon et al. 2012). Recent European studies of mallards imply that such introgression has already occurred and that it may affect morphology as well as migratory behavior (Söderquist et al. 2014, 2017). This too calls for an improved understanding of the magnitude of the number of farmed mallards that survives hunting and potentially enters the wild breeding population.

A widespread argument for releasing mallards is to maintain high hunting bags without negative impact on the wild breeding population. This assumes that released birds survive until the hunting season starts and that they are overrepresented in the subsequent hunting bag. From a European perspective—and indeed anywhere restocking of mallards is practiced—it is thus crucial to obtain a better understanding of how surviving farmed individuals affect the wild population. A first step towards gauging their impact is to document survival and see if it differs from that of wild mallards.

As described above, previous studies comparing survival in wild versus farmed mallards provide a picture of lower survival in the latter. However, most of these studies were carried out several decades ago, when hunting pressure was different and before changes in climate and agricultural practices made it easier for mallards to survive the winter in many areas (Guillemain et al. 2010; Gunnarsson et al. 2011). These changes may benefit released mallards more than local wild-type conspecifics, as the former are less inclined to migrate (Söderquist et al. 2013). Also, earlier studies have been based on local rather than national data, hence not embracing the substantial variation in the number of released birds among large- and small-scale restocking sites. Finally, research on wild mallard broods shows that survival is generally higher in early hatched broods than in late (e.g., Norris 1993 and references therein; Rohwer 1992; Verhulst et al. 1995). It is not known if this is true also for farmed ducklings, but if so, it is an important aspect for managers who want to maximize the hunting bag. It will also influence how many birds survive long enough to enter the wild breeding population.

Using nation-wide data from Sweden and own ringing data from 21 sites spread out over the main regions in Sweden where mallard restocking is practiced, mortality causes as well as annual survival and recovery probabilities were estimated. For the latter (annual survival and recovery), effects of sex, age, and year were considered. Based on previous research, the following predictions were addressed:

1) Farmed mallards have lower annual survival than wild mallards.
2) In released farmed ducklings, longevity (here, time from ringing until recovery) is positively related to body condition at the time of release.
3) In released farmed ducklings, longevity is higher in early releases than in late.

Material and methods

Ringing and release of farmed mallards

A total of 13,533 farmed mallard ducklings were ringed before release in 2011–2014 and 2017–2018, in 14 different areas in southern Sweden (21 release sites; Table 1). Both small- and large-scale restocking sites were included in the study. In areas 1–10, rather few mallards were released, all were ringed (mean ± 1 SD, 321 ± 209; range, 10–750), and only educational or leisure hunts were conducted. In areas 11–14, large numbers of farmed mallards without rings were

Table 1 Number of ringed released farmed mallards, number and percent of released birds shot during the first hunting season at release sites, and percent wild/unringed birds of the total hunting bag 2011–2014 and 2017–2018 at 21 sites in 14 areas (first digit in "site" below) in southern Sweden. In 2018, farmed and ringed mallards were released on two occasions 3 weeks apart at sites 8.2 and 8.3. All mallards released at sites 1–10 were ringed, whereas at sites 11–14, additional farmed mallards without rings were released, too. Three different types of hunts were conducted at the release sites: educational hunts for teaching and training, small-scale leisure hunts at private estates, and large-scale commercial hunts on large estates that sell hunting opportunities. In columns with wild birds, N/A (not available) means that the number of shot wild birds was not reported, or that not all released birds on the location were ringed

Site	Province	2011			2012			2013		
		Released	Shot	Wild	Released	Shot	Wild	Released	Shot	Wild
1	Scania	351	125 (36%)	27 (18%)	504	19 (4%)	N/A	-	-	-
2	Uppland	60	12 (20%)	2 (11%)	-	-	-	-	-	-
3	Västmanland	400	130 (33%)	152 (54%)	-	-	-	400	158 (40%)	165 (51%)
4	Småland	200	62 (31%)	28 (31%)	200	45 (23%)	49 (52%)	200	48 (24%)	66 (58%)
5	Scania	101	13 (13%)	23 (64%)	122	4 (3%)	139 (97%)	-	-	-
6	Scania	315	32 (10%)	69 (68%)	-	-	-	-	-	-
7.1	Scania	-	-	-	251	47 (19%)	6 (11%)	150	55 (37%)	158 (38%)
7.2	Scania	-	-	-	112	10 (9%)	2 (17%)	30	6 (20%)	
7.3	Scania	-	-	-	394	42 (11%)	7 (14%)	558	194 (35%)	
7.4	Scania	-	-	-	10	0 (0%)	N/A	-	-	-
7.5	Scania	-	-	-	-	-	-	-	-	-
8.1	Småland	-	-	-	511	188 (37%)	5 (3%)	500	130 (26%)	1 (1%)
8.2	Småland	-	-	-	502	82 (16%)	4 (5%)	500	59 (12%)	7 (11%)
8.3	Småland	-	-	-	-	-	-	-	-	-
9.1	Scania	-	-	-	101	2 (2%)	N/A	-	-	-
9.2	Scania	-	-	-	41	0 (0%)	N/A	-	-	-
10	Scania	-	-	-	-	-	-	35	25 (71%)	N/A
11	Scania	-	-	-	-	-	-	849	368 (43%)	N/A
12	Blekinge	-	-	-	-	-	-	600	70 (12%)	N/A
13	Scania	-	-	-	-	-	-	350	13 (4%)	N/A
14	Scania	-	-	-	-	-	-	500	111 (22%)	N/A
Annual total		1427	374 (26%)	321 (46%)	2748	339 (12%)	212 (39%)	4672	1237 (26%)	396 (38%)
Grand total		13533 released, 3060 (22.6%) shot, 1077 (26%) wild in hunting bag								

Site	2014			2017			2018:1		2018:2		2018	Hunting type
	Released	Shot	Wild	Released	Shot	Wild	Released	Shot	Released	Shot	Wild	
1	-	-	-	-	-	-	-	-	-	-	-	Education
2	-	-	-	-	-	-	-	-	-	-	-	Leisure
3	-	-	-	-	-	-	-	-	-	-	-	Leisure
4	150	47 (31%)	60 (56%)	-	-	-	-	-	-	-	-	Leisure
5	-	-	-	-	-	-	-	-	-	-	-	Leisure
6	-	-	-	-	-	-	-	-	-	-	-	Leisure
7.1	201	55 (27%)	N/A	-	-	-	-	-	-	-	-	Education
7.2	-	-	-	-	-	-	-	-	-	-	-	Education

