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The ecological effects of the release and management of large numbers of mallard *Anas platyrhynchos* for recreational hunting

Joah R. Madden [a,*], Tom C. Cameron [b], Chas A. Holt [b,c]

[a] Centre for Research in Animal Behaviour, University of Exeter, Exeter, EX4 4QG, UK
[b] School of Life Sciences, University of Essex, Wivenhoe Park, Colchester, CO43SQ, UK
[c] Adonis Blue Environmental Consultants, Kent Wildlife Trust Group, Tyland Barn, Chatham Road, Maidstone, ME14 3BD, UK

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ABSTRACT

Millions of Mallard *Anas platyrhynchos* are artificially reared and released annually in the USA, Europe and, at particularly high densities, the UK, for recreational shooting. These releases and associated management practices have both positive and negative ecological impacts—locally through direct effects and more broadly through ecological interactions. These may affect wild conspecifics, other waterbirds, and the wider aquatic ecosystem. While we have a moderate understanding of the ecological effects of releasing other gamebirds (e.g. pheasants *Phasianus colchicus*, red-legged partridge *Alectoris rufa*), knowledge about Mallard rear-and-release impacts is limited. Our systematic review found little relevant evidence, especially regarding high-density UK releases, but identified three key patterns. First, released Mallards often interbreed with wild conspecifics. If hybridisation reduces survival or reproductive fitness, it could harm wild populations, though field and population-level evidence is limited. Second, released birds exert direct effects on release areas. Aside from eutrophication, evidence for impacts like resource competition, disease transmission, predation, and support of generalist predators is limited. Third, management by gamekeepers or landowners – such as wetland creation, supplementary feeding, and predator control - has associated effects on other waterbirds and aquatic species more generally. However, motivations for these actions may relate to other gamebird or wild waterbird shooting, making net ecological impacts hard to assess. We call for markedly more research into Mallard release and management effects and identify five key knowledge gaps that that need addressing to provide a robust evidence base for stakeholders, policymakers, and legislators about this widespread, culturally significant, and economically important activity.

1. Introduction

Tens, perhaps hundreds, of millions of gamebirds, are reared and released annually for recreational shooting, across Europe and North America (Powolny and Czajkowski, 2022; Burden, 2013). These mainly comprise Galliformes (e.g. Pheasants *Phasianus colchicus*, Red-legged Partridge *Alectoris rufa*, Chukar Partridge *Alectoris chukar* and (Northern) Bobwhite Quail *Colinus virginianus*). The release and subsequent management of these birds exerts a range of effects, ecologically both positive and negative, on and beyond the areas where they are released and shot (Madden and Sage, 2020; Sage et al., 2020; Mason et al., 2020; Madden, 2023). The Mallard *Anas platyrhynchos,* an Anserifome, is also released in large numbers across Europe, North America and the UK. In contrast to Galliformes, the release of Mallard (hereafter game-farm Mallard, to distinguish them from wild Mallard) is much less well-studied and its accompanying ecological effects are less well understood. Releasing game-farm Mallard for recreational shooting is believed to have started in the UK in 1890 (Sellers & Greenwood, 2019). It was common practice to supplement hunted wild populations by the 1950s (Boyd, 1957). Currently, release practices vary both within and between countries. For example, in Sweden, ducklings are given a soft release in May–July when only 2–3 weeks old, placed into small, fenced areas in managed wetlands including both inland and coastal areas, with feed and predator control, from where they can gradually disperse as they develop (Jagareforbundet, *pers comm*, Jan 2026). In the UK, releases are typically made when the birds are 6–10 weeks old, when they are introduced from mid to late summer to ponds where supplementary food is provided, and which can also be protected from terrestrial predators

* Corresponding author.
E-mail address: j.r.madden@exeter.ac.uk (J.R. Madden).

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by fencing and legal lethal control. The game-farm Mallard settle on these ponds and typically stay within the confines of a property to which they are introduced for much of the summer until early autumn when they will start to fly and explore their local landscapes. These releases commonly occur on inland shoots that also release Pheasant and Red-legged Partridge for shooting. Increasingly there are commercial shoots dedicated to driven duck shooting that predominantly release large numbers of Mallard. In the USA, releases may be similar to those used in Sweden and the UK, but releases also occur at "tower shoots" where fully mature game-farm Mallard (16+ weeks old) are held in crates until immediately before shooting starts and then released towards the waiting guns, either from the ground or raised locations (Anon, 2013). The released birds, and the management interventions such as regular feeding on release ponds, may attract other wild Mallard and ducks to roost or feed on the same ponds.

Exactly how many game-farm Mallard are released annually is not certain. Powolny and Czajkowski (2022) summarise annual release data from a number of European countries, with 1.4 million released in France, half a million in Denmark, a quarter of a million in each of the Czech Republic and Sweden and 100,000 in each of Germany, Portugal and Spain. It is estimated that perhaps one million are released annually in the USA (Burden, 2013) with reports of releases of 122,000 at a single preserve in one year (Osborne et al., 2010). Releases in the UK may be even higher. The 2019 Animal and Plant Health Agency Poultry Register (the official record of poultry held in the UK, whose completion is a legal requirement for all flocks of >50 birds, and ostensibly an accurate record of releases) shows that 435,907 'duck' were held for release for shooting. Harradine (1985) believed there to be around 500,000 Mallard released annually in the UK during the early 1980s. Madden (2021) used a triangulation approach to combine a range of messy datasets, producing an estimate of 2.6 million Mallard (range 0.9–6.0 million) released annually in the UK in the late 2010s. Aebischer (2024) used bag records from a series of c700 collaborating shoots and hunters, and arrived at a lower estimate of 1.3 million released in 2022, but with tighter confidence intervals (0.9–1.8 million). There is a record of 150,000 being released at a single site in the UK (Madden and Sage, 2020). Regardless of the absolute numbers, there has been a clear trend of increases in Mallard releases. Aebischer (2024) concludes that releases of Mallard in the UK have increased by almost 50% from 2001 to 2022. Data from the Game and Wildlife Trust National Gamebird Census (NGC) reveals that the index of releases has increased nine-fold between 1961 and 2022 (GWCT, 2024). In the USA, 317 preserves were licenced to release Mallard in 2001 (USFWS, 2003). In the UK, approximately one fifth to one quarter of the estimated 7000–9000 shoots in the UK appear to release Mallard (Madden, 2021). In the UK, and also likely in the USA, there is a skewed distribution of release sizes, with a few sites responsible for a disproportionate number of Mallard releases (see Fig. 3C in Madden and Sage, 2020). It is an economically and culturally important activity. Economic values for Mallard shooting are hard to isolate but likely substantial. UK commercial shoots charge about £30 per bird, and with an estimated 940,000 Mallard shot in 2016 (Aebischer, 2019), the shooting value alone could reach £28 million annually. In North America, waterfowl hunting is worth about $100 million per year, with Mallard comprising roughly a third of the bag (Johnsgard, 2010). In Mississippi, hunting waterbirds generated $86.8 million annually (Grado et al., 2011). Internationally, released Mallard hunting is worth several tens of millions of pounds each year and is culturally significant (Green and Elmberg, 2014), involving up to two million waterbird hunters in the USA (Johnsgard, 2010) and 3.2 million across Europe (Scott, 1982).

In contrast with releases of many other gamebirds, where the introduced birds do not overlap their natural ranges, Mallard are almost always released into areas where "wild" populations of Mallard already exist. These releases may be markedly higher than the populations of wild Mallard in the area. For context, 59,000–140,000 breeding pairs of presumed wild Mallard were recorded in Great Britain during the 2016 breeding season, with a median estimate of 61,000 (Woodward et al., 2020), perhaps <10% of the number released. These counts likely include some released Mallard, because the birds are indistinguishable morphologically from wild conspecifics in the field (Söderquist et al., 2014). The wild population include wild-born birds, released birds and the many generations of matings between these groupings, making it difficult to accurately distinguish origins.

