Assessing geographic changes in hunting pressure on wildfowl through ring recovery locations

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Abstract

Management of exploited populations needs to account for hunting pressure, yet estimating this parameter remains challenging. The study presented here compares the geographic distribution of dead recovery sites between the mid-20th century (1953–1983) and early 21st century (2002–2025), for birds all ringed in the same initial area (the Camargue in southern France) and proposes that this approach be used as a method for evaluating changes in relative hunting pressure over time. Analysis of ring recovery data from Common Teal *Anas crecca*, used as an example, suggests that hunting pressure on these birds has become increasingly concentrated in France in the 21st century, highlighting the responsibility of the country for hunting management of this species.

Key words: *Anas crecca*, Europe, hunting pressure, ring recoveries, Teal.

Hunting pressure is often a major determinant of game species population dynamics and spatial distribution (*e.g.* Lebreton 2005; Casas *et al.* 2009; Servanty *et al.* 2011), yet in the absence of hunting statistics, its magnitude, distribution and effect is difficult to assess because it is determined by a combination of geographic, technical and societal processes (*e.g.* McCulloch *et al.* 1992). A range of methods have been suggested to estimate levels of local hunting pressure, but each of these has significant limitations (*e.g.* Guillemain *et al.* 2023). For instance, the number of registered hunters or hunting licences sold in a given area does not take into account the actual activity of those hunters, so that the number of days spend hunting (*i.e.* daily hunting effort) may increase even if the number of licences sold decreases (Brown *et al.* 2000). Similarly, the number of individuals shot in a given area may not be indicative of hunting pressure, since it also depends on the density of birds living in that area. Hunting bag estimation protocols may also be too different among geographic areas to allow direct comparison (Aubry *et al.* 2020). Moreover, the spatial distribution of rings or other markers recovered on the death of the marked individual may be influenced by differences between regions in the probability of people (including hunters) reporting such marks to organisations responsible for collating recovery data (Dunn 2001; Royle & Dubowsky 2001; Thorup & Conn 2009; Korner-Nievergelt *et al.* 2010; Roy *et al.* 2015).

Modern techniques such as satellite telemetry tags with 3D accelerometers may provide useful tools for determining animal mortality events and sometimes also the likely cause of death through changes in speed and direction of movement (*e.g.* Jiguet *et al.* 2023). When such data points towards mortality caused by shooting (*e.g.* if the speed of movement suddenly decreases and the tag subsequently moves towards a building or along roads), it provides some insight into spatial variation in hunting pressure. Likewise, networks of automatic sound detectors may also allow mapping of hunting shot density (Hedley *et al.* 2022). However, such methods remain expensive to deploy over large areas, and do not allow retrospective analyses of information to assess historical changes in hunting pressure.

Wildfowl (Anatidae) are among the most hunted bird species (Guillemain *et al.* 2016; Sørensen *et al.* 2025); hence, hunting pressure may be a strong driver of their demography and habitat use (Madsen 1998a,b). A recent analysis has demonstrated unsustainable harvest of some duck species in the European Union, suggesting that harvest rates should be reduced in several species, including the Common Teal *Anas crecca* (Carboneras *et al.* 2024). Hunting management ideally should be targeted at areas of high hunting pressure, because this is where it will be the most effective when hunting activity has to be regulated. Unfortunately, estimating hunting pressure on ducks suffers from the drawbacks listed above, so a general evaluation for a range of quarry species is not possible, despite recurrent calls in the European scientific literature (Elmberg *et al.* 2006; Holopainen *et al.* 2018). On the other hand, some species of wildfowl have been ringed in vast numbers for a century, so a lot of information derived from such markings is available. The ring recovery rate (*i.e.* the proportion of rings fitted eventually reported to the ringing centres) is the product of hunting pressure and reporting rate (*i.e.* the likelihood that a found ring is reported). Ring reporting rates are known to differ geographically, owing to different levels of information or interest in ringing issues among regions/countries, but may show similar rates of change over time among regions. For instance, Arnold *et al.* (2020) illustrated a parallel increase over time in the ring reporting probability for Mallard *Anas platyrhynchos* in North America and in the waterfowl harvested in eastern Canada only, although the mean reporting probability was *c.* 20 percentage points lower in the latter region. Of course, the likelihood of obtaining ring recoveries from a given area also depends on the proportion of live birds wearing a ring in that region, which itself is determined by the location of ringing sites. These relationships however suggest that changes in the geographic distribution of ring recoveries, for birds all ringed at the same location, may be indicative of changes in the relative hunting pressure among regions over time, on the basis that reporting rates should have varied at the same rate across the range. Although it does not provide a quantitative estimate of absolute hunting pressure, this method may help to assess where hunting pressure has increased or decreased the most over time, and thus inform policymakers as to where a reduction of hunting pressure should have the greatest effect for species of concern.