Table 1 (continued)

7.3	500	133 (27%)	N/A	-	-	-	-	-	-	-	-	Education
7.4	-	-	-	-	-	-	-	-	-	-	-	Leisure
7.5	335	89 (27%)	N/A	-	-	-	-	-	-	-	-	Leisure
8.1	-	-	-	500	34 (7%)	2 (6%)	-	-	-	-	-	Education
8.2	-	-	-	500	175 (35%)	21 (11%)	500	166 (33%)	500	100 (20%)	37 (12%)	Education
8.3	-	-	-	-	-	-	750	157 (21%)	750	154 (21%)	28 (8%)	Education
9.1	-	-	-	-	-	-	-	-	-	-	-	Leisure
9.2	-	-	-	-	-	-	-	-	-	-	-	Leisure
10	-	-	-	-	-	-	-	-	-	-	-	Leisure
11	-	-	-	-	-	-	-	-	-	-	-	Commercial
12	-	-	-	-	-	-	-	-	-	-	-	Commercial
13	-	-	-	-	-	-	-	-	-	-	-	Commercial
14	-	-	-	-	-	-	-	-	-	-	-	Commercial
Annual total	1186	324 (27%)	60 (56%)	1000	209 (21%)	23 (10%)	1250	323 (26%)	1250	254 (20%)	65 (10%)	
Grand total	13533 released, 3060 (22.6%) shot, 1077 (26%) wild in hunting bag											

released alongside the ringed ones, and hunting opportunities were sold on a commercial basis (Table 1).

At the time of ringing, ducklings were two to 3 weeks old, at which age tarsus width is close to final adult width (Greenwood 1975), with low risk for ring loss. At this age, sex determination by cloacal examination, so called vent sexing, is possible (Hochbaum 1942). However, it is an invasive as well as a time-consuming technique and was therefore not used in this study. Hence, all analyses including sex as a variable were dependent on sex being reported after recovery. Ringing occurred the same day as release, which took place between the end of May and the beginning of July, depending on year and site. Consequently, release date was seven to 13 weeks before the start of the hunting season in Sweden (August 20th). The mallard season closes December 31st.

Birds were ringed with conventional tarsal steel rings from the Swedish Bird Ringing Centre (SBRC; Museum of Natural History, Stockholm). Each ring has a unique number and a web address showing where recoveries and observations can be reported.

All ducklings released in 2018 (2500) were weighed and their tarsus length was measured with calipers. The latter measurement was made on different birds by two persons. When controlling for measurement bias between the two, a significant difference was found (t test, $p < 0.0001$, $t = 22.134$, df = 2497). As no such difference should be expected between the two groups, which were randomly chosen ducklings from the same captive population, tarsus length was increased by 5.2% for data from the "lower measuring person," to compensate for the mean difference.

In 2018, ducklings were released in two batches 3 weeks apart (May 30 and June 19) at sites 8.2 and 8.3 (500 + 500 at 8.2, and 750 + 750 at 8.3; Table 1); they were the same age (days since hatching) at the time of their respective release. This part of the study design was thus tested for the equivalent of early versus late broods and not for duckling age per se (cf. Sjöberg et al. 2010).

At all release sites, supplemental feeding occurred from the day of release until the last hunt of the season. However, feeding was suspended if ice formed on a release wetland to encourage mallards to commence migration. Landowners and hunters at release sites were instructed to note ring number, date, sex, and recovery details (e.g., shot or taken by predator) of all dead recovered mallards. Recoveries or sightings away from the release sites were reported to the SBRC by hunters, ornithologists, and other people. Such data were subsequently reported by the SBRC to us.

Ringing and recovery of wild mallards

To assess mortality patterns and annual survival of farmed and wild mallards, we used complete nationwide capture-recapture data from 2002–2018 for the latter group, provided by the SBRC. In total, 19,820 wild mallards were ringed in Sweden during this period, of which 6674 were sexed as females, 11,473 as males, whereas 1673 were not sexed. Of these mallards, 1369 were subsequently reported to SBRC as dead recoveries.

To make the estimates of mortality patterns and annual survival comparable to those in earlier analyses of the same population of wild mallards, we used the same filtering criteria as in Gunnarsson et al. (2008) to refine the recovery data set. In brief, we excluded data concerning birds for which circumstances deviated from normal conditions in any way (e.g., manipulation, poor condition) or if there were any uncertainties in recovery information (e.g., date, status). In line with Gunnarsson et al. (2008), mallards ringed or recovered in park areas in the city of Malmö (55° 34′–55° 37′ N, 12° 58′–13° 02′ E) were also excluded from the analyses.

Capture-recapture analysis of wild and farmed mallards

Annual survival of wild and farmed mallards was analyzed using the Seber modelling approach based on recoveries of dead birds only (Seber 1970) using program MARK (White and Burnham 1999), yielding estimates of survival (S_i) and recovery (r_i; i.e., the probability of being recovered and reported).

Data from the farmed mallards were from fewer years than were data for wild. In addition, all farmed mallards were ringed as pulli (i.e., downy flightless young) but the wild ones as fledged (the sample of ringed wild pulli was too small to analyze). Two separate analyses were therefore carried out: one for farmed mallards (n = 10033; only data from years 2011–2014 were analyzed since there was not any ringing done in 2015 and 2016, i.e., data from 2017–2018 were not included in order to obtain a continuous time series) and one for those ringed as full-grown birds in the wild, i.e., as juveniles (first calendar year), adults (second calendar year or older), or of unknown age (first calendar year or older) (years 2002–2018). In the latter analysis, six groups were contrasted: (1) adult females (n = 1439), (2) juvenile females (n = 2979), (3) unaged females (n = 1300), (4) adult males (n = 4746), (5) juvenile males (n = 3985), and (6) unaged males (n = 1370).

For each individual mallard, an encounter history was constructed in a "live-dead" format. Since "occasion" was years (four for farmed mallards ringed as pulli and 17 for full-grown wild birds), estimates of survival and recovery were on an annual basis, i.e., from ringing in year i to i + 1. Goodness of fit was estimated with parametric bootstrapping, running 100 simulations of the most parameterized model from each of the two analyses. Overdispersion was then corrected for by adjusting the variance inflation factor ($\hat{c}$) by dividing observed $\hat{c}$ by the mean $\hat{c}$ from the simulations.