Released Mallard, rather like released Galliformes, may exert a series of direct impacts on the environment. These might include changing nutrient levels, damaging flora and predating fauna, affecting the wider aquatic ecosystem; and acting as vectors of disease and serving as food for a range of predators, affecting other waterbirds (and perhaps fauna more widely) and especially wild conspecifics (Madden and Sage, 2020). We might also expect that their release stimulates a range of associated environmental effects caused by the actions of the gamekeepers managing them. These might include the creation, improvement and retention of habitats, the provision of supplementary feeding sites, and the reduction in numbers of predators, all of which are likely to affect wild conspecifics, other waterbirds and the ecosystem more widely. In the case of Galliformes, these effects appear to correspond to changes in the populations of a range of taxa (foxes, carrion crows, squirrels, rodents, butterflies, beetles, farmland and woodland birds) (Madden et al., 2023). Unlike non-native Pheasants and Red-legged Partridges, released Mallard might be expected to exert particularly strong effects on sympatric wild conspecifics, including detrimental effects such as competing for resource and mates or beneficial effects from provisioned food and breeding habitats. Released Mallard which survive their first winter might breed with wild birds leading to hybridisation and introgression (Luukkonen et al., 2025). In addition, wild Mallard may be affected by being targeted as quarry even if the intention is only to harvest released birds. It is evident that large numbers of birds are released in many locations, and therefore, we might expect this activity to have a range of effects on a) wild populations of conspecific Mallard; b) other waterbirds occupying similar habitats; and c) the wider aquatic ecosystem.

The effects of released Mallard were deliberately excluded from three recent reviews of the effects of released gamebirds in the UK (Mason et al., 2020; Sage et al., 2020; Madden, 2023), primarily because the numbers involved were lower than those of Pheasants and Partridges which formed to focus of those reviews. Their effects have been considered more specifically in tow further reviews. Callaghan (1996) conducted an international review of the biodiversity and sustainability effects of release of waterfowl for shooting, but the scale of releases in the subsequent 30 years has increased markedly. He concluded that there were six negative effects (nutrient dynamics, disease, hunting pressure, problems with monitoring wild populations, depletion of conservation resources) and two positive effects (restriction of more damaging activities, re-establishment of species) on biodiversity arising from release. A more recent review was conducted by VKM (2017) evaluating the risks associated with the import and release of Mallard in Norway. This considered potential interactions between wild and farmed Mallard, potential genetic impacts of interbreeding, potential impacts on local fauna and flora, nutrification impacts, and disease risks. However, with a reported 10,000 Mallard released annually in Norway, less than half of 1 % of the total released annually in the UK, or less than 10% of releases in other countries where the practice occurs, the scale and type of impacts are likely to differ.

In this review, we searched both peer-reviewed and grey literature for direct, circumstantial and anecdotal evidence about the potential direct and associated effects that the release and management of Mallard might have on the environment and biodiversity, including effects on wild Mallard populations, other waterbirds and wider aquatic ecosystems.

2. Methods

Research and reports relating to the effect of the release and

management of Mallard is likely to take many forms including formal, peer reviewed research papers, public and private reports for government and non-government agencies, and advice to land managers. Therefore, we adopted multiple, simultaneous approaches to locate material. Evidence was obtained in six ways between March–August 2024. First, papers identified by Madden and Sage (2020) following the search methods that they described were collected (N = 12 papers). Second, we searched the citations of these papers made post-2020 to identify any development of the original findings and then searched references in these new papers to identify any additional papers that were not included by Madden and Sage (2020) (N = 11 new papers). Third, we searched previous Review papers (Callaghan, 1996; VKM, 2017) for references (in other languages) that we had previously not used (N = 3 new papers). Fourth, we conducted literature searches on Google Scholar and Web of Science in June 2024 [Google Scholar: "*anas platyrhynchos*" AND "release*" AND "hunt*" 1996–2024 (1996 is post Callaghan review) = 412 results; Web of Science: *anas platyrhynchos* AND release* and hunt* Abstract only = 19 results]. We assessed the relevance of the papers by reading the Title and if necessary, the Abstract, including only those that described studies of released Mallard and ecological effects (N = 9 new papers). Fifth, we searched the Conservation Evidence database https://www.conservationevidence.com/ with the search term "Mallard" (N = 1 new paper). We removed any duplicates as they were encountered. Finally, we were approached by the author of an ongoing relevant review in conjunction with other work that we were conducting and obtained their report (N = 1 new paper). We then read the papers and extracted information about any reported effects, providing us with 41 distinct effects. Our search results are summarised according to PRISMA guidelines (Liberati et al., 2009) in Fig. 1. We deliberately excluded effects arising from the actual shooting of the released Mallard. These may include disturbance, misidentification of quarry and the ingestion of lead shot. Such effects may occur during the shooting of wild Mallard, regardless of whether releases occur or not, although they may be more likely when larger numbers of (released) Mallard are shot. We discuss these effects briefly later. We assigned reported effects to one of three kinds (Fig. 2). First, some studies describe how introgression from released Mallard alters the genetic composition, and hence behaviour and/or life history, of wild Mallard populations. Second, some studies describe how the direct effects of released Mallard, such as competition for resources, disturbance or exposure to disease, have the potential to affect populations of UK flora and fauna. Third, some studies describe how associated effects of the management of released Mallard such as protection and provision of habitats or feed, supplementation of predator diets, reduced human disturbance or predator control, have the potential to affect populations of UK flora and fauna. We recorded what was the likely subject of the reported effects, being either conspecifics, other heterospecific waterbirds or wider parts of the aquatic ecosystem (Fig. 2). We classed the evidence in two dimensions. i) Strength of link to fitness/population/conservation status: 3 = explicit links demonstrated; 2 = links implied/invoked in the Discussion but unsubstantiated; 1 = no link mentioned. ii) We classed the quality of the evidence using three classifications. 3 = experimental/matched sample design; 2 = correlational/unmatched sample design; 1 = anecdotal/no controls.

3. Results

3.1. Summary of evidence

The evidence comprised 37 publications including 41 effects (Table 1). Fourteen reported effects arose from genetic mixing between released and wild Mallard or other closely related ducks, 15 effects were considered to directly arise from the actions of the released Mallard, and 12 were associated with the management that accompanied releases. Twenty-three effects were considered by the authors to have ecologically negative consequences, seven to have ecologically positive consequences, nine to be ecologically neutral (no effect) and for seven effects it was not possible to conclude whether the effects were ecologically positive, negative or neutral. Most effects involved conspecific Mallards (Fig. 3A). About half of the effects were explicitly linked to ecological outcomes (Fig. 3B). Just under a quarter of the effects were derived from high quality evidence based on experimental or matched sample design studies or systematic reviews.

3.2. Description of effects

3.2.1. Effects of introgression

Fourteen effects were reported, with 13 of them being deemed negative, with eight having demonstrable links to outcomes and one being considered as high-quality evidence (Table 1). In areas where farmed Mallard are released into areas where Mallard are native, interbreeding with wild conspecifics or other *Anas* species is possible.