Here we utilise a long-term (> 70 years) dataset on Common Teal (hereafter Teal) ringed in the Camargue, southern France, and the mapping of ring recoveries over time across their flyway, to evaluate the extent to which the relative spatial distribution of hunting pressure may have changed over the last decades. This information may be used to indicate where to focus potential hunting restrictions, following the European Commission's observation that this species may be being harvested unsustainably in the European Union.

Methods

Ringing dataset

Teal have been ringed in Camargue, southern France (notably at Tour du Valat, 43°30'N, 04°40'E) since the end of the 1940s. The ringing methods and dataset have been described previously (*e.g.* Guillemain *et al.* 2011). In this study, we compared the geographic distribution of ring recoveries between two time periods: historical (1953–1983) and recent (2002–2025). Changes in the distribution of ring recoveries were evaluated both visually, by computing density maps of ring recoveries, and quantitatively by statistically comparing the proportion of recoveries in each country between the two time periods.

Ringing in the Camargue occurred during the non-breeding period (August to March). As the hunting season in France during the recent (21st century) period occurs from August to the end of January, we only considered recoveries from 1st March onwards after ringing, in order to remove direct hunting recoveries and thus avoid local bias (Henny & Burnham 1976). The filtered dataset contained 6,767 recoveries from the historical period and 207 recoveries from recent times.

Spatial distribution of recoveries

To model the distribution of dead Teal recoveries, the locations of ring recovery sites were first transformed using the ETRS89 Lambert Azimuthal Equal Area Coordinate Reference System (ETRS89-extended/LAEA Europe, EPSG 3035), which is dedicated to statistical analyses over the Pan-European area when true area representation is required. All dead recoveries were included because most known sources of mortality in the present dataset were from hunting, so birds found dead were considered to be crippled individuals. Recovery density estimation was performed using bivariate Gaussian kernels, with the bandwidth for the entire dataset determined using the rule of thumb 'bandwidth.nrd()' function of the MASS package in R (Venables & Ripley 2002). We used the model implemented in the 'kde2()' function of the MASS package run from R (R Core Team 2025). It is important to note that this method does not distinguish between land and sea water, so non-zero densities occur over marine areas even though they were estimated from points on land only. The density surface was divided into three levels delimiting the smallest areas to obtain 50%, 75% and 95% of recoveries (red, light blue and dark blue on the maps).

Proportions of recoveries per country and time period

For this analysis, 17 countries with > 30 recoveries were included. The proportion of recoveries $\mathbf{p_{t,i}}$ for period *t* in country *i* was estimated using a binomial distribution, where $\mathbf{N_t}$ is the total number of recoveries for period *t*, and $\mathbf{n_{t,i}}$, is the number of recoveries for period *t* in country *i*:

$$\mathbf{n_{t,i}} \sim \boldsymbol{Binom}(\mathbf{N_t}, \mathbf{p_{t,i}})$$

The proportion of recoveries $\mathbf{p_{t,i}}$ is then not a raw proportion, but a parameter of a model defined as a statistical distribution. Changes in the proportion of recoveries were estimated for each country using the ratio of $\mathbf{p_{t,i}}$ between the historical and recent time periods. The Netherlands and Czechia banned Teal hunting between the two time periods considered here. It was therefore expected that these countries would not yield hunting recoveries in recent years, contributing to a change in the proportion of recoveries elsewhere. A Bayesian framework was used for parameter estimation due to its efficiency at error propagation (*i.e.* its ability to predict effectively uncertainty in the estimated values) and easy assessment of the significance of changes over time. We used vague priors for all parameters in order not to constraint the estimation of parameters. Three chains 10,000 in length were generated, with a thinning of 1 because there was no autocorrelation in the samples, and discarded the first 1,000 samples as burn-in. We checked the chain convergence using the Gelman and Rubin convergence diagnostic ($\hat{R}$ < 1.1; Gelman & Rubin 1992). The model was fitted using NIMBLE (de Valpine *et al.* 2017) run from R (R Core Team 2025). Estimation ranges reported in the figure in the Results section correspond to the 95% highest posterior density interval. Highest posterior density interval was preferred to equal-tailed credible interval as it is better suited for skewed distributions (Wakefield 2013). Values in the map are derived from the medians of the posterior distributions of ratios of recovery probabilities.

