An initial assessment of the sustainability of waterbird harvest in the United Kingdom

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Abstract

1. There is a need to assess the sustainability of current harvest levels of wild birds in the United Kingdom (UK), and more widely, across Europe. Yet data on population and harvest size, as well as population demographics of many species are limited.
2. We used a Demographic Invariant Method (DIM) to estimate Potential Excess Growth (PEG) for populations of waterbirds wintering in the UK and calculated a Sustainable Harvest Index (SHI) for each species or population. We compared this with population trends and conservation classifications (e.g. Birds of Conservation Concern) to assess the sustainability of harvests and the utility of these classifications.
3. Our approach found no evidence for overharvest of any duck or wader species, except potentially for gadwall *Mareca strepera*. We estimated that Canada geese *Branta canadensis* and both British and Icelandic greylag geese *Anser anser* are potentially overharvested in the UK. With the exception of Icelandic greylag geese, all of the goose populations predicted to be experiencing overharvest show strong population growth. This conflicting result raises concern about current population size estimates, harvest estimates or both.
4. We found no relationship between sustainable harvest indices and short-term or long-term wintering trends in harvested species, or conservation classification under the UK's Birds of Conservation Concern framework.

   Policy Implications: Our results suggest that UK based harvest is unlikely to be a major determinant of population trends for overwintering waterbirds in the UK. Additionally, the lack of a relationship between conservation classifications and SHI strongly suggests that these are not an appropriate tool for making decisions about harvest management. Our assessment provides the basis for a framework to make evidence-based decisions on sustainable harvest levels in the UK in the face of

incomplete data. Investment in data collection for European waterbird population size and harvest is long overdue.

Keywords

Waterbirds, harvest, hunting management, potential excess growth, demographic invariant method

Word count

6996

Introduction

Hunting of waterbirds in the UK with shotguns has occurred since at least the 1600s (Helme, 1614; Markham, 1621). Contemporary recreational hunting of waterbirds in the UK targets nine species of duck, four species of goose and three waders. Coot *Fulica atra* and moorhen *Gallinula chloropus* are also huntable but are rarely pursued and there are no modern estimates of the harvest of these species. The total annual harvest of ducks, geese and waders in the UK is estimated at approximately 1.4 million (Aebischer, 2019; PACEC, 2014). These same species, hunted in winter in the UK, breed across Northern, Eastern Europe and Russia and are also hunted by nations in the breeding range and across their migration routes.

The British Association for Shooting and Conservation (BASC) is the largest representative body for shooting sports in the UK. BASC has approximately 8,000 wildfowling members, which is likely to represent the majority of self-identified wildfowlers hunting ducks and geese on UK coasts and estuaries. Of these wildfowlers approximately 25% hunt at least once per season, and they harvest an average of 8 birds each per season (Crown Estate, 2021; Ellis, 2014). This leads to an estimated coastal harvest of 16,000 waterbirds. The approximately 1.4 million remaining harvested waterbirds are harvested inland on fields and a broad range of wetlands, often on artificially fed sites. Released

mallard *Anas platyrhynchos* are a significant proportion of the inland waterbird harvest with current release estimates of approximately 2.6 million (Madden, 2021), and harvest estimates of approximately 950,000 birds per year (Aebischer, 2019). Therefore, a significant proportion of other wild duck and goose species are also harvested in these inland areas due to the creation and provision of appropriate habitat, as well as supplementary feeding.

The conservation status of birds in the UK has been assessed under the Birds of Conservation Concern (BoCC) methodology since 1996 (Gibbons et al., 1996). This assessment is carried out at regular intervals (approximately every six years) by a consortium of Non-Governmental Organisations (NGOs) and statutory agencies and assesses the broad conservation status of birds in terms of rarity, localisation and population trends. Species are assessed against the published criteria and assigned the highest priority rating (Red>Amber) for any of the criteria they satisfy such that, for example, a species which exceeded the Amber breeding range decline criterion and the Red breeding population decline criterion would be classified as Red-listed. Any species which do not satisfy any of the assessment criteria are placed on the Green list. A species with an increasing or stable UK population could be classed as Amber due to, for example, the UK holding an internationally important proportion of the European population– e.g. Pink-footed goose *Anser brachyrhynchus*. This approach is different to the better known International Union for the Conservation of Nature (IUCN) Red List which only reviews the extinction risk for species (IUCN, 2020). This can lead to disparities due to differences in the scale of assessment. For example, a species such as the Eurasian woodcock *Scolopax rusticola* can be classed as being of least conservation concern by the IUCN due to a very large and stable global population and large range but has Red status in the UK due to long and short term declines in UK breeding range.