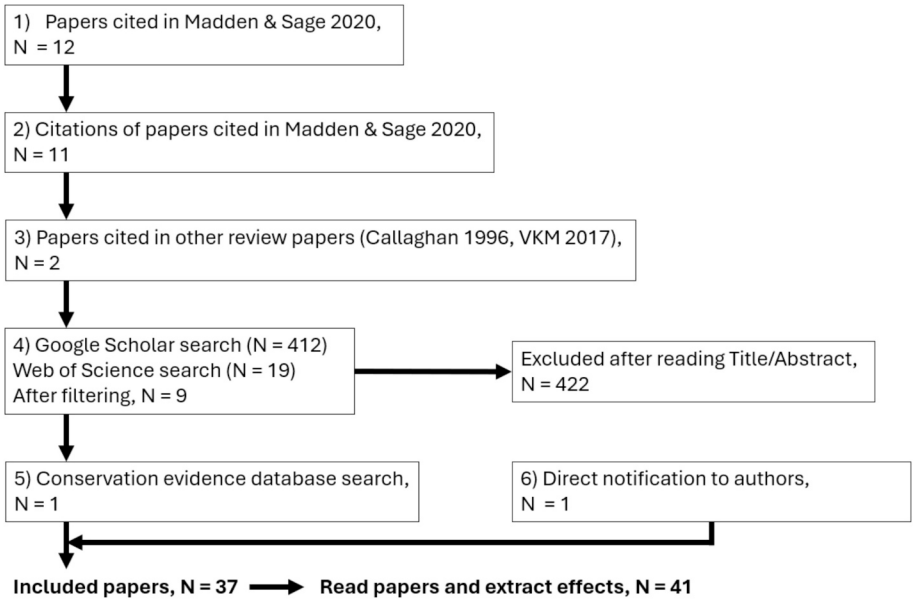


Fig. 1. Summary of literature search and selection of studies for use in this review.

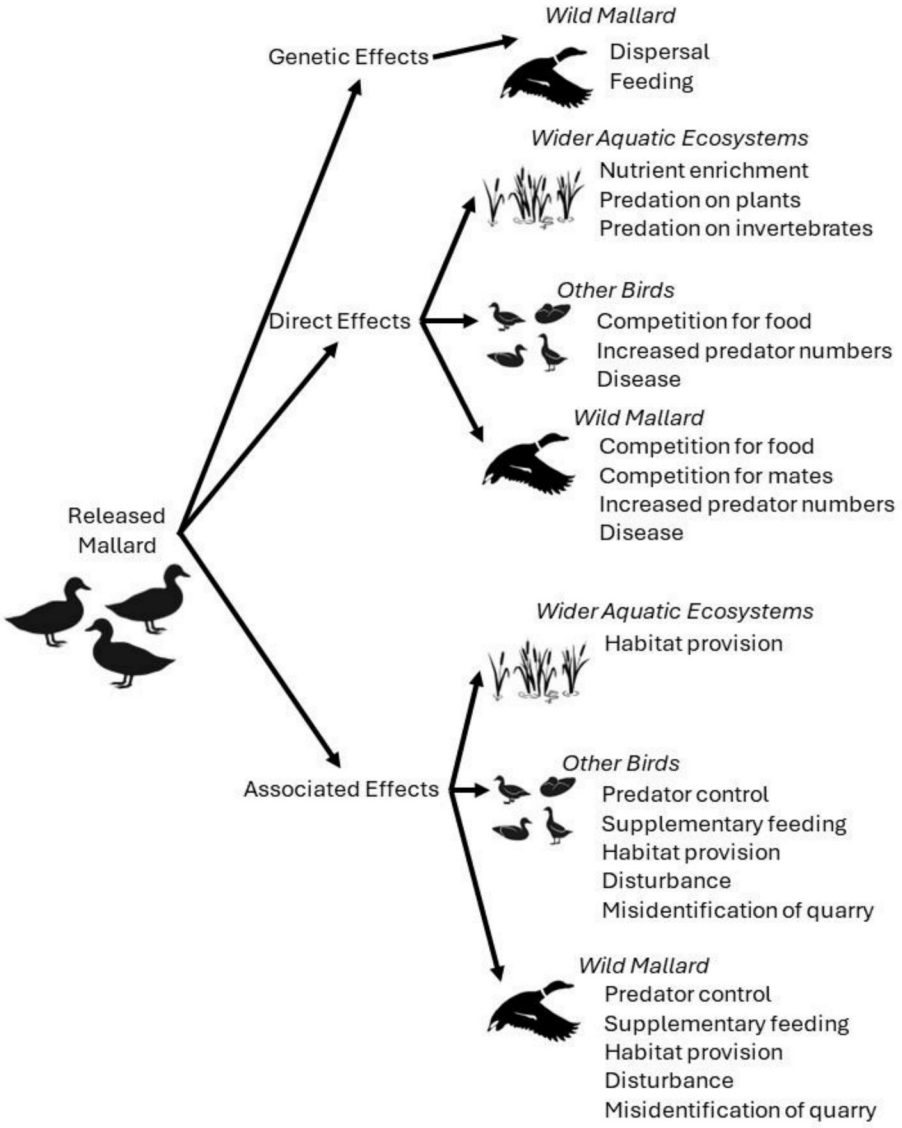


Fig. 2. Summary of genetic, direct and associated effects of released Mallard on wild Mallard, other waterbirds and the wider aquatic ecosystem.

This presents two possible threats to biodiversity.

First, hybridisation might lead to the disappearance of other species, swamped by the releases of Mallard. This has been suggested as contributing to the decline in Grey Duck *Anas superciliosa* numbers in New Zealand, in conjunction with direct competition and misidentification of quarry (Williams, 2017). However, while also suggested to be responsible for declines in Black Duck *Anas rubripes* in the USA, there is little genetic evidence of their hybridisation (Lavretsky et al., 2020).

Second, released Mallard may interbreed with conspecifics introducing maladaptive traits to wild populations, reducing survival. In an international-scale analysis of introgression and hybridisation in Mallard, Lavretsky et al. (2023) identified a single source population for game-farm Mallard across both Europe and the USA in a sample of 1916 wild and feral Mallard. However, some populations that likely originated from these feral birds, in New Zealand and Hawaii, are now strongly genetically differentiated. They also report that although demographic studies suggest that domestic and wild Mallard diverged perhaps thousands of years ago, this seems unlikely with propagation for releases and hunting first documented in the 1600's in the UK and organised breeding and releases for hunting only starting in the 1890's, suggesting distortions in genetic patterns due to severe bottlenecks.

In Europe, consistent genetic differences between wild and farm-bred Mallard are found. In the Camargue in France, where large scale release of Mallard has occurred since the 1970s, the genetic signature of game-farm Mallard were still clearly distinct from those of presumed wild Mallard caught in no-shooting areas, despite significant rates of hybridization between reared and wild-born birds (Champagnon et al., 2013). In Italy, a large admixture of wild and farmed strains was evident at eight sites (Baratti et al., 2015). A broader survey of Mallard populations in northern mainland Europe also revealed clear genetic differentiation between game-farm and presumed wild Mallard, but with admixed individuals within the wild-born population suggesting introgression (Söderquist et al., 2017). Čížková et al., 2012 compared wild and game-farm Mallard populations in the Czech Republic and found marked genetic divergence and lower genetic diversity among game-farm Mallard.

In the USA, the pattern of mixing between game-farm and wild Mallard differs across the country, with an indication of increasing levels of hybridisation from east to west of the country. Around the middle to lower Mississippi flyway in the USA, of 499 shot Mallard, 28% contained game-farm derived mitochondrial DNA, although only 4% contained game-farm derived nuclear DNA, suggesting low levels of hybridisation (Davis et al., 2022). The results also suggest that although there was a period of game-farm introgression in the past, such mixing has

Table 1
Evaluation of the relevance and quality of evidence pertaining to the effects of released Mallard on flora and fauna in the UK. i) Strength of link to fitness/population/conservation status: 3 = explicit links demonstrated; 2 = links implied/invoked in the Discussion but unsubstantiated; 1 = no link mentioned; ii) Quality of Evidence: 3 = experimental/matched sample design OR systematic review; 2 = correlational/unmatched sample design; 1 = anecdotal/no controls. The Direction of Effect measure is somewhat subjective. – indicates an ecological effect deemed to be negative; + indicates an ecological effect deemed to be positive;? indicates that an effect was detected but it was unclear whether it has ecologically positive, negative or neutral effects.