Sample sizes were much greater in the historical than in the modern part of the dataset, and the large reduction in sample size between study periods could have some effect on the distribution of recoveries between countries, leading to incorrect conclusions about changes in the spatial distribution of hunting pressure. To test whether drawing on fewer samples resulted in a more concentrated distribution being described, we repeated the analysis 3,000 times with a subsample of data from the historical period (taken at random from the full historic dataset) that was of the same

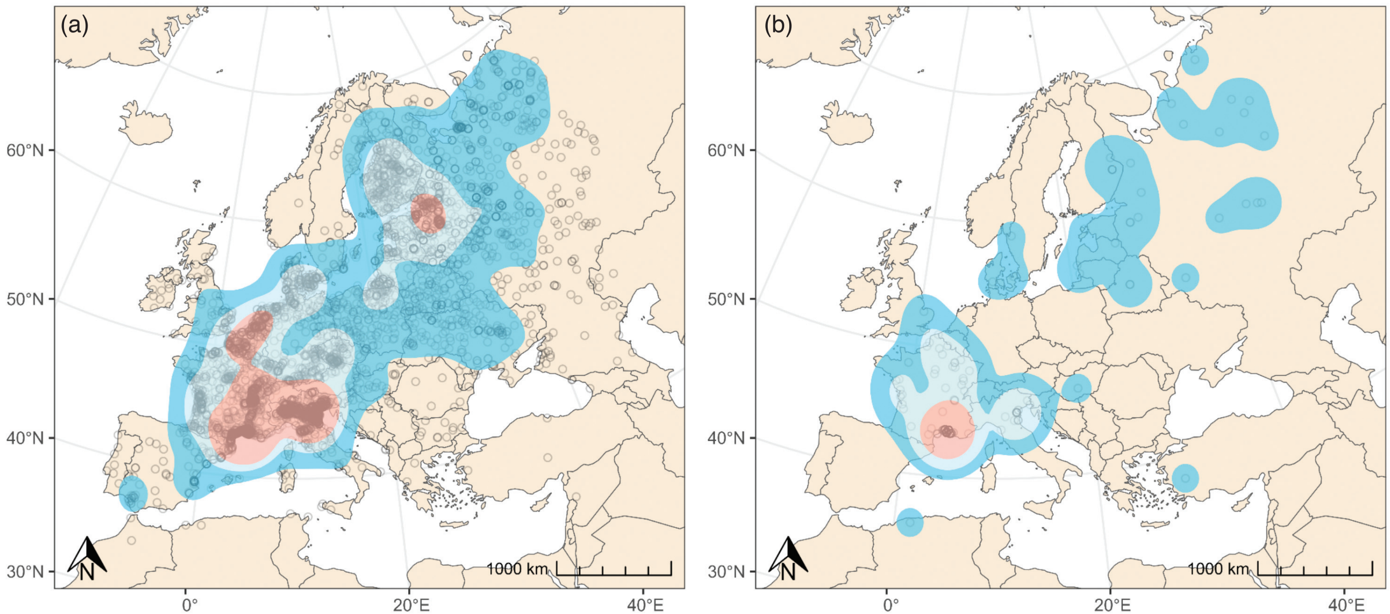

Figure 1. Camargue Teal ring recovery distribution during: (a) the historical period (1953–1983; n = 6,767; left) and (b) the recent period (1997–2025; n = 207; right). Red shading = smallest area containing 50% of ring recoveries (high density); light blue shading = smallest area containing the next 25% of ring recoveries (intermediate density); dark blue shading = smallest area containing the next 20% of ring recoveries (low density).

size as that of the modern years (*i.e.* 207 ring recoveries) then combined the results, for comparison with results obtained when the full dataset was used.