Increasingly there have been calls to prohibit or restrict the hunting of species that are Red or Amber listed on BoCC (Thomas, 2021; Welsh Parliament, 2020). Similar calls drawing attention to the BoCC status of hunted birds have been made by social media

influencers such as Chris Packham (Common, 2016; UK Government and Parliament, 2016). Currently all huntable ducks and geese in the UK, with the exception of tufted duck *Aythya fuligula* and Canada goose *Branta canadensis*, are Red or Amber listed using BoCC, and the most common reason for listing was due to the UK holding >20% of the European wintering population, rather than due to declines in breeding or wintering populations. Apriori then, BoCC may not be the most appropriate metric to judge conservation risks from additional winter mortality, but this has not yet been tested. Likewise, there have been calls to prohibit or restrict the harvest in protected areas where statutory agencies have regulatory roles, for example in coastal hunting areas over nationally and internationally protected sites. Typically, on these sites, harvest data is robust, and harvests are low (1% of the estimated UK harvest), compared to inland areas which account for 99.9% of the UK waterbird harvest but where regulatory authorities currently have limited room to act. These regulatory disparities lead to conflicts and this calls for an assessment of the sustainability of the UK harvest of such highly mobile species, that are constantly responding to food availability, recreational disturbance and hunting pressure with shifting range size and range location, at an appropriate spatial scale (Beatty et al., 2014; O'Connell et al., 2007).

In the absence of regular and systematic monitoring of breeding range population sizes, geographic populations structures or harvest returns for huntable species in the UK it has historically been difficult to assess the likely sustainability of current harvest levels. Particularly so for data poor ducks compared to more regularly monitored European goose populations (Holopainen, Arzel, et al., 2018; Madsen et al., 2015). However, the development of methods allowing for estimates of harvest levels in the UK (Aebischer, 2019), and the development of analytical tools to assess the sustainability of harvest with incomplete demographic data now allows for initial assessments to be made even in the face of uncertainty (Eraud et al., 2021). The UK is a party to the Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA) which is developing mechanisms to ensure flyway-level harvest sustainability and in the long term will be a more appropriate level to make these decisions (Elmberg et al. 2006; Madsen et al. 2015). However, in the

absence of these mechanisms we present an initial assessment of the sustainability of winter hunting mortality of UK waterbirds using best-available data, whilst recognising the likely sources of error and identifying areas where further research would be particularly valuable.

Materials and Methods

We collated harvest estimates, population estimates, population trends and demographic data on huntable ducks, geese and waders in the UK. This included nine species of ducks (mallard *Anas platyrhynchos*; Eurasian teal *Anas crecca*; Eurasian wigeon *Mareca penelope*; gadwall *Mareca strepera*; northern pintail *Anas acuta*; northern shoveler *Spatula clyptea*; tufted duck *Aythya fuligula*; common pochard *Aythya ferina*; and common goldeneye *Bucephala clangula*), three waders (Eurasian woodcock *Scolopax rusticola*; common snipe *Gallinago gallinago*; and golden plover *Pluvialis apricaria*) and three goose species comprising a total of four goose populations (British (resident) and Icelandic (migratory) greylag goose A*nser anser*; Greenland/Icelandic pink-footed goose *Anser brachyrhynchus*; and, resident Canada goose *Branta canadensis*).

Estimating harvest sustainability

A Sustainable Hunting Index (SHI + 95% confidence interval (CI)) was calculated for each species using the potential excess growth (PEG) function in the popharvest R package (Eraud et al., 2021). This index is calculated as the ratio of harvest to PEG such that any value in excess of 1 indicates overharvest and values under 1 are increasingly less likely to be unsustainable as they approach zero (Niel and Lebreton 2005). This is not unlike a surplus production model approach that is commonly applied to data poor or initial assessments for harvest of other vertebrate systems, i.e. fisheries (Jennings et al., 2008). The PEG for each species was calculated using a Demographic Invariant Method (DIM) which allows estimation of maximal potential population growth rates (λ_{max}) with relatively few demographic parameters including age at first reproduction and life-history strategy

categorisation (Johnson et al., 2012). Estimated λ_{max} were compared with other published assessments in the most common species geographic range and differential growth in BTO breeding and wintering abundance indexes to make sure our DIM approach was producing reasonable estimates (Table S1).