From the most parameterized model, we ran the simplified models that were deemed biologically relevant (Doherty Jr. et al. 2002) and ranked them based on the quasi-likelihood Akaike's Information Criterion (QAICc) (Akaike 1973; Burnham and Anderson 2002). Models differing ≥ 2 in QAICc were considered being different from each other. Conversely, models were regarded as having similar fit if the difference in QAICc was < 2. In the latter cases and in line with parsimony, the least complex model was ranked as being superior to more complex models.

Body condition, longevity, and early versus late release of farmed mallards

We used general linear models (GLM) to study effects of sex, release occasion (fixed factors), and site (random factor) on body condition. Such an index (i.e., body condition index (BCI)) was calculated using residuals in a body mass–tarsus length regression (Jakob et al. 1996; Schulte-Hostedde et al. 2005; but see Green 2001) and based on data of farmed mallards released in 2018 at sites 8.2 and 8.3 (Table 1). Along with the main effects, the interaction between the two fixed factors was analyzed in the GLM. Non-significant variables were removed from the analyses according to a backward stepwise model selection approach.

To analyze effects of BCI and release occasion (early versus late) on longevity (again, only data from 2018), defined as the number of days from release date until recovery date, non-parametric tests were used since data (residuals) were not normally distributed. Consequently, Spearman correlation was used to study the relationship between longevity and BCI, whereas the Mann-Whitney U-test was used to compare early versus late releases. To compensate for the fact that half of the ducklings were released 20 days before the second half, 20 days was subtracted from the total longevity for the former. Further, an independent samples t test with unequal variances was used to analyze if release occasion influenced BCI for recovered mallards. A chi-square test was used to analyze if recovery rate differed between the two release occasions at sites 8.2 and 8.3 in 2018.

SPSS 24 was used for all statistical analyses.

Results

Recoveries of farmed and wild mallards

In total, 3583 (26.5%) of the 13,533 farmed mallards were recovered, of which 35.5% were reported as females, 36.1% as males, and 28.4% as not sexed. Among the recovered birds, 3348 (93.4%) were reported as shot during hunts (anywhere), of which 37.1% were reported as females, 37.3% as males, and 25.6% were not sexed. Harvest at the release sites peaked in the second half of September (Fig. 1).

In total, 3060 (22.6%) of the released mallards were shot during hunts at the release site, that is, one kilometer or less from where they were released. On the site level, the share of released birds subsequently shot locally varied between 0 and 71% (Table 1). The share of unringed (i.e., assumed wild) mallards shot at the release sites varied between 1 and 97% (Table 1). Of all recovered farmed mallards, 4.1% (147) were found more than 3 km from their release site, of which 79.6% were recovered as shot, 11.5% were observed alive, 4.8% were found dead (unknown cause), 3.4% were taken by other animals, and 0.7% had joined domesticated mallards at a farm. Of these "external" recoveries, 108 were from Sweden, 34 from Denmark, 4 from Germany, and 1 from Poland.

Of the 19,820 wild mallards ringed in Sweden during the study period, 1369 (6.9%) were subsequently recovered and reported to SBRC, of which 29.6% as females, 67.7% as males, and 2.7% as unsexed. Of the recovered birds, 968 (70.7%) were reported as shot during hunts, of which 26.8% as females, 71.5% as males, and 1.8% as unsexed. In contrast to the farmed mallards, no clear temporal harvest peak was seen among wild mallards (Fig. 1). Further, 16.1% were observed alive, 6.1% were found dead (unknown cause), 2.6% had collided with objects, 1.6% were taken by other animals, 1.6% were injured or sick, whereas the remaining 1.2% were reported as referring to "other circumstances". Of all recovered wild mallards, 91.1% (1247) were found more than 3 km from their ringing site, of which 269 in Sweden, 323 in Denmark, 205 in Finland, 163 in Germany, 122 in Russia, 58 in the Netherlands, 30 in Poland, 25 in Latvia, 22 in France, 11 in Estonia, 4 in England, 3 each in Belgium and Czech Republic, 2 in Norway, and 1 each in Georgia, Ireland, Italy, Lithuania, Romania, Scotland, and Ukraine.

Table 2 Model results for survival (*S*) and recovery (*r*) parameters from analyses of farmed pullus-ringed mallards in Sweden in 2011–2014 (*year*)

Model	QAICc[a]	ΔQAICc[b]	w_i[c]	*K*[d]	QDeviance[e]
1. *S*(.) *r*(year)	5143.37	0.00	1.00	5	3.67
2. *S*(.) *r*(.)	5201.42	58.05	0.00	2	67.73

[a] Quasi-likelihood Akaike's Information Criterion adjusted for low sample size

[b] Difference in QAICc between the actual model and top model

[c] Model weight

[d] Number of parameters

[e] Deviance adjusted for overdispersion

Annual survival of farmed and wild mallards

In the analyses of farmed mallards ringed as pulli, overdispersion was controlled for by adjusting $\hat{c}$ to 2.33, derived by dividing the deviance (8.56) from the most parameterized model (#1 in Table 2) by the mean deviance from the bootstrap simulations of the same model (3.65). The corresponding $\hat{c}$ adjustment for the analyses of full-grown wild mallards was 1.20, based on bootstrap simulations of model #3 in Table 3 (observed deviance, 807.21; mean simulated deviance, 675.43).

For farmed mallards ringed as pulli, there were only two models with estimable parameters (Table 2). The highest ranked model was outstanding compared to model #2 by the inclusion of a year effect for recovery parameters. Real estimates derived from the highest ranked model yielded an annual survival rate of 0.02 (SE = 0.004), whereas the annual recovery rate ranged between 0.18 and 0.31 (2011 0.28, SE = 0.02; 2012 0.18, SE = 0.01; 2013 0.31, SE = 0.01; 2014 0.28, SE = 0.02).