Results

The spatial distribution of dead recoveries of Camargue-ringed Teal for the historical and recent time periods is shown in Figure 1. During the historical period, Camargue Teal ring recovery hotspots (*i.e.* the smallest area covering 50% of recoveries) were the eastern half of France, northern Italy and the Baltic States. A continuous area of high recovery density (the smallest area covering the next 25% of recoveries) also extended from northeastern Spain to eastern Russia, including most of Europe except the Balkans, Norway and northern Sweden (Fig. 1). The picture was very different for the more recent period, where only the local area in southern France was a hotspot, and the area of high recovery density was much patchier, encompassing only northern Italy, Denmark and the Baltic States, plus a few isolated areas notably in the Czech Republic or eastern Russia.

The pattern was therefore that of a major concentration of ring recoveries (and hence of relative hunting pressure) into France between historical and recent times. France was the only country where the percentage of recoveries increased significantly (by +96%) between the two periods. There was conversely a significant decrease in all other countries formerly contributing the greatest numbers of recoveries; *i.e.* –42% to –88% in Italy, Russian Federation, Finland, Germany, Netherlands, Poland, Ukraine, Spain and Czechia (Fig. 2). In accordance with the protected status acquired by Teal in the Netherlands and Czechia between the two study periods (through legislation on 1 April and 1 July 2002, respectively), the number of ring recoveries fell from 205 and 124 to zero in the two countries, respectively.

The analysis repeated 3,000 times with a subsample of the historical dataset, to take into account the reduction in sample size between the two time periods, led to increased uncertainty, especially for countries with few recoveries, and significant changes in the percentage of recoveries were found in six countries instead of ten. However, the large increase in recoveries in France compared to the other countries was not affected: the relative increase in France was then +94.2% (range = +47.1 to +147%), in comparison with +96% on the insert map in Figure 2 using the full dataset.

Discussion

The results for Teal ringed during the non-breeding season in Camargue are striking: while the recovery distribution of their rings globally covered the whole geographic area of their flyway during historical years (see map in Scott & Rose 1996), it is today much more concentrated into France and a few isolated foreign areas. This suggests that most hunting pressure on this part of the population is now concentrated in France. That France should have such an important role in the hunting of Teal is not entirely surprising, given earlier assessments of national hunting bags for the species across Europe (Guillemain *et al.* 2016). It is also consistent with the known social importance of hunting (including wildfowling) in France, which for example is among the