Paper	Literature Type	Effect	Form of effect	Direction of effect	Likely effects act on	Strength of link to outcome	Quality of evidence
Interbreeding							
Baratti et al., 2015	Journal article	Genetic differentiation	Genetic mixing	–	Wild Mallard	2	1
Champagnon et al., 2010	Journal article	Bill morphology	Morphological change	–	Wild Mallard	2	2
Champagnon et al., 2013	Journal article	Genetic differentiation	Genetic mixing	–	Wild Mallard	3	2
Champagnon et al., 2016a	Journal article	Differential survival	Genetic mixing	–	Wild Mallard	3	2
Champagnon et al., 2016b	Journal article	Effect on wild population size and persistence	Genetic mixing	–	Wild Mallard	3	1
Čížková et al., 2012	Journal article	Genetic differentiation (and disease susceptibility)	Genetic mixing	–	Wild Mallard	2	1
Davis et al., 2022	Journal article	Genetic differentiation	Genetic mixing	–	Wild Mallard	3	2
Lavretsky et al., 2020	Journal article	No genetic hybridisation with black duck	Hybridisation	neutral	Other waterbird (other *Anas* species)	2	1
Lavretsky et al., 2023	Journal article	Genetic differentiation	Genetic mixing	–	Wild Mallard	2	2
Schummer et al., 2023	Journal article	Genetic differentiation	Genetic mixing	–	Wild Mallard	3	2
Söderquist et al., 2017	Journal article	Genetic differentiation	Genetic mixing	–	Wild Mallard	2	3
Söderquist et al., 2021b	Journal article	Differential survival		–	Wild Mallard	3	2
Svobodová et al., 2020		Differential growth rates		–	Wild Mallard	3	2
Williams, 2017		Genetic differentiation,	Genetic mixing	–	Wild Mallard	3	1
Direct Effects							
Söderquist et al., 2021a	Journal article	Nutrient levels,	Phosphorous	–	Aquatic ecosystem (likely widespread taxa)	3	2
Söderquist et al., 2021a	Journal article	Nutrient levels	pH	neutral	Aquatic ecosystem (likely widespread taxa)	3	2
Wiberg-Larsen et al. 2000 in VKM, 2017	Report	Nutrient levels	Phosphorous	–	Aquatic ecosystem (likely widespread taxa)	3	2
Noer er al. 2009 in VKM, 2017	Report	Nutrient levels	Phosphorous	–	Aquatic ecosystem (likely widespread taxa)	1	2
Söderquist et al., 2021a		Predation on plants	Macrophyte cover	neutral	Aquatic ecosystem (Aquatic plants)	1	2
Reichof 1973 in Callaghan, 1996	Conference proceedings	Predation on invertebrates	Abundance of invertebrates	?	Aquatic ecosystem (Diptera, Coleoptera, Daphnia, Mollusca)	1	2
Champagnon et al., 2012	Journal article	Foraging competition	Differential dietary preferences	neutral	Wild Mallard	3	2
Guillemain and Fritz, 2002	Journal article	Foraging competition	No effect on foraging behaviour of heterospecifics	neutral	Other waterbirds	2	2
Cheng et al., 1978	Journal article	Competition for mates	Strain-specific partner preference	neutral	Wild Mallard	2	3
Padyšáková et al., 2011	Journal article	Support for increased predator populations	Increased predator activity	neutral	Other waterbirds	3	3
Otter et al., 2018	Journal article	Disease	Botulism	–	Other waterbirds	2	2
Stallknecht and Brown, 2007	Journal article	Disease	Avian influenza	–	Wild Mallard, Other waterbirds	2	3
Steensels et al., 2016	Journal article	HPAI disease amplification	Avian influenza	–	Wild Mallard, Other waterbirds	3	3
Therkildsen et al., 2011	Journal article	Disease	Avian influenza	–	Other waterbirds	3	1
Donald, 2024	Scoping review	Disease	Avian influenza	–	Wild Mallard, Other waterbirds, Aquatic ecosystem (e.g. mammalian predators)	2	3
Associated Effects							

(*continued on next page*)

Table 1 (*continued*)

Paper	Literature Type	Effect	Form of effect	Direction of effect	Likely effects act on	Strength of link to outcome	Quality of evidence
Stewart and McDougall, 2022	Journal article	Predator control	Predation on artificial Mallard nests	?	Wild Mallard, Other waterbirds	2	1
Amundson et al., 2013	Journal article	Predator control	Nesting success and population growth	+	Wild Mallard, Other waterbirds	3	3
Champagnon et al., 2012	Journal article	Supplementary feeding	Access to supplementary food	?	Wild Mallard	1	2
McGeehan, 2005	Conservation Evidence	Supplementary feeding	Access to supplementary food	–	Other waterbirds	2	3
Söderquist et al., 2024	Journal article	Supplementary feeding	Access to supplementary food	+	Wild Mallard, Other waterbirds	3	3
Cox et al., 1996	Report	Provision of suitable habitat	Creation/retention of water features	+	Wild Mallard, Other waterbirds, Aquatic ecosystem	3	3
Lewis-Phillips et al., 2019	Journal article	Provision of suitable habitat	Bird species diversity, abundance and activity	+	Other waterbirds	2	1
Stewart et al., 2022		Provision of suitable habitat	Creation of ponds	+	Aquatic ecosystem (Eels)	1	2
Gaget et al., 2024	Journal article	Provision of suitable habitat	Mitigation of distribution shifts due to climate change	+	Other waterbirds	1	3
Dittmer et al., 2024	Journal article	Provision of suitable habitat	Access to preferred habitat	+	Wild Mallard	3	2
Söderquist et al., 2021a	Journal article	Provision of suitable habitat	Species richness	neutral	Other waterbirds	3	1
Söderquist et al., 2021a	Journal article	Provision of suitable habitat	Species presences/ richness	- (presence) neutral (richness)	Aquatic ecosystem (Amphibians)	1	1

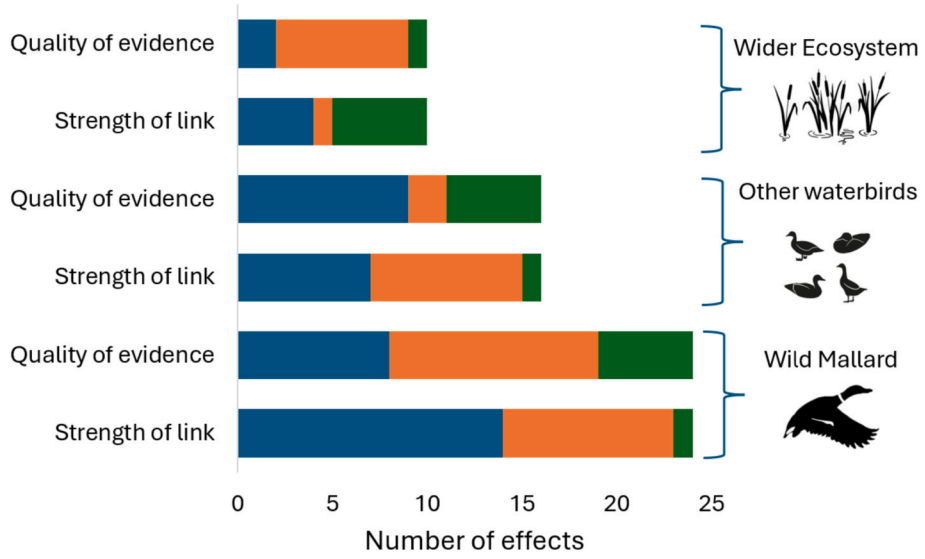


Fig. 3. Summary of the available literature, showing the number of effects reported for each of the three main subjects, showing for each the quality of evidence (blue bar - experimental/matched sample design OR systematic review; orange bar - correlational/unmatched sample design; green bar- anecdotal/no controls) and the strength of link (blue bar - explicit links demonstrated; orange bar - links implied/invoked in the Discussion but unsubstantiated; green bar - no link mentioned). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

subsequently decreased, perhaps in conjunction with lower release numbers. In Ohio, USA, of a sample of 296 hatch-year shot Mallard, 35% were wild and the other 65% exhibited at least some evidence of hybridisation either as early generation (F1-F3) hybridisation (12%) or a more established mixing resulting in membership of a hybrid swarm (53%) (Schummer et al., 2023). Historically, Mallard releases have been greatest along the eastern Atlantic coast, indicating a link between local release intensity and hybridisation (Schummer et al., 2023). Lavretsky et al. (2020) conclude that Mallard in the USA are becoming a hybrid swarm, with extensive mixing between game-farm and wild populations, with the strongest evidence for this in eastern USA where releases are largest and longest established.