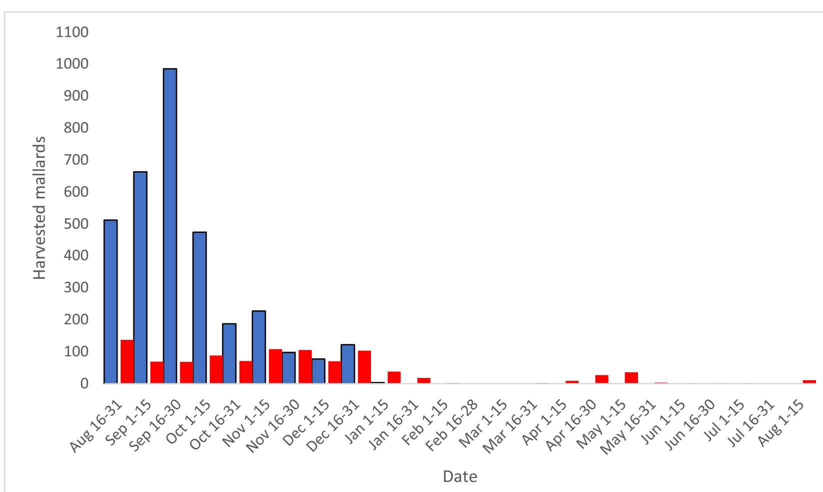

Fig. 1 Semi-monthly distribution of recoveries of harvested farmed (blue, *n* = 3348) and wild (red, *n* = 968) mallards in Sweden 2002–2019. Mallards recovered in spring were primarily from other countries than Sweden, which still permit spring hunting

Two models (#1 and #2) from the analyses of full-grown wild mallards matched data better than others (Table 3). Since inclusion of age changed QAICc only marginally, the less complex model including a sex effect only for survival as well as for recovery probability (#2 in Table 3) was regarded as being superior. The general estimate of annual survival was lower for females (0.64, SE = 0.02) than for males (0.71, SE = 0.01), as were also annual recovery rates (females 0.05, SE = 0.003; males 0.07, SE = 0.003).

Body condition, longevity, and release time of farmed mallards

Descriptive statistics (mean, standard deviation, and sample size) of body mass, tarsus length, and BCI for all released, recovered, and not recovered mallards, as well as longevity for recovered mallards, can be found in Table 4.

A GLM for all recovered ducklings in 2018 revealed that the early batches had a significantly higher BCI than those released 3 weeks later ($F_{1,\ 581} = 7.931$, $p = 0.005$). Recovered mallards sexed as females had a significantly higher BCI at ringing than did males ($F_{1,\ 581} = 6.411$, $p = 0.012$), whereas BCI did not differ significantly between release sites ($F_{1,\ 581} = 0.003$, $p = 0.959$). The interaction between sex and release occasion showed a significant effect on BCI ($F_{1,\ 581} = 3.931$, $p = 0.048$). An independent samples t test did not show any significant difference in BCI between recovered and not recovered mallards ($t = -0.614$, df = 2495, $p = 0.539$).

Looking at the recovered mallards only, there was not any significant correlation between BCI and longevity ($r_s = -0.049$, $n = 601$, $p = 0.235$). Further, Mann-Whitney U-tests did not show any effect of release site ($U = 44{,}062.5$, $n_{8.2} = 268$, $n_{8.3} = 333$, $p = 0.786$) or sex ($U = 41{,}836$, $n_{\text{females}} = 284$, $n_{\text{males}} = 302$, $p = 0.598$) on longevity of recovered mallards. There was, however, an effect of release occasion (early versus late batch) on longevity ($U = 22{,}770.5$, $n_{\text{early}} = 343$, $n_{\text{late}} = 258$, $p < 0.001$); mallards released 3 weeks later had a higher longevity than those released early ($\text{median}_{\text{early}} = 84$ days, SE = 2.54; $\text{median}_{\text{late}} = 100$ days, SE = 1.42).

Among recovered mallards, an independent samples t test with unequal variances showed that those released early had a higher BCI than those released late ($\text{mean}_{\text{early}} = 4.06$, SD = 39.63; $\text{mean}_{\text{late}} = -3.53$, SD = 35.45; $t = 2.467$, df = 579.634, $p = 0.014$). A chi-square test demonstrated a higher percentage of recovered mallards among those released early (27.4%) compared to later releases (20.6%) ($\chi^2 = 15.826$, df = 1, $p < 0.001$).

Discussion

Recoveries of farmed and wild mallards

The higher recovery rate of farmed mallards compared to wild-ringed birds was expected, as these birds are released explicitly for hunting purposes and the hunters were instructed to report all shot birds. Of all wild mallards ringed in Sweden, a total of 10% have been recovered (Swedish Bird Ringing Centre 2009). However, recovery rate has been declining during the last 50 years and the rate of 7% for wild mallards found in this study is consistent with the recovery rate reported by Guillemain et al. (2011) for France. Even though the recovery rate is higher than in wild-ringed mallards, there is still a

Table 3 Model results for survival (*S*) and recovery (*r*) parameters from analyses of wild mallards ringed in Sweden in 2002–2018 (*year*). *Sex* is male or female, and *age* is juvenile, adult, or unknown (but not pullus)

Model	QAICc[a]	ΔQAICc[b]	w_i[c]	K[d]	QDeviance[e]
1. *S*(sex+age) *r*(sex)	8719.18	0.00	0.40	8	713.38
2. *S*(sex) *r*(sex)	8720.11	0.93	0.25	4	722.31
3. *S*(sex+age+year) *r*(sex+age)	8721.33	2.15	0.14	28	675.43
4. *S*(sex+age) *r*(sex+age)	8722.51	3.32	0.08	12	708.69
5. *S*(sex) *r*(sex+age)	8723.41	4.22	0.05	8	717.60
6. *S*(sex+year) *r*(sex)	8723.63	4.45	0.04	20	693.78
7. *S*(sex) *r*(sex+year)	8724.32	5.14	0.03	20	694.47
8. *S*(.) *r*(sex)	8724.84	5.66	0.02	3	729.04
9. *S*(age) *r*(age)	8737.87	18.69	0.00	6	736.07
10. *S*(age) *r*(.)	8740.83	21.64	0.00	4	743.03
11. *S*(.) *r*(age)	8744.07	24.89	0.00	4	746.27
12. *S*(sex) *r*(.)	8745.89	26.71	0.00	3	750.09
13. *S*(.) *r*(.)	8746.66	27.48	0.00	2	752.86

[a] Quasi-likelihood Akaike's Information Criterion adjusted for low sample size

[b] Difference in QAICc between actual model and top model

[c] Model weight

[d] Number of parameters

[e] Deviance adjusted for overdispersion

Table 4 Descriptive statistics (mean, standard deviation, and sample size) for body mass (gram), tarsus length (mm), and body condition index (BCI) of mallards (recovered as well as not recovered), released in two batches 3 weeks apart at two sites (see Table 1) in 2018