In order to account for uncertainty in reported life history characteristics we ran 10,000 Monte Carlo simulations per species with population estimates drawn from a uniform range equal to the 95% confidence intervals calculated from the Wetland Bird Survey (WeBS) indices for 2012/13 – 2016/17. Adult survival was drawn from a beta distribution with a standard deviation equal to the calculated 95% confidence intervals. Harvest was drawn from a uniform range equal to the 95% confidence intervals of published estimates (Aebischer, 2019). Distributions for drawing simulation parameters from were guided by those recommended by the package authors (Eraud et al., 2021) and references therein. Age at first reproduction was taken to be fixed at 1 for all duck species, 2 for all waders and 3 for all geese (Robinson, 2005). All ducks and waders were assumed to have a “short” life history strategy and geese a “long” life history strategy. The statistical package includes a safety factor (F_s) which can be set from 0-1 to limit harvest to only a proportion of the PEG (with a recommended maximum of $F_s = 0.5$) and it is recommended to set this at $F_s = 0.5$ for species listed as least concern by IUCN (Dillingham & Fletcher, 2008). We therefore set $F_s = 0.5$ for all species except pochard which is listed as Vulnerable under IUCN and therefore we assigned an $F_s = 0.1$. However, this does not well represent the sustainability of a harvest where hunters are being encouraged to maximise their harvest, for example on non-native geese or geese with expanding populations, e.g. Canada or pink footed goose. We shall examine this issue later in the discussion. As well as calculating an SHI the package also calculates the probability that the current level of harvest is unsustainable.

We tested for relationships between SHI and Birds of Conservation Concern category using a Welch’s one-way ANOVA, which allows for unequal variance and between SHI and wintering population trend (short and long term) using multiple linear regression. All analyses were conducted in R version 4.1.2 (R Core Team, 2021).

Data sources

Wintering bird populations for the UK were obtained from the latest published estimates (Frost et al., 2019). The estimate for mallard was increased by 2.6 million birds to account for the annual release of captive-raised birds for shooting purposes (Madden, 2021). We estimated a standard deviation for the population estimates by averaging the Wetland Bird Survey (WeBS; Frost et al. 2021) index for each species for the winters 2012/13 – 2016/17, which corresponded to the period used to estimate duck populations. We treated this mean index as equal to the estimate from Frost et al. (2019) and then calculated population estimates for each year based on their WeBS indices and calculated the standard deviation of these estimates. Population estimates for greylag goose, pink-footed goose, golden plover, snipe and woodcock were based on single years, but the same time frame was applied to standard deviation estimates in order to account for any interannual differences. The latest (2016) harvest estimates and 95% confidence intervals were taken from Aebischer (2019).

We modelled the resident and migratory populations of greylag geese and woodcock separately. The resident woodcock population was estimated as three times the number of breeding males. This was subtracted from the total estimated overwintering woodcock population to provide an estimate of the migratory woodcock population. Resident woodcock harvest was estimated as equal to the proportion of breeding birds in the overwinter population (13%) The remaining 87% of total harvest was assigned to migratory woodcock. We recognise that further mortality of UK breeding woodcock will occur outside the UK in southern Europe, but we have no estimate of this mortality and can only consider the contribution of UK hunters to the harvest of birds that winter in the UK in this initial assessment. Population estimates for Icelandic and British greylag geese overwintering in the UK are reported separately and no adjustment is needed. An estimated harvest of migratory Icelandic greylag geese in the UK (Frederiksen, 2002) was deducted from the total UK greylag goose harvest to provide an estimate of the harvest of British greylag geese.

However, it should be noted that the estimate was from 1996-2000 and no new estimates have been made.

Short-term (2008-2018) and long-term (1970-2018) wintering population trends were taken from Burns et al. (2020), except for common snipe and Eurasian woodcock. Common snipe trends were taken from Woodward et al. (2020), with caution advised due to the small sample size. Resident woodcock long-term and short-term population trends were estimated at -29% for both on the basis of reported declines in breeding woodcock (Balmer et al., 2013; Heward et al., 2015). Migratory woodcock short-term and long-term trends were estimated at -11% and -22% on the basis of a 4-18% decline from 2008-2018 and an 11-33% decline from 1980-2018 (BirdLife International, 2021). Bird population status in the UK (Red/Amber/Green) was taken from Birds of Conservation Concern 5 (BoCC5; Stanbury et al. 2021).

Estimates of adult survival were taken from Robinson (2005) with reported standard errors multiplied by 1.96 to give an approximate 95% confidence interval. The average standard error for all reported waterbirds (0.03) was used for species when no standard error was reported (e.g. wigeon, shoveler, greylag goose, woodcock and golden plover). We used the same survival estimates for both resident and migratory populations of woodcock and greylag geese. These adult survival estimates include mortality from hunting and so are likely to underestimate the maximum achievable survival rates under optimal conditions and are therefore conservative. Age at first reproduction (alpha) was also taken from Robinson (2005).