Morphological features suggest that interbreeding between wild and game-farm Mallard might be leading to changes in bill morphology, affecting feeding. Specifically, lamellar density has decreased in Mallard in Europe over the past 30 years, making filter feeding less efficient, and because this change was not seen in Teal *Anas crecca*, the assumption is that it is because of changes in phenotypes due to interbreeding with game-farm birds (Champagnon et al., 2010). Likewise, the bills of wild Mallard have become more "goose-like" (wider, higher and shorter) than ancestral Mallard bills, again suggested to be the consequence of breeding with game-farm Mallard and again leading to inefficient

feeding behaviour in the wild (Söderquist et al., 2014). Very recent work that we did not encounter during our search repeats the finding that bills morphology differs as previously reported and that game-farm Mallard have longer bodies and tarsi, and shorter heads and wings than wild Mallard (Halligan et al., 2025).

Wild and game-farm birds also exhibit differences in some behaviours. Game-farm Mallard dispersed or migrated less well than wild Mallard (Söderquist et al., 2013). For a Swedish sample, game-farm Mallard were recovered a mean distance of 523 km (SE = 36) from ringing site whereas comparable measures for wild birds were 676 km (SE = 58). For a Finnish sample, game-farm Mallard were recovered a mean distance of 157 km (SE = 110) from ringing site whereas comparable measures for wild birds were 1213 km (SE = 81). The authors note that these differences between early-life conditions may be partially driven by differences in survival (see below) and that differences between sites may depend on climate and landscape. Only 4% of game-farm Mallard were recovered >3 km from their Swedish release site, whereas 91% of wild-caught ringed Mallard were recovered >3 km from their ringing site (Söderquist et al., 2021b). However, game-farm and wild Mallard did not differ in their behavioural time budgets for activity or foraging times (Champagnon et al., 2012). Separating out the role of genetic from early-life experience in determining these behaviours is difficult. Therefore, it is unclear how susceptible they are to interbreeding.

While the behavioural and morphological differences described above are likely a combination of inherited effects and rearing/maternal influences, it is possible that game-farm Mallard breeding with wild conspecifics may produce offspring poorly suited to the wild environment with low dispersal and inefficient feeding abilities, leading to population declines. Game-farm Mallard released into the wild had lower first year survival in central France, about half that of local wild Mallard (Champagnon et al., 2016a). For a Swedish sample, 77% of game-farm Mallard died in <1 year compared to 45% of wild Mallard. For a Finnish sample, 90% of game-farm Mallard died in <1 year compared to 66% of wild Mallard. This may be because game-farm Mallard were in poorer body condition than wild Mallard at the same site (Champagnon et al., 2012), especially when combined with Nordic winter conditions. In the USA, game-farm Mallard had a 30% higher first Autumn mortality compared to wild Mallard (Brakhage, 1953), while in Canada, wild Mallard had a 5.3 times higher survival rate compared to game-farm Mallard (Dunn et al., 1995). An even more extreme difference was reported in Scandinavia with wild Finnish Mallard having ~ten times higher survival rates than game-farm Mallard in Sweden (Söderquist et al., 2021b). It is unclear whether these differences in survival are the result of genetic effects, differential maternal effects or differences in early-life conditions that (fail to) prepare the birds for adult life in terms of learning foraging or predator avoidance skills from parents. The effects from Scandinavia and Canada may be especially strong under harsh winters when combined with low heritable or learned migration behaviours. Experimental rearing of birds from game-farm and wild strains under the same artificial conditions resulted in game-farm Mallard growing faster and larger than strains of wild conspecifics over the first 20 days post-hatching (Svobodová et al., 2020), indicating genetic or maternal effects, but these might improve post-independence survival. Game-farm Mallard show higher growth rates and different immune strategies to wild conspecifics (Svobodová et al., 2020). Released populations do not disperse far, tend not to survive till the breeding season, and discriminate against wild birds when choosing a mate. This may explain why, despite large releases of game-farm Mallard, there are relatively low levels of hybridisation and introgression with wild populations.

3.2.2. Direct Effects of released mallard

Fifteen effects were reported, with eight of them being deemed negative, with seven having demonstrable links to outcomes and five being considered as high-quality evidence (Table 1).

There has been only a single matched-site study that explicitly searched for population/ecosystem effects of game-farm Mallard on a suite of biodiversity measures. In Sweden, wetlands where Mallard were released didn't differ in species richness of other waterbirds or amphibians, didn't differ in macrophyte cover, and didn't differ in pH levels from those without releases, but sites where releases occurred had higher phosphorous levels and fewer of these release sites had breeding amphibian populations than non-release sites (Söderquist et al., 2021a).

3.2.2.1. Nutrient enrichment. There is the potential for eutrophication arising from large numbers of game-farm Mallard on a small pond which could degrade local biodiversity. Estimations of nutrient enrichment by Mallard in North America suggest that each bird introduces 0.72 g Nitrogen (N) and 0.23 g Phosphorous (P) per day into their water body (Manny et al., 1994). However, such eutrophication may already be accounted for by depositions from wild birds. A population of wild birds, including Mallard, were reported to contribute 73% of the external P and 17% of external N entering a UK pond (Chaichana et al., 2010). Levels of P in waterbodies in the 1990s in Denmark were described as "negatively influenced" where Mallard were released (Wiberg-Larsen et al. 2000 in VKM, 2017). Lakes where Mallard were released had average P levels of 0.52 mg P/l whereas those without releases had levels of 0.30 mg P/l (Noer et al. 2009 in VKM, 2017). In Sweden, wetlands where Mallard were released had higher P levels but didn't differ in pH levels from those without releases (Söderquist et al., 2021a). High levels of P (Crocker et al., 2023) and N (Yousaf et al., 2021) pose a threat to biodiversity, so we believe that large-scale Mallard releases accompanied by high inputs of nutrients could produce ecological harm to local fauna and flora.

3.2.2.2. Predation on plants. Mallard commonly forage on aquatic plants. The total seed biomass in digestive tracts of shot birds did not differ between game-farm and wild–born Mallard in France, although there were differences in species diet frequencies (more *Ludwigia peploides, T. aestivum, Polygonum lapathifolium* in game-farm birds; more *Potamogeton pusillus, P. nodosus, Echinocloa* sp. in wild Mallard) (Champagnon et al., 2012). In Southern Sweden, macrophyte cover didn't differ between wetlands where Mallard were, or were not, released (Söderquist et al., 2021a).

3.2.2.3. Predation on invertebrates. Wild adult females and ducklings largely eat high-protein invertebrates in spring/breeding season with a higher proportion of animal matter in the diet during rather than outside the breeding season. Wild Mallard ducklings aged 0–3 days eat Diptera and Coleoptera, but by 12–24 days they have switched to feed on Mollusca and *Daphnia,* and for post-fledging Mallard, the diet is predominantly seeds, including cereals (Dessborn et al., 2011a). If the diet of game-farm Mallard matches that of wild conspecifics, this may pose a risk for local invertebrate populations at high volume release sites. Circumstantial evidence that high levels of (wild) waterfowl, presumably including Mallard, affects invertebrate abundance is provided by work in Germany in which invertebrate abundance was observed to be higher in marshes where shooting was permitted compared to marshes that were protected, with the assumption being that disturbance and/or mortality reduced waterfowl numbers in hunted areas and so reduced predation on invertebrates (Reicholf 1973 in Callaghan, 1996).