Site and batch	Measurement	All released			All recovered			Recovered females			Recovered males			Not recovered		
		Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*
8.2	Body mass (g)	400.93	52.4	499	409.81	51.7	167	403.06	49.0	69	414.56	53.2	98	396.46	52.3	332
Early	Tarsus (mm)	55.98	2.2	500	56.22	2.1	167	55.48	2.0	69	56.75	2.0	98	55.85	2.3	333
	BCI	− 0.06	37.7	499	4.72	40.1	167	10.57	36.6	69	0.60	42.1	98	− 2.46	36.2	332
	Longevity (days)	-	-	-	90.31	37.1	167	88.86	17.6	69	91.33	46.2	98	-	-	-
8.2	Body mass (g)	334.64	54.9	499	338.91	60.0	100	333.24	51.15	58	346.74	70.4	42	333.57	53.6	399
Late	Tarsus (mm)	52.27	2.4	500	52.58	2.6	101	52.27	2.27	58	53.00	2.9	43	52.19	2.4	399
	BCI	− 3.24	34.3	499	− 4.61	36.7	100	− 4.59	35.2	58	− 4.64	39.1	42	− 2.90	33.7	399
	Longevity (days)	-	-	-	111.15	28.3	101	111.19	29.5	58	111.09	27.0	43	-	-	-
8.3	Body mass (g)	404.38	52.9	749	402.12	53.1	176	397.84	52.0	73	408.60	54.2	90	405.07	52.9	573
Early	Tars (mm)	55.86	2.4	749	55.85	2.5	176	54.95	2.5	73	56.69	2.2	90	55.86	2.4	573
	BCI	5.51	40.3	749	3.43	39.3	176	14.37	39.9	73	− 4.43	38.2	90	6.14	40.7	573
	Longevity (days)	-	-	-	96.58	54.7	176	92.77	55.1	73	91.24	41.1	90	-	-	-
8.3	Body mass (g)	331.14	50.9	750	334.10	51.5	157	328.10	49.7	84	341.58	53.3	71	330.36	50.7	593
Late	Tarsus (mm)	52.07	2.4	750	52.22	2.4	157	51.78	2.2	84	52.73	2.6	71	52.03	2.4	593
	BCI	− 3.30	33.9	750	− 2.85	34.7	157	− 1.47	34.9	84	− 4.23	35.1	71	− 3.43	33.7	593
	Longevity (days)	-	-	-	101.72	17.7	157	98.49	13.2	84	103.24	16.8	71	-	-	-

significant loss of birds, likely due to natural mortality, as few venture far from the release sites according to our recovery data (also supported by unpublished gps data). Hunting was the most common cause of death in both groups, a fact that compares well with earlier studies (e.g., Guillemain et al. 2015; Gunnarsson et al. 2008).

An interesting discrepancy appears between recovered wild and released mallards. The sex ratio of shot and sexed released birds is even, while that of wild mallards is strongly skewed in favor of males. Wild duck populations frequently have an uneven sex ratio skewed towards males (e.g., Nilsson 1976), which is corroborated by the present study. This widespread pattern is most likely a result of higher breeding season mortality in females (Arnold et al. 2012). However, this does not entirely explain the dominance of males in the hunting bag of wild mallards, as they rarely make up more than 60% of the population (Nilsson 1976). The difference between the groups (released versus wild) in this study is a bit puzzling, as most recoveries in both data sets were made in fall and winter when the population is dominated by first year mallards, long before the next breeding season during which a higher mortality in nesting females would manifest.

A main objective for landowners and managers releasing mallards is to increase the hunting bag locally. The opinion and impression of many landowners is that the majority of birds shot on their land are the ones they have released; however, this was not entirely supported by our data. Instead, the hunting bags consisted of large numbers of unringed individuals, which we presume to be wild conspecifics attracted by the supplementary feeding, or by the presence of farmed-released birds.

These patterns prompt the question of what happens to "the missing" released mallards. Since a majority are not recovered at the release site, it can either mean that they have a high mortality prior to hunting and are thus never recovered or that they are mobile and move away from the release sites before hunting starts. Almost all released birds that were recovered were shot near the release site, whereas most wild mallards were recovered far away from the ringing site. In other words, the farmed mallards appear to be very sedentary. Some of the mallards in this study were fitted with gps-loggers (a detailed analysis will appear in a forthcoming paper) and most of those birds never ventured away from their release site. It also seems to be a general pattern that farmed mallards that survive the fall hunt migrate later and sometimes slower than wild birds (Brakhage 1953), even though they frequently adopt a natural migratory direction (Söderquist 2015). Taken together, this suggests that "the missing" released mallards die at their release site before the hunting season starts.

The number of released mallards and the hunting pressure varied greatly among the study sites. Our study included release sites with low, intermediate, and high hunting pressure. In actual numbers, there were obviously more mallards shot at locations where releases were large (Spearman's rho $r = 0.806$, $n = 37$, $p < 0.01$), but still there was not any correlation between the number of released mallards at a site and the share of released mallards in the subsequent hunting bag (Spearman's rho $r = 0.264$, $n = 37$, $p = 0.114$). Regardless, we believe this study to be a fair representation of the situation in Sweden and thereby that the average 22.6% harvest return is a representative number for farmed-released mallards in the country.

Annual survival of farmed and wild mallards

Based on previous studies of recovery and dispersal (e.g., Brakhage 1953; Dunn et al. 1995; Fog 1964), there is a strong indication that mortality rate is much higher in released birds than in wild. However, our two modelling analyses are based on Swedish mallards ringed in different life stages (pulli versus fledged), and the absolute survival rates produced in them are thus not readily comparable. Instead, our mark-recapture model for released mallards can be compared with Finnish data based on ringed wild pulli (Gunnarsson et al. 2008), which yields a clear difference: the annual survival estimate for Finnish wild unsexed pulli was ten times higher than that for our farmed mallards (0.21 versus 0.02).