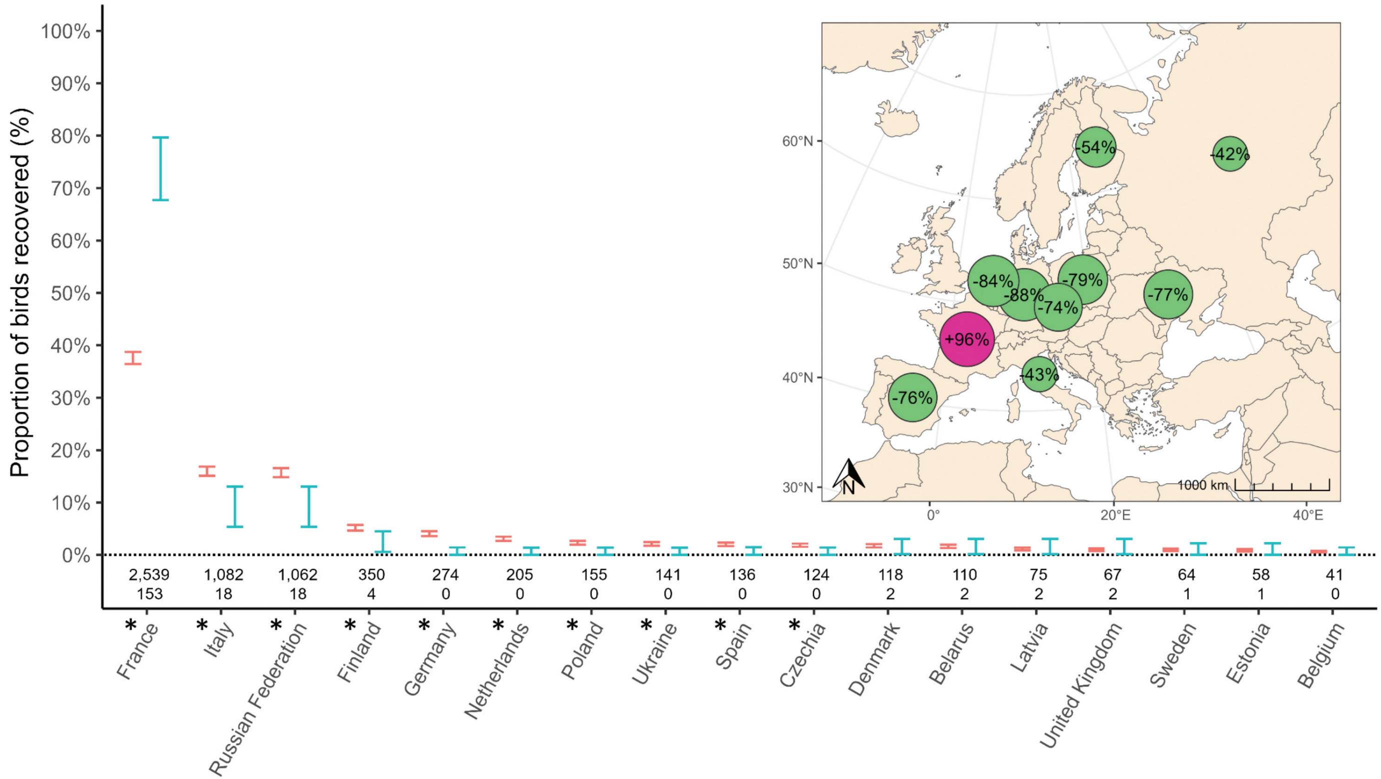

Figure 2. Proportions of recoveries by countries of the flyway (95% highest posterior density intervals). Red = historical years; blue = recent years. Numbers above each country indicate sample size per time period (upper: historical, lower: recent period). The inset map shows the percentage change between the historical and recent time periods in the proportion of recoveries only for countries with a significant change (*). Purple and green circles indicate positive and negative changes, respectively.

only countries to allow nocturnal duck hunting (Urbaniak *et al.* 2024).

Although France is not a major breeding ground for Teal, with only *c.* 700 pairs nesting in the country (C. Francesiaz, unpubl. data), it is an important wintering area for birds migrating over relatively long distances, notably from Finland and around the White Sea region (Guillemain *et al.* 2014). Previous analyses indicate that breeding origin and relative distribution of French-wintering Teal has not changed between the historical and recent time periods considered in this study, so the concentration of the proportion of ring recoveries in France cannot be attributed to a shift in Teal distribution associated with, for instance, climate change (*e.g.* Guillemain *et al.* 2005, 2009a, 2014). If anything, short-stopping in response to climate change should instead lead these birds to remain further north along the flyway, in countries to the northeast of France which are closer to their breeding grounds (Elmberg *et al.* 2014). All Teal from the current dataset were ringed in Camargue; hence they spent at least part of one winter down in this southern region. It cannot be excluded, however, that the results obtained here hold only for those Teal which migrate over long distances, and Teal now living essentially in more northern countries escape hunting pressure in France. A similar analysis for birds which both breed and winter further north therefore would be interesting.

It is logical that Teal ringed in France (Camargue) are likely to be recovered in France. Although we used only indirect recoveries (*i.e.* excluded recoveries within the hunting season of initial ringing) to avoid an overrepresentation of local recoveries soon after ringing, Teal are known to be faithful to their wintering grounds over several years (Guillemain *et al.* 2009b). Earlier analysis of the same dataset suggested increasing philopatry to the Camargue wintering grounds from historical to current times (Guillemain *et al.* 2015). Camargue Teal nowadays consume more agricultural and hunting bait food than they did in the 1960s (Brochet *et al.* 2012). Such a change in diet has been associated with improved body condition (Guillemain *et al.* 2010) and dabbling ducks seem to be more faithful to such Mediterranean areas than climate change would predict (Gaget *et al.* 2024). Local management in and around the Camargue may thus have contributed to higher local ring recovery rates. However, it is unlikely that the Camargue conditions alone could be responsible for the whole flyway-scale pattern observed here: in mid-January 2024 the Camargue hosted < 30,000 wintering Teal out of a total of > 200,000 individuals in France, and flyway totals of 670,000 and 1,000,000 birds for the two populations visiting France during the non-breeding season (LPO 2024).