3.2.2.4. Competition for food. A study in France reported that there was no effect of increasing (natural) Mallard density on the foraging behaviour of other dabbling ducks, suggesting thatgame-farm Mallard are unlikely to directly compete with or interfere with the foraging of other granivorous ducks (Guillemain and Fritz, 2002). This may be because game-farm Mallard generally exhibited dietary preference for anthropogenic food (waste grain or bait) compared to wild Mallard (Champagnon et al., 2012).

3.2.2.5. Competition for mates. Game-farm Mallard preferentially mate with a partner of the same strain (Cheng et al., 1978) suggesting that disruption of mating or competition for mating opportunities for wild Mallard may not be especially common. However, genetic data (see above) reveals that at least some mating between wild and game-farm birds occurs leading to introgression.

3.2.2.6. Support for increased predator populations. Bicknell et al. (2010) and others (e.g. Roos et al., 2018) discuss the idea that generalist predators, attracted to or sustained by high numbers of released game during the winter, remain on site and switch to other prey such as ground-nesting waders when the numbers of released birds decline in the following spring. Game-farm Mallard may be predated on by a range of generalist predators, depending on the life stage, with nests being predated by corvids (Mallard eggs constituted 13% of shell fragments found in carrion crow diet in Poland) (Opermanis et al., 2001) and a suite of mammalian predators (Padyšáková et al., 2011). Adults and ducklings are killed on the water by Pike *Esox lucius* (Dessborn et al., 2011b), Marsh Harriers *Circus aeruginosus*, and American Mink *Neovison vison* (Opermanis et al., 2001). Consequently, the populations of these predators may be increased in the local presence of high numbers of game-farm Mallard, affecting populations of other species. However, the ecosystem consequences of such increases are hard to predict: the VKM (2017) report postulates that pike numbers might increase locally (constrained if in still-water bodies) due to their predation on game-farm Mallard but these elevated numbers of pike might induce cannibalism feedbacks, or also reduce small fish numbers such that invertebrate numbers rise.

Experimental increases in densities of (simulated) duck nests in the Czech Republic were not accompanied by increased rates of predation on them in that season, suggesting that short-term, local increases in density perhaps resulting from the survival of game-farm Mallard does not immediately increase risk of predation of the nests of similar resident ducks or a local, short-term increase in predator activity (Padyšáková et al., 2011). In the UK, this does not correspond to the period when releases occur (with ~8 week-old game-farm Mallard being released compared to day-old wild-born chicks). However, in Sweden, ducklings may be released in May–July when only 2–3 weeks old (albeit usually in fenced areas with feed and predator control) which may either supplement or divert predator diets during this critical breeding period (Jagareforbundet, *pers comm*, Jan 2026).

3.2.2.7. Vectors of disease. Disease and pathogens may accumulate and evolve in Mallard flocks under dense, stressful, rearing conditions and these may leak into the wider landscape e.g. botulism (Otter et al., 2018). Game-farm Mallard may be susceptible to infection from wild conspecifics that share food or water where viral and bacterial disease abundance can be amplified. This was seen in one case of avian influenza (H7N1) where a strain of the virus was detected in both a reared flock and local wild birds (Therkildsen et al., 2011). In that case, the infected game-farm flock was culled, but if undetected, infected game-farm Mallard may form a reservoir for or spread such infections (Stallknecht and Brown, 2007). Steensels et al. (2016) found that between 1.5 and 13.7% of harvested Mallard tested positive for avian influenza (AI) compared to 2.1% of live-ringed ducks caught during the hunting season, and suggest that the release of immuno-naïve captive bred birds may act to amplify AI circulating in the wild but clear evidence for this is lacking. Donald (2024) conducted a quick scoping review of the risks from avian influenza (specifically H5N1) to wild birds from game-farm Mallard and concluded that there was a "very high likelihood of major consequences to populations of wild birds associated with Mallard releases". The review concludes that there are routes of infection by Highly Pathogenic Avian Influenza (HPAI) and Low-Pathogenicity Avian Influenza (LPAI) between wild and released ducks, and vice versa, including by bridging species such as Gulls. Mortality in infected birds is likely to be high, although Mallard are relatively unaffected and so can carry the disease for some time acting as "spreaders". Donald (2024) describes any maternal immunity to AI that game-farm Mallard might have as likely to wane by release (6+ weeks). Consequently, juveniles are likely to be more immunocompromised than adult birds, but young released birds may exhibit greater immunocompetence due to their higher quality feeding and husbandry. Donald (2024) reports a study from Spain where there was higher prevalence of LPAI in smaller water bodies, attributed to high densities of waterfowl in smaller areas (Pérez-Ramírez et al., 2012), replicating what might be expected in released Mallard scenarios.

3.2.3. Associated effects of management of released mallard

Twelve effects were reported, with two of them being deemed negative and seven positive, with five having demonstrable links to outcomes and five being considered as high-quality evidence (Table 1).

The release of Mallard (and other gamebirds) is typically accompanied by management actions by gamekeepers or preserve managers who are motivated to improve the survival, and perhaps breeding success, of their stock by reducing predators, creating, preserving or enhancing habitats and/or providing supplementary feed. These actions may simultaneously affect populations of wild Mallard or other species in the area (Madden and Sage, 2020). It is difficult to disentangle effects exclusively attributable to the release of Mallard as opposed to other gamebirds released at the same sites, or actions motivated solely by the release of game-farm Mallard as opposed to those intended to attract, support and retain wild Mallard (and other ducks) for shooting through provision of supplementary feed (bait) or attractive habitat. Equally, the potential negative associated effects of gamebird release, such as supporting increased generalist predator populations, disturbance caused by shooting, or the spread of lead shot that may occur are hard to attribute specifically to Mallard releases on mixed game shoots.

Therefore, in this section we report a small series of studies that have focussed on Mallard but we advise readers to also consider more general associated effects which may affect populations of wild fauna and flora, either positively or negatively, as part of the management of mixed game shoots where Mallard are released. These more general associated effects are reviewed by Madden and Sage (2020), Mason et al. (2020), Sage et al. (2020) and Madden (2023).

3.2.3.1. Reduction of predators. In the UK, shoots commonly target foxes and corvids to protect gamebird populations, including released Mallard (Ewald and Gibbs, 2020). In general, predator removal efforts are an effective strategy for conserving bird populations (Smith et al., 2010). In their review, Mustin et al. (2018) concluded, from 13 studies focussed largely on abundance and breeding success of birds, that legal predator control associated with game management had a positive effect on some other wildlife. Two of these studies occurred at specific sites where gamebirds (not Mallard) were being released, but the analysis did not consider how predator control was explicitly related to these releases. Several studies consider predator removal from wetland sites where Mallard hunting (but not necessarily release) occurs. In New Zealand, a study experimentally trapped a range of potential predators rather different from those commonly targeted in the UK comprising Feral Cats (*Felis catus*), mustelids and European Hedgehogs (*Erinaceus europaeus*). This trapping did not affect predation on artificial Mallard nests, but did reduce non-predatory visits to nests by potential predators, perhaps reducing disturbance, adult predation or abandonment (Stewart and McDougall, 2022). There have been a number of studies in North Dakota, USA where mammalian mesopredators have been removed over sustained periods of time from hunting and conservation wetland sites. These studies typically show that predator removal (or more properly control, since not all studies report significant decreases in predator signs) almost doubles nesting success and thus influences population growth of Mallard (summarised in Amundson et al., 2013). It

is not clear how closely this form of predator control matches that conducted at Mallard release sites, nor whether the guild of predators and Mallard and other bird populations on the sites elsewhere would respond to control in the same way.