Survival and recovery rates in released farmed mallards have been studied since the early 1930s, when Lincoln (1934) deemed releases of farmed mallards in North America expensive and not practical, as only 1.5% of the released birds were recovered. Also, Brakhage (1953) found a 30% higher first fall mortality in released mallards compared to wild. Several other subsequent studies corroborate low survival and recovery rates in farmed-released mallards, 0.19 and 0.33 first-year survival rates for males and females, respectively, in Soutiere (1989); 5.3 times higher survival rate in wild mallards in Dunn et al. (1995); and 0.18 survival rate from release to onset of breeding season in Champagnon et al. (2016). Note, however, that Lee and Kruse (1973) found similar survival rates in wild and farmed mallards. Comparing estimated survival rates between studies from different countries and decades is fraught with problems, though. Release techniques, origin and age of released individuals, hunting pressure, extent of supplemental feeding, etc. are all likely to affect the outcome. Nevertheless, the general pattern is clear: farmed released mallards have a much lower survival rate than wild conspecifics.

The very low annual survival in Swedish farmed-released birds can at least in part be explained by the high hunting pressure at the sites where they were released. However, a French study showed that survival in released mallards was low even in the absence of hunting (Champagnon et al. 2011). Natural duckling mortality has been shown to be highest the first weeks after release (Champagnon et al. 2011; Osborne et al. 2010; Schladweiler and Tester 1972), but because released mallards are fed ad libitum and often protected against predators, their survival can potentially be kept high (Champagnon et al. 2016). As less than a quarter of the released mallards in the present study were shot on the release site and very few were recovered long distances from it, our results nevertheless indicate that mortality is high directly after release and during the summer, before hunting starts.

The underlying causes for high summer mortality cannot be determined from our study, but as ducklings are often released in ponds or lakes of limited size, it may attract predators as well as create an environment ideal for diseases and parasites. Ducklings are generally immuno-naïve and therefore more susceptible to disease (van Dijk et al. 2014). As a case in point, a 99% infection rate of low pathogenic influenza, H10N7, was found at a game bird farm in southern France (Vittecoq et al. 2012). Low annual survival in released mallards may also be due to differences in morphology, such as maladapted bills (Champagnon et al. 2010; Söderquist et al. 2014) or digestive organs (Champagnon et al. 2011). This would influence their survival outside of the release wetlands where they no longer have access to supplementary feeding.

The present annual survival estimates for wild Swedish mallards are in line with recent values for Finland (Gunnarsson et al. 2008). This is perhaps a bit surprising, as the breeding population size is roughly the same in the two countries, but the hunting bag is considerably larger in Finland (Dalby et al. 2013). Also, releases of farmed mallards in Sweden should ideally decrease hunting pressure on the wild population (large-scale releases no longer occur in Finland). Comparing survival estimates is frequently problematic, as different analytical methods may yield different estimates. However, the datasets in the present study and in Gunnarsson et al. (2008) were filtered in the same way and analyzed using the same methods and by the same person.

The pattern in the present study of higher annual survival in wild males compared to wild females is consistent with the findings in Gunnarsson et al. (2008) for Finnish wild adults and juveniles. As discussed above, higher annual survival in adult males is common in dabbling ducks. However, we found such a difference in juveniles, too, i.e., for birds that have not yet experienced a breeding season. That nesting females have a higher mortality risk is therefore a moot point in this case. The full explanation behind the difference in survival between sexes is not clear to us and needs further attention.

Body condition, longevity, and release time of farmed mallards

In the 2500 farmed ducklings that were measured before release in 2018 (Table 4), body condition index (BCI) was higher in early batch birds than in late. This is somewhat puzzling as age, origin, and feeding regime were the same for the two batches. We speculate that light regime, temperature, or some other factor differed between batches and may have affected their growth. On the other hand, duckling BCI did not differ between the two release sites, which were similar wetlands located only 21 km apart. In other words, we should not expect any site effect in the analysis of recovered birds, which also turned out to be the case. This indicates that this result is generally applicable to releases, also in other geographical areas. BCI at release was higher in recovered females than in males, i.e., the former had a higher body mass/tarsus length ratio. Neither body mass nor tarsus length should vary between the sexes in wild mallards in this early stage of life (Office National de la Chasse 1982), which makes our result hard to explain. What further complicates the matter is that there was not any difference in BCI between all recovered and not recovered mallards. Neither was there an effect of sex on longevity. This suggests that the advantage of a high BCI for wild mallards in natural environments in this case was overridden by the supplemental feeding at release sites. We argue that without the additional food, a higher BCI in released mallards would probably correlate with a higher survival. Results concerning differences between the sexes may also be confounded by the fact that we only had data on sex for recovered and not all released mallards.

Also, among the recovered ducklings, those from the early batch had a significantly higher BCI at release than did the late batch birds. However, in the end, there was no correlation between individual BCI at release and subsequent longevity. This indicates that food was not limiting from the time of release until they were shot. Yet, longevity was higher in late batch birds than in early, which is puzzling as both groups were subjected to the same regime of hunting and disturbance. We speculate that ducklings released later, which also had a lower mean BCI, were more prone to act like young ducklings in the beginning of the hunting season, showing less flight activity, and as a result reducing the risk of being shot during early hunts. As a consequence, a higher proportion of the early released batch would have been shot early and the longevity for the same birds lower. This view is supported by a temporal difference in harvest date between the two groups, that is, an earlier peak in early batch birds (Fig. 2). The overall higher proportion of harvested birds in the early batch is probably due to a higher pre-hunting survival in these birds compared to the late batch. Lower survival in ducklings released later in the season may be attributed to higher mortality when common predators have young to feed.

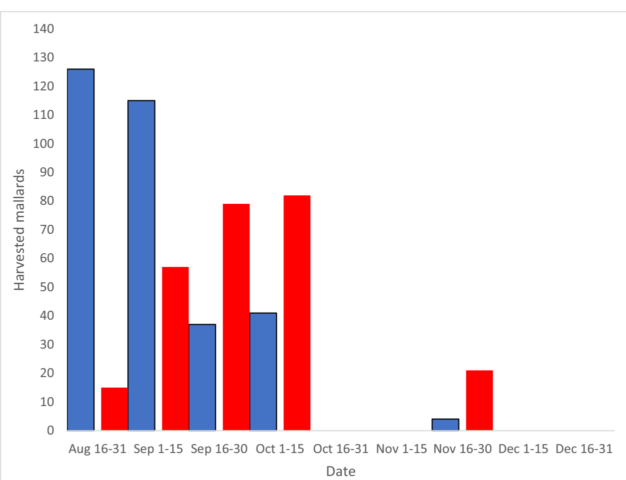

Fig. 2 Semi-monthly distribution of recovery of harvested farmed mallards during the 2018 hunting season, released at two sites either in May (early batch; blue, $n = 323$) or June (late batch; red, $n = 254$)