Results

The estimated potential excess growth (PEG), sustainable hunt index (SHI) and probability of unsustainable harvest can be found in Table 1. The current harvest for Canada goose and both British and Icelandic greylag goose were predicted to be unsustainable with harvest levels two, three and four times greater than potential excess growth for each population respectively when F_s is set to 0.5. The current harvest of Pink-footed goose has an SHI

value of 0.44 with a low probability of an unsustainable harvest (Table 1). The highest predicted SHI for duck species was for Eurasian teal at 0.61, followed by mallard, gadwall, shoveler and wigeon in decreasing order (Table 1). As well as no duck mean SHI approaching a value of 1, the 95% CIs did not overlap a value of 1 for all ducks other than gadwall. The probability of an unsustainable harvest of wintering UK ducks, that is harvest greater than 50% of the maximum potential surplus production of current winter population sizes, were all very low (0-0.04). For pochard, where the threshold for sustainability was set to only 10% of the maximum surplus growth due to recent breeding population declines in continental Europe as well as poor UK breeding and harvest data, SHI was 0.21 with a low probability of unsustainable harvest. For the four wader populations considered none had SHIs or 95% CIs exceeding 1 and the probability of an unsustainable harvest was low (Table 1).

There was no significant relationship between the average SHI and the BoCC5 category across all species ($F_{(2,4.569)} = 1.017$, $p = 0.431$), and there was also no significant relationship between average SHI and short-term ($\beta = -0.004$, $p = 0.678$) or long-term wintering trends ($\beta = 0.009$, $p = 0.061$).

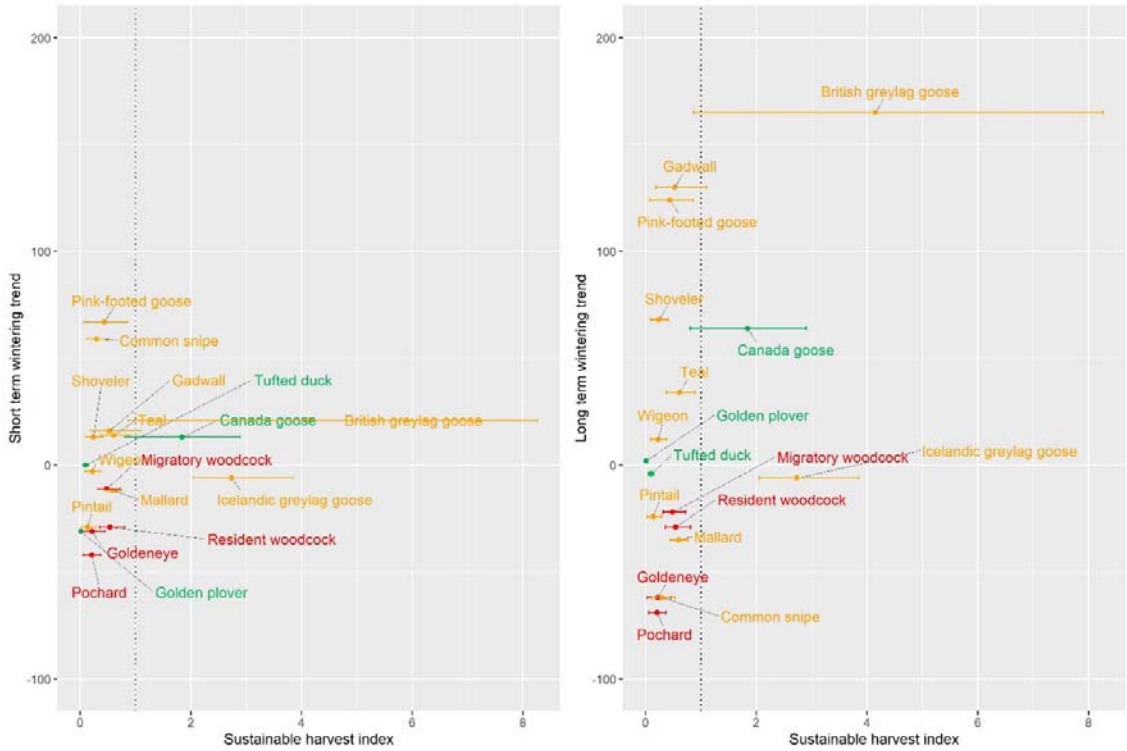

Figure 1: Mean and 95% confidence intervals for the sustainable harvest index (SHI) for huntable waterbirds in the United Kingdom along with their short-term (2008-2018) and long-term (1970 – 2018) wintering population trends. The dotted line at SHI = 1 represents the threshold for overharvest such that species falling to the right of the line are likely to be experiencing overharvest. SHI is calculated based on an F_s of 0.5 for all species other than pochard which is set to 0.1. Species are colour coded according to their classification under Birds of Conservation Concern 5 (BoCC5).

Discussion

In this study we used data on waterbird population sizes and harvest levels to estimate sustainable harvest indices (SHI). For the majority of ducks and all waders hunted in the UK we found no evidence of unsustainable harvests, but we recommend further scrutiny for gadwall. For this assessment we used a moderating factor (F_s) of 0.5 for all ducks and waders other than pochard. If a socio-ecological management plan for duck or wader harvest in the UK and Europe aimed for higher or lower harvests than 50% of the surplus production, then the SHI assessment would change.