3.2.3.2. Provision of supplementary feed. Shoots in the UK commonly provide supplementary food, including grains or potatoes, around ponds to attract or retain Mallard, with wild Mallard or other species potentially benefiting. The practice is banned in North America, but before the ban started, during the hunting seasons in the early 1930s it was estimated that supplementary feeding in the Illinois river Valley was enough to feed 2 million ducks a day for 70 days – which would have almost certainly had large effects on overwinter survival (Cottam, 1934). Game-farm Mallard generally exhibit dietary preference for anthropogenic food (waste grain or bait) compared to wild Mallard (Champagnon et al., 2012) suggesting that the wild Mallard may not benefit as much as their game-farm conspecifics from supplementary feeding. Furthermore, wild Mallard attracted to supplementary feed might be at greater risk of hunting mortality and disease transmission. Therefore, the relative effect of feeding on natural vs. hunter caused mortality in wild ducks remains unknown. Supplementary feed (a seed mix) consumed by Mallard in Northern Ireland led to them dominating and excluding other smaller duck species, including Teal and Wigeon *Anas penelope*, from the feeding area (McGeehan, 2005). Söderquist et al. (2024) speculate that wild Mallard are disturbed by hunting but return to a site where supplementary feeding occurs, attracted by that food, while the game-farm Mallard released there seldom leave the site.

3.2.3.3. Provision of suitable habitat. The release of Mallard is commonly accompanied by habitat creation, retention or enhancement and this has the potential to benefit a range of wetland species. There are an estimated 9900 ha of flight ponds managed for shooting in the UK (PACEC, 2006), but these include both ponds used for Mallard release and those used to attract wild ducks. When considering individual shoots, there was a reported increase in the percentage of shoots that engaged in land management of water/marshland (presumed motivated at least partially by the desire to shoot ducks, although again it is not possible to distinguish released from wild bird shooting) from 18% of responding shoots in 1977–78 to 49% in 1991/1992 (Cox et al., 1996). In North America, a reported 15 million acres of wetlands and associated uplands have been conserved for waterfowl shooting (https://www.ducks.org/conservation/national/15-million-acres-and-counting), but again, this does not specify release sites and these North American habitat creation programs typically create much larger scale natural habitats than UK "flight-ponds".

In the UK the construction and management of open-canopy ponds (the type most usual for release and holding Mallard) resulted in higher bird diversity (64 vs 37 species), abundance and activity compared to un-managed ponds features (Lewis-Phillips et al., 2019). In New Zealand, ponds created for duck hunting (including, but not exclusively, for releases) support almost 100,000 native eels, providing some compensation for recent declines due to other wetland losses (Stewart et al., 2022). In Sweden, wetlands where Mallard were released did not differ in species richness of other waterbirds or amphibians from non-release sites, although fewer of these release sites had breeding amphibian populations (Söderquist et al., 2021a). It's not clear whether these wetlands were created specifically for shooting or were natural sites used for releases.

The creation of habitats for hunted waterfowl (including, but not exclusively, for releases) might permit quarry species, and others, to avoid having to shift their distribution in response to climate warming (Gaget et al., 2024). This may buffer them against having to move to less favourable areas. However, it could also increase vulnerability to sharp population declines if habitat management or maintenance changed or stopped.

There is an indication that wild Mallard in the USA preferred human-constructed ponds to natural tidal marshes (Casazza et al., 2021) and preferred areas managed for hunting over non-hunting sanctuary areas where game management is not practiced (Dittmer et al., 2024). This is perhaps unsurprising as hunting areas are designed and managed to provide highly suitable resting and foraging habitats for huntable waterfowl. During the day when hunting occurs, Mallard moved from hunting areas to sanctuaries, but at night, or when the hunting season had finished, Mallard moved back to hunting areas. They were 1.6–2 times more likely to use these hunting areas, compared to sanctuaries, two weeks after the end of the season (Dittmer et al., 2024). However, it is unclear what aspects of the managed hunting areas make them so attractive nor whether they are equally attractive to other, non-quarry species.

4. Discussion

Research on the ecological effects of Mallard release and management is limited, especially when conducted at the intensity seen in the UK. This contrasts with extensive work on Galliformes releases in woodlands and farmland (Madden and Sage, 2020; Mason et al., 2020; Sage et al., 2020; Madden, 2023). Most previous reviews (except Madden and Sage, 2020), and perhaps much empirical research, exclude Mallard likely because they are released in smaller numbers than Galliformes and because research on wildfowl harvest has focused on shooting wild birds at coastal sites, where releases are rare and harvests lower (Ellis and Cameron, 2022). Consequently, little evidence informs the ecological impact of Mallard releases, despite millions of birds being released at thousands of sites annually worldwide. In the UK, where releases are largest and densest and so effects might be greatest, there are no studies of interbreeding or direct effects and only two on associated effects. Negative impacts reported from other countries on wild Mallard behaviour, morphology, reproduction, and survival may intensify or shift under high-density releases.

Not only was there little evidence available, but of the 41 reported effects, only ten were robust (experimental, matched, or systematic reviews); most were correlational, descriptive, or anecdotal. Just over half (21/41) linked clearly to fitness or conservation status of other species, with the other half of studies either implying links or not mentioning them. Thus, understanding relies on limited, low-quality evidence with weak links to outcomes.

Available evidence suggests three patterns. First, released game-farm birds often interbreed with wild conspecifics. Farmed under semi-domesticated conditions, they show distinct genotypes and phenotypes, including morphological changes, altered mate choice, faster growth, lower survival, reduced movement, and different disease susceptibility (Champagnon et al., 2010, 2016a; Čížková et al., 2012; Svobodová et al., 2020). Introgression may affect wild Mallard phenotypes and at least some of these effects may be negative, but fitness and population consequences remain unclear (Champagnon et al., 2016b). Released game-farm phenotypes may suit modern agricultural landscapes. Second, direct effects on release sites are poorly documented. Unlike Galliformes, these effects cannot (yet) be deemed predominantly negative. Evidence exists for eutrophication of waterbodies (Söderquist et al., 2021a; Wiberg-Larsen et al. 2000 in VKM, 2017; Noer et al. 2009 in VKM, 2017), but for other direct impacts including predation on plants and invertebrates, competition with wild waterbirds, or support for predator populations, evidence is weak or absent (Champagnon et al., 2012; Guillemain and Fritz, 2002; Padyšáková et al., 2011). Disease transmission is plausible but poorly quantified (Otter et al., 2018; Stallknecht and Brown, 2007; Donald, 2024), with speculation that rearing may improve immunity or favour lower pathogenicity (Pérez-Ramírez et al., 2012). Evidence relating to disease risk generally excludes areas of large-scale, high-density releases, so patterns may differ there. Third, management practices exert associated effects. Predator control may benefit local birds (Stewart and McDougall, 2022;

Amundson et al., 2013), but no evidence links this directly to Mallard releases. Supplementary feeding, common for Galliformes, is poorly studied for Mallard; food type and distribution differ and may alter feeding behaviour or cause competition (Champagnon et al., 2012; McGeehan 2005; Söderquist et al., 2024). Fitness consequences remain unknown. Wetland creation for shooting may attract wild species (Cox et al., 1996; Stewart et al., 2022; Lewis-Phillips et al., 2019; Dittmer et al., 2024). However, such management is commonly conducted with mixed motivations. Consequently, it was difficult to confirm that effects were the exclusive result of Mallard releases rather than a more general motivation to hunt wild and released wildfowl and other gamebirds at the same sites.