The present analysis largely relies on the hypothesis that ring reporting rates, although likely to differ on average among geographic areas (Nichols *et al.* 1995; Boomer *et al.* 2013), vary at the same rate among different regions (as found by Arnold *et al.* 2020, see above). Under this hypothesis, differential changes in ring recovery rates among countries over time would therefore indicate differential changes in hunting pressure. It would be useful to test such a hypothesis in the future, especially since the work of Arnold *et al.* (2020) was from North America and not Europe. The best way to disentangle hunting pressure (harvest rate) and ring reporting rate is to rely on a subset of reward rings, whose reporting rate is expected to be 100% (Henny & Burnham 1976; Nichols *et al.* 1995). Such a reward ring scheme has been set-up in France, which will provide the first European estimation of ring reporting rates in ducks (G. Souchay, unpubl. data). We recommend that such studies be initiated in other countries, and repeated over time, to check whether potential changes in ring reporting rates over the years are indeed consistent among European countries.

At the same time as Teal hunting recoveries became concentrated in France, their distribution became much patchier in the 21st century. Results obtained on repeating the analysis with subsamples of the historical dataset were similar to those obtained on analysing the full set of historical and recent recovery data. The finding is therefore robust to the reduction in sample size between the two time periods. In addition to the reduced ringing effort in Camargue in recent years, a general decrease in recovery rates has been reported by several other ringing schemes, for a range of different species, not just for waterbirds (*e.g.* Dunn 2001; Robinson *et al.* 2009; Guillemain *et al.* 2011). The likelihood of receiving at least one recovery from a given country therefore has probably decreased over time. In addition, the protected status acquired by Teal in the Netherlands and Czechia from historical to recent years contributed to the patchier distribution of ring recoveries for the modern period.

Teal has long been considered as a species with a healthy population in western Europe, and is currently classified as "Least Concern" by the International Union for Conservation of Nature in the IUCN's Red List (https://www.iucnredlist.org). However, the European Commission has recently added this duck to the list of the 42 huntable bird species with an unfavourable conservation status in the EU, owing to declining breeding populations. This was notably the case in Finland where EU breeding population size is the largest (see European Environment Agency 2020). This does conflict with increasing trends in numbers during winter counts (Wetlands International 2025), but such increases could be to the result of short-stopping of birds formerly wintering in Africa. Analyses conducted for the European Commission, based on Birds Directive Article 12 hunting bag reporting by the member states for the 2013–18 period suggest current harvest level at EU scale is unsustainable in this species (M. Cruz-Flores, unpubl. data). It is a fact that bag statistics collection schemes should be improved and coordinated at international scale (Aubry *et al.* 2020), but apparent unsustainability of EU harvest has already led the Commission to recommend "management measures […] to reduce hunting pressure" (Carboneras *et al.* 2024). The current study does not aim at evaluating harvest sustainability in each country. Nonetheless, it suggests that France has a major responsibility for hunting Teal at flyway scale and should therefore take a significant part in any European coordinated effort if hunting bags are to be reduced.

The analysis reported here has been conducted for Teal because there has been a major and sustained ringing effort from one single area in the Camargue, and relatively high recovery rates of such rings, mostly from hunters. It would be interesting to check with the large modern ringing dataset for Teal from Portugal (*e.g.* Rodrigues *et al.* 2001) whether these birds are likewise mostly recovered in France, to support the view that hunters in France have a prevalent role in harvesting Teal. A similar approach to the one presented here may also be applied to other species with sufficient ring recoveries. This could be undertaken even when ringing occurred at several places, so long as the distribution of such ringing sites has not changed too much and in a way that could affect the distribution of later recoveries. The approach could also be adopted for other causes of mortality, where the cause of death for individual birds is recorded systematically and consistently over time (*e.g.* poisoning, collision with man-made infrastructures and diseases with mandatory reporting). This would allow the mapping of areas where a given risk or threat is or becomes concentrated, so that appropriate conservation measures can be undertaken.

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