Our estimates of SHI for wild geese suggest that Canada geese and Icelandic and British greylag geese may be subject to unsustainable harvest levels in the UK. This remains the case for Canada goose and both greylag goose populations if a higher moderating factor is chosen (F_s=0.9 where harvest target is 90% of maximum surplus growth). However, British greylag goose, Canada goose and indeed gadwall experience strongly increasing population trends in recent years (Frost et al., 2019). Although there is some evidence of levelling off of these trend increases in the most recent years (Frost et al., 2021). Our review of observed maximum population growth rates of the most common hunted waterbird species across their range gives us confidence that our DIM approach is not underestimating λ_{max}, e.g. maximum realised population growth of Canada goose in North America and the UK is c8-10% per year (Table S1). This suggests that there are likely to be errors in the assessment of the UK population size or hunting mortality. This uncertainty is reflected in the large confidence intervals of the SHI for these three populations.

Our SHI estimate for the migratory Icelandic greylag goose population is high with a high probability of unsustainable harvest. The Icelandic greylag goose population trend is declining, and this species is subject to significant additional hunting mortality outside of the UK. However, there are difficulties in accurately assessing the proportion of the harvest to assign to the resident and migratory populations and between the two main nations that hunt this population, which can clearly have a significant impact on the calculation of the SHI. For example, the mean annual harvest of greylag geese in Iceland was 43,000 per annum from

2015/16 to 2019/20 (Statistics Iceland, 2022), and we estimated the harvest for the UK as 22,500, giving a total estimated harvest of 65,500 from a total estimated population of 60,000 (Brides et al., 2021). But this does suggest action to improve estimates or limit the total harvest of this population would be warranted, at least as an adaptive experiment to seek a small positive change in population growth, e.g. adaptive management.

We found no relationship between SHI and short-term or long-term wintering population trends. We suggest that this indicates that hunting of waterbirds in the UK is not a primary driver of population trends. This is to be expected as waterfowl harvests tend to be a function of waterfowl productivity in a given year (Fox et al., 2016; Holopainen, Christensen, et al., 2018).This means hunters tend to harvest more ducks in years when surplus production is higher and moderate harvests tend not to have long term effects on waterfowl population sizes. That is not to say that the sum of harvests across the flyway would give similar results, and we encourage further work using these tools but on international scales. Likewise further scrutiny of trends and over what period they apply may be useful as long-term trends for the total Eurasian woodcock population size (e.g. 25yr), were stated as stable in 2015 but are now stated as having strong declines (Birdlife 2015 vs 2021). Immediate steps would be to build further realism into this initial model assessment of sustainability by incorporating the demographic breakdown of the hunting bag as affecting juvenile or adult survival and attempting the model with estimates of population sizes and hunting mortality at larger spatial scales across the UK, mainland Europe and western Russia.

The lack of a relationship between SHI and BoCC5 categories suggests that classification as Red or Amber listed by this scheme is not an appropriate tool to use as an aid to harvest management decisions. This is not unexpected as BoCC5 classification depends on a variety of factors including breeding and wintering localisation and is not solely dependent on international population trends or demographic sensitivities of the species concerned. For example, pink-footed geese are amber listed for non-breeding localisation (greater than 50% of the UK non-breeding population at ten or fewer sites) and non-breeding

international importance (UK holds at least 20% of the European non-breeding population)(Stanbury et al., 2021), despite significant long and short term population increases (Burns et al., 2020). However, this does not undermine the value of BoCC as a useful tool for the initial prioritisation of species of potential conservation concern at appropriate spatial scales; particularly for making habitat availability and restoration decisions.

In estimating the potential excess growth or annual recruitment in a bird population with which to assess the sustainability of harvest, a safety feature has been included so that the threshold with which to judge overharvesting is a proportion of the excess growth (Eraud et al., 2021; Johnson et al., 2012; Niel & Lebreton, 2005). This is wise due to well recognised risks in using surplus growth approaches in data poor systems (Jennings et al., 2008). The sequential use of this safety feature in frameworks designed for initial assessments of the sustainability of wild bird harvests has led to a clear and well described framework where the proportion of the excess growth that should not be exceeded by harvest can decline with data availability, population size, and declining conservation status (Dillingham & Fletcher, 2008; Eraud et al., 2021). But this initial assessment method does not take into account any specific harvest management objectives that may be equally important in utilitarian conservation systems such as legal recreational fishing or hunting, where the objective may be to maximise harvest opportunities for some species. This may be due to the species being non-native (e.g. Canada or Egyptian goose *Alopchen aegyptiaca* and Mandarin duck *Aix galericulata* in the UK), causing damage (e.g. pink-footed goose) or due to its relatively high abundance and productivity (e.g. Eurasian teal) it is a candidate for safe, sustainable regulated harvesting of wild food resources. Here we have chosen a “safety” net of 0.5 to apply to excess growth of all species (except pochard) as they are of Least Concern conservation status according to IUCN (IUCN, 2022). Harvesting up to 50% of the surplus production of highly productive species such as waterfowl is not unreasonable, where, in North America for example, 5.9 million Mallards were harvested from a breeding population of 14 million in 1999 (Wilkins & Cooch, 1999). Assuming the DIM