We deliberately excluded reviewing effects arising from the actual shooting of the game-farm Mallard, which may involve disturbance, quarry misidentification, and lead ingestion. Gunshots and human (and dog) activity likely impose stress, increase energy use, and alter behaviour (Madsen and Fox, 1995). Wild Mallard show stronger tachycardia under disturbance than released birds, suggesting greater susceptibility (Heise, 1989). Shooting can alter waterbird assemblages in disturbed wetlands (Paillisson et al., 2002), and releases may intensify hunting locally. Misidentification may arise when hunters face large flocks, risking accidental shooting of other species, as seen in New Zealand where Grey Duck *Anas superciliosa* are (mistakenly) shot alongside Mallard (Williams, 2017). If releases encourage lead shot use, other wildlife may ingest it. Lead ingestion reduces Mallard survival by 19% (Tavecchia et al., 2001) and, across species, correlates with population declines in Europe and the UK (Mateo, 2009; Green and Pain, 2016).

Two ecological effects noted for releases of Galliformes lack Mallard-specific research. First, ammonia volatilisation and subsequent nitrogen deposition linked to Pheasant releases (e.g. Bosanquet, 2018; Sage, 2018) are unstudied for Mallard but may occur around large numbers of released birds. Second, gamebird releases in the UK have been associated with illegal raptor killing. There is no mention of Mallard released for shooting as a contributing factor to any of the confirmed incidents of illegal raptor killing presented in the RSPB Bird Crime reports 2018–2022 (Archived here). The three recent RSPB Bird Crime reports (2020−2022) do not classify any of the 306 confirmed incidents that year occurring at sites where Mallard releases are conducted. However, as ~25% of Pheasant shoots also release Mallard (see §1), some of the 40% of incidents on mixed-game sites may include motivation from Mallard releases. Both effects could be studied using methods applied to Galliformes.

Five key knowledge gaps remain. First, and most importantly, evidence for impacts on populations or conservation status of other species is largely circumstantial, based on anecdote or extrapolation. An experimental approach is needed. Söderquist et al. (2021a) offer a template for quasi-experimental studies comparing sites with and without, or before and after, releases, measuring indicators including nutrient levels, behaviour, and reproductive outputs. Management effects could be assessed by comparing sites with varying practices or habitat creation. UK-wide analyses are hampered by poor release data, though better records exist elsewhere. Second, most studies are short-term, small-scale, and bivariate and they ignore ecological complexity (but see VKM, 2017 for a suggested example of complex effects of predator release) or population-level consequences. A holistic approach is needed to weigh net effects. For example, one might ask whether a new pond created for Mallard, but which becomes eutrophic, is ecologically positive overall compared to no pond being created. Third, scaling effects with release size or density is unknown; direct Pheasant impacts rise above habitat-specific thresholds (Madden and Sage, 2020), but Mallard thresholds are unstudied. Further, associated effects of game management likely scale with the numbers being released in an area, but the occurrence of this relationship concerning Mallard is unknown. Fourth, despite extensive international research on genetic effects, UK data on hybridisation and introgression are lacking. There is also no attempt to separate out the contribution that both sets of birds make to wintering and breeding flyway populations. Although game-farm Mallard can be marked on release, this is not common. A survey of museum and taxidermic specimens may provide an indication of historical patterns and subsequent changes in levels of introgression and how these correspond to changes in release and management behaviours. Finally, behavioural and life-history data for released game-farm Mallard are scarce. Studies on diet, movement, breeding success, and survival, facilitated by improved tracking technologies, are essential to understand direct effects and integration with wild populations.

It may be reasonable to ask whether short-term high numbers and/or densities of wildfowl are unnatural and thus whether the effects are uniquely anthropogenic. There is considerable historical qualitative evidence that waterbirds, wildfowl in particular, were much more abundant in the past than currently. Folkard (1859) makes several references to his own observations, as well as those of other authors (Dugdale 1662, Pennant 1779, Lubbock 1845, all cited in Folkard, 1859), where wild duck numbers were so numerous as to cover “acres of water”, and in numbers that would “astonish”. Such records are supported by catches from decoys with, for example, almost 10,000 ducks being caught in one season at one UK decoy in the 1920's (Matthews, 1969). Catches in earlier centuries might have been even higher, with numbers of 10–30 thousand a year being reported (Folkard, 1859). However, Folkard states that naturally high densities at individual sites may have been more ephemeral than today, with more alternative wetland sites for birds to move to so that any local effects were short-lived. Outside the UK, releases are thought to be smaller and at lower densities and may match or even be lower than some natural winter aggregations, meaning that any ecological effects might fall within natural levels of variation.

5. Conclusions

1) We know comparatively little about the ecological effects of releasing and managing Mallard for recreational shooting, despite this activity involving at least several million birds annually, occurring over wetlands across Europe and the USA and a substantial part of the lowland UK, and being an economically and culturally important activity.
2) What evidence we do have presents a mixed picture, with some effects being likely to be ecologically positive, while others are definitely negative, and others either neutral or their consequences are unknown due to lack of evidence or poor understanding of baselines. This is additionally problematic when considering Mallard because, unlike non-native gamebird releases, there are sympatric wild conspecifics. Therefore, it is reasonable to ask how many Mallard should we expect to be on our landscape and whether this is higher or lower than what appeared to be present at different historical times in the past. However, these released game-farm birds are not “wild” Mallard and as seen with releases of Galliformes, the birds themselves exert a series of direct effects that are likely to be predominantly negative: eutrophication, reservoirs of disease, and supplementary food for generalist predators. At the same time, their management may motivate associated effects including habitat creation, supplementary feeding and predator control which may offer positive benefits to wild species. Crucially, the current focus is entirely on simple, bivariate relationships and there is no consideration of the net effects of the activity, simultaneously accounting for both the direct effects of the released birds themselves and the associated effects of those managing and shooting them.
3) Uncertainty over the net effects of this activity is concerning because there are calls from some organisations to restrict or ban the release of gamebirds, while at the same time there is pressure from game shooters to maintain and even increase releases. If net effects of this activity are negative, then current levels or further growth will further erode ecologically important and sensitive aquatic

ecosystems, yet if the net effects are positive, then bans or restrictions may lead to loss of wetland habitat created or maintained for this activity plus the cessation of other management actions (such as supplementary feeding or predator control) that may bring benefits to the wider ecosystem. Wise decisions about the future of this activity demand accurate information, and this is currently lacking, yet ongoing degradation of wetland ecosystems means that it is a pressing matter, requiring rapid resolution. Our review should serve to justify and stimulate future research into this question, providing a robust evidence base for stakeholders, policy makers and legislators to shape the future of this activity.

CRediT authorship contribution statement

Joah R. Madden: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Tom C. Cameron:** Writing – review & editing, Writing – original draft, Investigation, Funding acquisition, Conceptualization. **Chas A. Holt:** Writing – review & editing, Writing – original draft, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

JRM has previously worked for the BTO and RSPB, and has had funded research collaborations with the Animal and Plant Health Agency (APHA), British Association for Shooting and Conservation (BASC), Game and Wildlife Conservation Trust (GWCT), Joint Nature Conservation Committee (JNCC), Natural England (NE), and Natural Resources Wales (NRW) in the area of the scale and effects of gamebird releases and regulation of wild bird harvests. TCC has worked as a consultant for the Secretary of State for the Environment, the Centre for Environment Fisheries and the Seas (CEFAS), Joint Nature Conservation Committee (JNCC), Natural England (NE), Zoological Society London (ZSL), and the British Association for Shooting and Conservation (BASC) on topics pertinent to the conservation and management of coastal protected areas. CAH is a trustee of Sussex Ornithological Society and has previously worked at the British Trust for Ornithology as a Research Ecologist and National Coordinator of the UK Wetland Bird Survey (WeBS).

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Data availability

No data was used for the research described in the article.

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