Conclusions and implications

Even though the present study indicates that most released farmed ducks die before the next breeding season, their sheer quantity is likely to affect the population of wild conspecifics. Based on our survival estimates and the estimate of 250,000 farmed-released mallards in Sweden annually, 5000 (95% CI, 3040–6960) will survive to potentially intermix with the wild population. There are now well-grounded conservation concerns that surviving released mallards may introduce semi-domestic traits to the wild population (Champagnon et al. 2012; Söderquist et al. 2017). A concern for conservation as well as management is that a significant share of the birds shot at release sites is in fact wild, likely attracted to the wetlands by supplemental feeding. This indicates that the practice of releasing farmed birds for hunting to protect wild populations may actually have the opposite effect. For wildlife managers whose goal is to promote sustainable hunting bags, it may be very hard to estimate the outcome of their efforts as long as they cannot determine if shot mallards are farmed or wild. This can be overcome by ringing released birds.

Our study shows that it is possible to affect harvest opportunities by altering the time of duckling release. Management striving to maximize hunting yield should rely on early release of ducklings, while those who wish to prolong the hunting season can adopt additional releases closer to the start of the hunting season. There is also a good potential to increase duckling survival locally after release.

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Code availability Not applicable

Author contribution All authors contributed to the study conception and design, material preparation, data collection, and analysis. Contribution to the first draft of the manuscript was made by all authors, and all authors commented on subsequent versions of the manuscript. All authors read and approved the final manuscript.

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Data availability All data are available on request from the Swedish Bird Ringing Centre.

Declarations

Conflict of interest The authors declare no conflict of interest.

References

Akaike H (1973) Information theory and an extension of the maximum likelihood principle. In: Petrov BN, Csaki F (eds) Proceedings of the 2nd international symposium on information theory. Akademiai Kiado, Budapest, pp 267–281

Arnold TW, Roche EA, Devries JH, Howerter DW (2012) Costs of reproduction in breeding female mallards: predation risk during incubation drives annual mortality Avian. Conserv Ecol 7:7. https://doi.org/10.5751/ACE-00504-070101

Brakhage GK (1953) Migration and mortality of ducks hand-reared and wild-trapped at Delta, Manitoba. J Wildl Manag 17:465–477

Burnham KP, Anderson DR (2002) Model selection and multi-model inference: a practical information-theoretic approach, 2nd edn. Springer-Verlag, New York

Champagnon J, Guillemain M, Elmberg J, Folkesson K, Gauthier-Clerc M (2010) Changes in mallard *Anas platyrhynchos* bill morphology after 30 years of supplemental stocking. Bird Study 57:1–8

Champagnon J, Guillemain M, Elmberg J, Massez G, Cavallo F, Gauthier-Clerc M (2011) Low survival after release into the wild: assessing the burden of captivity on Mallard physiology and behaviour. Eur J Wildl Res 58:255–267. https://doi.org/10.1007/s10344-011-0573-3

Champagnon J et al (2012) Assessing the genetic impact of massive restocking on wild mallard. Anim Conserv 16:295–305. https://doi.org/10.1111/j.1469-1795.2012.00600.x

Champagnon J, Gauthier-Clerc M, Lebreton J-D, Mouronval J-B, Guillemain M (2013) Les canards colverts lâchés pour la chasse interagissent-ils avec les populations sauvages? (In french). Faune Sauvage 298:4–9

Champagnon J et al (2016) Robust estimation of survival and contribution of captive-bred mallards Anas platyrhynchos to a wild population in a large-scale release programme. Ibis 158:343–352. https://doi.org/10.1111/ibi.12341

Dalby L et al (2013) The status of the Nordic populations of the mallard (Anas platyrhynchos) in a changing world. Ornis Fennica 90:2–15

Delany S, Scott DA (2006) Waterbird population estimates, 4th edn. Wageningen, Wetlands International

Doherty PF Jr et al (2002) Sources of variation in breeding-ground fidelity of mallards (Anas platyrhynchos). Behav Ecol 13:543–550. https://doi.org/10.1093/beheco/13.4.543

Dunn JP, Diefenbach DR, Hartman FE (1995) Survival and recovery distribution of wild and captive-reared mallards in Pennsylvania. Norteast Wildl 52:8

Errington PL, Albert WE (1936) Banding studies of semi-domesticated mallard ducks. Bird-Banding 7:69–73

Fog J (1964) Dispersal and survival of released mallards (*Anas platyrhynchos* L.). Dan Rev Game Biol 4:1–57

Fog J (1965) The mallards from the estate of Kongsdal. Dan Rev Game Biol 4:61–94

Fransson T, Pettersson J (2001) Svensk ringmärkningsatlas Swedish bird ringing atlas. vol 1. Ljungföretagen Tryckeri AB, Örebro. In Swedish, English summary

Green AJ (2001) Mass/length residuals: measures of body condition or generators of spurious results? Ecology 82:1473–1483. https://doi.org/10.1890/0012-9658(2001)082[1473:Mlrmob]2.0.Co;2

Green AJ, Elmberg J (2014) Ecosystem services provided by waterbirds. Biol Rev Camb Philos Soc 89:105–122. https://doi.org/10.1111/brv.12045

Greenwood RJ (1975) Reproduction and development of four mallard lines. Prairie Nat 7:9–16

Guillemain M, Elmberg J, Gauthier-Clerc M, Massez G, Hearn R, Champagnon J, Simon G (2010) Wintering french mallard and teal are heavier and in better body condition than 30 years ago: effects of a changing environment? Ambio 39:170–180

Guillemain M, Devineau O, Gauthier-Clerc M, Hearn R, King R, Simon G, Grantham M (2011) Changes in ring recovery rates over the last 50 years: shall we continue to ring ducks? J Ornithol 152:55–61

Guillemain M, Champagnon J, Massez G, Pernollet CA, George T, Momerency A, Simon G (2015) Becoming more sedentary? Changes in recovery positions of mallard Anas platyrhynchos ringed in the Camargue, France, over the last 50 years. Wildfow l:51–63