estimated maximum population growth rate used here of 1.979 for mallard, 50% of the surplus production would be 6.85 million ducks. Similar estimates of large harvest of 30+% of the annual surplus production of mallards in North America are common and sustained (e.g. U.S. Fish and Wildlife Service 2018). However, it is potentially informative to examine the effect of altering the level of precaution applied to the estimates of SHI. For example, reducing the F_s for Eurasian wigeon from 0.5 (reported in table 1) to 0.1 changes the mean SHI estimate from 0.222 to 1.127. Likewise, these models can be used to estimate the harvest required to achieve an SHI value ≥1 for pink-footed goose if the aim is to reduce or stabilise population growth and expansion, though the Prescribed Take Level (PTL) function of the popharvest package is better suited to this task.

We have completed this initial assessment of the sustainability of waterbird harvest in the UK using the best available data at this time. However, we recognise that there are multiple sources of uncertainty in our data. Population estimates of overwintering waterbirds in the UK are well documented and widely accepted, but there are known issues that influence reliability for this exercise. The latest population estimates are scored for reliability out of 3, where 3 is less reliable, and greylag geese, Canada geese, teal and goldeneye are scored 2 and mallard, snipe, woodcock and golden plover are scored 3 (Frost et al., 2019). Any underestimate of the population will result in underestimates of the potential excess growth, and changes to the methods used to make population estimates can have significant impacts. For example, the latest teal population estimates doubled from previous estimates as a result of new calculation methods (Musgrove et al. 2011; Méndez et al. 2015). Population estimates for waterbirds in the UK are essentially the average of peak counts at all counted sites across five years, with correction factors for missing data and extrapolation factors for species known to be undercounted (Musgrove et al., 2011). Counts are made by an extensive network of volunteers overseen by the British Trust for Ornithology (BTO), and for many sites data extends back to 1947. However, coverage is incomplete and 39% of WeBS sites are currently vacant, of which 19.5% are “high” or “very high” priority (BTO, 2022). Such gaps undoubtedly have an impact on the accuracy of population estimates.

These are likely our best estimates of the wintering population of hunted birds but do not solve the problem of an accurate assessment of the total Flyway or northern European breeding population of waterfowl as would be required for more realistic predictions of waterfowl productivity (Elmberg et al., 2006; Holopainen, Arzel, et al., 2018).

Waterbird survival estimates are reported variously from the UK, or across Europe, but generally from ringing recaptures. The DIM approach is sensitive to adult survival and requires good estimates of maximal survival under optimal conditions (Eraud et al., 2021). Our survival estimates are known underestimates as they are invariably measured in the presence of hunting mortality. Underestimates of survival rates will bias estimates of population growth rates, potentially overestimating excess growth and hence underestimating the sustainable harvest index. To test whether the DIM approach is generating sensible estimates of maximum population growth for waterbirds we reviewed estimates for two of the most well studied hunted species; Canada goose and mallard (Table S1). The DIM estimate of maximum population growth of 1.22 for Canada goose seems reasonable in light of studies across its range over varying time periods (1.07-1.74). However, for mallard, the DIM estimated maximum population growth of 1.979 appears high relative to realised maximum population growth observations of 1.2-1.59 (Table S1). As all realised population growth estimates include hunting mortality, variation caused by environmental conditions and suffer survey design error and biases, this may explain this discrepancy, but it warrants further investigation.

The accuracy of current UK waterbird harvest estimates is unknown (Aebischer, 2019). Developing a harvest recording system for the UK should remain a priority, not least to assist with management decisions at the flyway-scale (Madsen et al., 2015). However, at the UK-scale, the value of perfect harvest information is likely to be low so long as population estimates remain at their current level of precision. The prospects for improving harvest data quality through voluntary systems seem low in the UK, especially in light of the diversity of hunters and hunter organisations, low trust in regulatory agencies by hunters and low levels of participation in other voluntary schemes (Ellis, 2020). However, it would seem

to be of high policy importance to hunters and their organisations to be able to demonstrate the sustainability of their hunting activities. Appropriate policy intervention may be welcome in this area provided it is applied to all participants, so that harvest data is collected from inland and private land areas as well as public coastal areas, areas of significantly higher and lower hunting pressure respectively.