Gunnarsson G, Elmberg J, Dessborn L, Jonzen N, Pöysä H, Valkama J (2008) Survival estimates, mortality patterns, and population growth of Fennoscandian mallards *Anas platyrhynchos*. Ann Zool Fenn 45: 483–495

Gunnarsson G, Elmberg J, Waldenström J (2011) Trends in body mass of ducks over time: the hypotheses in Guillemain et al. revisited. Ambio 40:338–340

Hirschfeld A, Heyd A (2005) Mortality of migratory birds caused by hunting in Europe: bag statistics and proposals for the conservation of birds and animal welfare. Berichte Vogelschutz 42:47–74

Hirschfeld A, Attard G, Scott L (2019) Bird hunting in Europe: an analysis of bag figures and the potential impact on the conservation of threatened species. Br Birds 112:14

Hochbaum HA (1942) Sex and age determination of waterfowl by cloacal examination, vol 7. Transactions of the North American Wildlife Conference, Washington, D.C, pp 299–307

Jakob EM, Marshall SD, Uetz GW (1996) Estimating fitness: a comparison of body condition indices. Oikos 77:61–67. https://doi.org/10.2307/3545585

Lee FB, Kruse AD (1973) High survival and homing rate of hand-reared Wild-strain mallards. J Wildl Manag 37:154–159

Leopold A (1933) Game management. The University of Wisconsin Press, Madison

Lincoln FC (1934) Restocking of marshes with hand-reared mallards not proved practicable. Yearbook of agriculture 310–313

Markwell DD, Shortridge KF (1982) Possible waterborne transmission and maintenance of influenza viruses in domestic ducks. Appl Environ Microbiol 43:110–115

Mondain-Monval J-Y, Girard O (2000) Le canard colvert, la sarcelle d'hiver et autres canards de surface. Faune Sauvage 251:124–139

Nilsson L (1976) Sex-ratios of Swedish Mallard during the non-breeding season. Wildfowl 27:91–94

Noer, H., Søndergaard, M. & Jørgensen, T.B. 2008: Udsætning af gråænder i Danmark og påvirkning af søers fosforindhold.

Danmarks Miljøundersøgelser, Aarhus Universitet. pp 44. – Faglig rapport fra DMU nr. 687. http://www.dmu.dk/Pub/FR687.pdf
Norris K (1993) Seasonal variation in the reproductive success of blue tits: an experimental study. J Anim Ecol 62:287–294. https://doi.org/10.2307/5360
Office National de la Chasse (1982) Critères de détermination de l´âge du canard colvert de la naissance a 9 semaines. (In french). Bulletin Mensuel de l'Office National de la Chasse 63:1–5
Osborne CE, Swift BL, Baldassarre GA (2010) Fate of captive-reared and released mallards on eastern Long Island. N Y Hum Wildl Interactions 4:266–274
Rohwer F (1992) The evolution of reproductive patterns in waterfowl. In: BDJ B, Afton AD, Anderson MG, Ankney CD, Johnson DH, Kadlec JA, Krapu GL (eds) Ecology and management of breeding waterfowl. University Minnesota Press, Minneapolis, pp 486–539
Schladweiler JL, Tester JR (1972) Survival and behavior of hand-reared mallards released in the wild. J Wildl Manag 36:1118–1127
Schulte-Hostedde AI, Zinner B, Millar JS, Hickling GJ (2005) Restitution of mass–size residuals: validating body condition indices. Ecology 86:155–163. https://doi.org/10.1890/04-0232
Seber GAF (1970) Estimating time-specific survival and reporting rates for adult birds from band returns. Biometrika 57:313–318
Sjöberg K, Gunnarsson G, Pöysä H, Elmberg J, Nummi P (2010) Born to cope with climate change? Experimentally manipulated hatching time does not affect duckling survival in the mallard *Anas platyrhynchos*. Eur J Wildl Res 57:505–516. https://doi.org/10.1007/s10344-010-0459-9
Söderquist P (2015) Large-scale releases of native species: the mallard as a predictive model system. PhD thesis, Swedish University of Agricultural Sciences
Söderquist P, Gunnarsson G, Elmberg J (2013) Longevity and migration distance differ between wild and hand-reared mallards Anas platyrhynchos in Northern Europe. Eur J Wildl Res 59:159–166. https://doi.org/10.1007/s10344-012-0660-0
Söderquist P, Norrström J, Elmberg J, Guillemain M, Gunnarsson G (2014) Wild mallards have more "goose-like" bills than their ancestors: a case of anthropogenic influence? PLoS One 9: e115143. https://doi.org/10.1371/journal.pone.0115143
Söderquist P et al (2017) Admixture between released and wild game birds: a changing genetic landscape in European mallards (Anas platyrhynchos). Eur J Wildl Res 63:98. https://doi.org/10.1007/s10344-017-1156-8
Soutiere EC (1989) Survival rates of hand-reared mallards released on 2 private farms. J Wildl Manag 53:114–118
Swedish Bird Ringing Centre (2009) Number of birds ringed and recovered during the time period 1911-2008. https://www.nrm.se/en/forskningochsamlingar/miljoforskningochovervakning/ringmarkningscentralen/ringmarkningochaterfynd.763.html. Accessed 2021-02-03
U.S. Department of the Interior, U.S. Fish and Wildlife Service, and U.S. Department of Commerce, U.S. Census Bureau (2016) National Survey of Fishing, Hunting, and Wildlife-Associated Recreation
van Dijk JGB, Hoye BJ, Verhagen JH, Nolet BA, Fouchier RAM, Klaassen M (2014) Juveniles and migrants as drivers for seasonal epizootics of avian influenza virus. J Anim Ecol 83:266–275. https://doi.org/10.1111/1365-2656.12131
Verhulst S, van Balen JH, Tinbergen JM (1995) Seasonal decline in reproductive success of the Great Tit: variation in time or quality? Ecology 76:2392–2403. https://doi.org/10.2307/2265815
Vittecoq M et al (2012) High influenza A virus infection rates in mallards bred for hunting in the Camargue, south of France. PLoS One 7: e43974. https://doi.org/10.1371/journal.pone.0043974
Wetlands International (2020) Waterbird population estimates. Retrieved from www.wpe.wetlands.org. 2020-06-29
White GC, Burnham KP (1999) Program MARK: survival estimation from populations of marked animals AU – White. Bird Study 46: S120–S139. https://doi.org/10.1080/00063659909477239