Making decisions with incomplete data is difficult. We have used the best available data to make this preliminary assessment of the sustainability of harvest levels in the UK, but clearly further work is needed, including a structured assessment of the harvest at the flyway-scale and identification of key areas which could improve the accuracy of these initial sustainability assessments. Our assessment provides a first step towards an informed discussion of harvest levels in the UK and whilst improved data collection will be useful, a collaborative approach to management based on the principles of Structured Decision Making and Adaptive Management could provide a transparent and trusted system to initiate with existing data that is “good enough” (Holopainen, Arzel, et al., 2018; Johnson et al., 2018; Williams & Brown, 2014). This approach is beginning to be developed in Europe by AEWA through mechanisms such as the European Goose Management Platform. This removes the need to rely on simplistic and inappropriate traffic light systems (such as Birds of Conservation Concern) which invariably result in poorly supported and simplistic outcomes (prohibiting versus continue allowing hunting). This is especially the case as we have shown their use to be unrelated to hunting mortality across all species. We would instead recommend a move towards a system which explicitly values recreational hunting, as the UK values recreational fishing, and allows for an ecologically sustainable approach which is socially acceptable, evidence based and able to initiate with incomplete data.

Authors’ Contributions

ME and TC conceived the idea, ME designed the methodology, collected and analysed the data, and wrote the first draft of the manuscript. TC contributed critically to drafts of the manuscript, validated the analyses and produced the supplementary information

Conflict of interest

MBE is employed by and is a member of BASC, the UK's largest representative body for shooting sports. TCC is a member of BASC, the British Trust for Ornithology and Essex Wildlife Trust.

Data availability statement

Data will be hosted on the DataDryad Digital Repository [DOI to be added]

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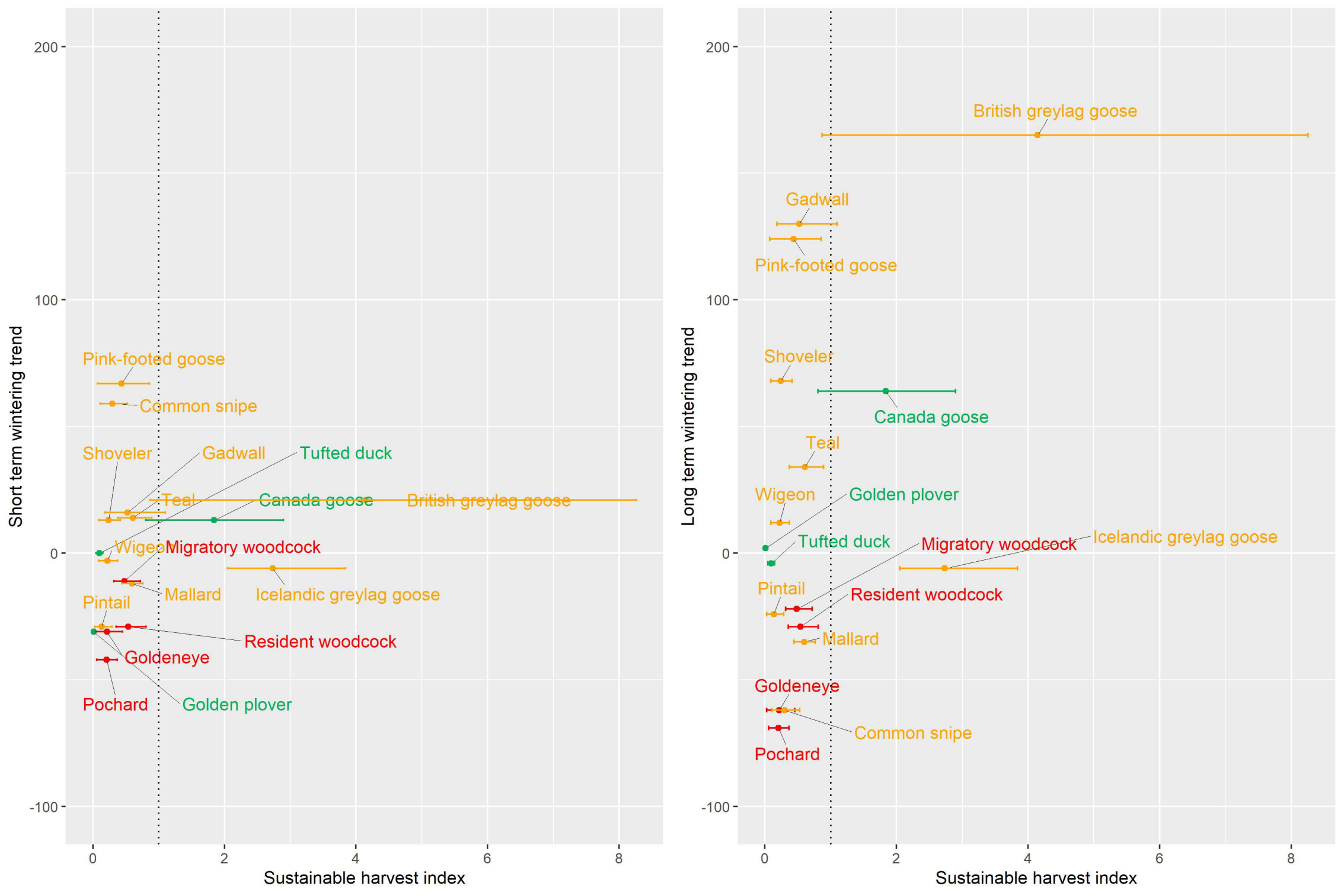
Table 1: estimated mean λ_{max}, potential excess growth (PEG; reported to two significant figures), sustainable hunt index (SHI) and the probability of current harvest levels being unsustainable with a safety factor (F_s) = 0.5 for huntable waterbird species populations overwintering in the United Kingdom, except for pochard where F_s = 0.1. The mean potential excess growth is also displayed as a proportion of the population estimate.

Species	Estimated λ_{max} (95% CI)	Mean Potential Excess Growth (95% CI)	PEG as proportion of population	Mean Sustainable Hunt Index (95% CI)	Probability of unsustainable harvest
Mallard	1.979 (1.886 – 2.068)	1,600,0000 (1,500,000 – 1,800,000)	0.49	0.596 (0.441 – 0.764)	0.000
Teal	2.112 (1.900 – 2.302)	240,000 (190,000 – 290,000)	0.56	0.610 (0.376 – 0.894)	0.004
Wigeon	2.224 (1.902 – 2.307)	250,000 (210,00 – 300,000)	0.56	0.222 (0.089 – 0.375)	0.000
Gadwall	1.818 (1.447 – 2.197)	13,000 (6900 – 19,000)	0.41	0.522 (0.184 – 1.099)	0.043
Pintail	1.916 (1.603 – 2.213)	9200 (5900 – 13,000)	0.46	0.136 (0.027 – 0.286)	0.000
Shoveler	2.047 (1.880 – 2.204)	10,000 (8300 – 12,000)	0.52	0.241 (0.091 – 0.414)	0.000
Tufted duck	1.853 (1.784 – 1.920)	60,000 (55,000 – 65,000)	0.43	0.098 (0.048 – 0.151)	0.000
Pochard	1.947 1.866 – 2.028)	2700 (2400 – 3100)	0.09	0.209 (0.058 – 0.372)	0.000

Goldeneye	1.473 (1.334 – 1.232)	5000 (3500 – 6500)	0.24	0.218 (0.030 – 0.454)	0.000
Canada goose	1.225 (1.218 – 1.232)	19,000 (17,000 – 20,000)	0.11	1.826 (0.811 – 2.881)	0.885
Greylag goose (Icelandic)	1.185 (1.133 – 1.231)	8400 (6000 – 11,000)	0.09	2.732 (2.047 – 3.793)	1.000
Greylag goose (British)	1.185 (1.133 – 1.231)	13,000 (9300 – 16,000)	0.09	4.101 (0.851 – 8.123)	0.952
Pink-footed goose	1.188 (1.173 – 1.202)	48,000 (39,000 – 57,000)	0.09	0.436 (0.073 – 0.859)	0.000
Woodcock (Resident)	1.354 (1.310 – 1.393)	36,000 (25,000 – 49,000)	0.22	0.540 (0.354 – 0.812)	0.00
Woodcock (Migratory)	1.354 (1.310 – 1.393)	270,000 (180,000 – 370,000)	0.22	0.482 (0.317 – 0.722)	0.00
Common Snipe	1.393 (1.327 – 1.446)	220,000 (170,000 – 270,000)	0.25	0.294 (0.109 – 0.524)	0.000
Golden plover	1.517 (1.404 – 1.626)	110,000 (80,000 – 130,000)	0.41	0.020 (0.003 – 0.041)	0.000


Short term wintering trend
200
100
0
-100
Pink-footed goose
Common snipe
Shoveler
Gadwall
Tufted duck
Teal
Canada goose
British greylag goose
Wigeon
Migratory woodcock
Mallard
Icelandic greylag goose
Pintail
Resident woodcock
Goldeneye
Pochard
Golden plover
0
2
4
6
8
Sustainable harvest index
Long term wintering trend
200
100
0
-100
British greylag goose
Gadwall
Pink-footed goose
Shoveler
Canada goose
Teal
Wigeon
Golden plover
Tufted duck
Migratory woodcock
Icelandic greylag goose
Pintail
Resident woodcock
Mallard
Goldeneye
Common snipe
Pochard
0
2
4
6
8
Sustainable harvest index