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ORIGINAL ARTICLE

Recent increase in annual survival of nesting female Common Scoter *Melanitta nigra* in Iceland

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Abstract
Despite their unfavourable conservation status, little is known about the population status, trends and demography of Common Scoter *Melanitta nigra*. Capture-mark-recapture (CMR) data from 154 recapture events of 88 individually marked breeding female Common Scoter *Melanitta nigra* in the Aðaldalur valley, northeast Iceland, during 2009–2018 generated an estimated annual apparent survival probability of 0.848 (95% CL 0.775–0.901). This exceeds a previous Icelandic CMR estimate (0.783, 95% CL 0.715–0.839) from nesting females during 1925–1958 at the nearby Mývatn (45 km to the SSE) when the population was declining at c. 2% per annum. Spring count data from Mývatn show that numbers of male and female Common Scoter at this important breeding site (thought to constitute over 80% of the Icelandic breeding national total) have increased by c. 1.8% per annum since 1974, and by 4–5% per annum since 2009. A population model showed that the observed change in survival corresponded well with the observed change in population growth rate. We reflect on causes of the increase in mean expected lifespan (from 4.1 to 6.1 years) between 1925–1958 and 2009–2018, speculating whether changes in food supply and/or reduction in gill-net fishing on Mývatn in the last 25 years could have been contributing factors to explain recent increases in breeding females there. An alternative, not necessarily mutually exclusive explanation could also be that the dramatic declines in chronic marine oil spill pollution in European waters could have contributed to higher recent female annual survival. While fully recognising the challenges of comparing survival rates from two sites in two different periods, survival rate has increased significantly between the two studies in a way that could potentially explain the increase in abundance at Mývatn. This could indicate that female survival has increased in the population as a whole. We strongly recommend demographic monitoring as a contribution to monitoring sea duck populations, species that are difficult to count and otherwise monitor annual changes in abundance in any meaningful way across large geographical ranges.

Keywords Aðaldalur · Capture-mark-recapture · Demography · Mortality · Mývatn · Sea duck

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Zusammenfassung

Aktueller Anstieg der jährlichen Überlebensrate nistender weiblicher Trauerenten Melanitta nigra in Island

Trotz ihres ungünstigen Erhaltungszustandes ist nur wenig über Bestandsituation, Trends und Demographie der Trauerente Melanitta nigra bekannt. Fang-Wiederfang Daten aus 154 Wiederfängen von 88 individuell markierten brütenden Trauerentenweibchen aus dem Aðaldalur Tal im Nordosten von Island in den Jahren 2009–2018 ergaben eine geschätzte jährliche Überlebenswahrscheinlichkeit von 0.848 (95% CL 0.775–0.901). Das übersteigt den Wert früherer Berechnungen aus Fang-Wiederfang Daten aus Island (0.783, 95% CL 0.715–0.839) von nistenden Weibchen aus den Jahren 1925–1958 am nahe gelegenen See Mývatn (45 km Richtung SSO) als die dortige Population jährlich um ca. 2% abnahm. Frühjahrszähldaten vom Mývatn zeigen, dass die Anzahl männlicher und weiblicher Trauerenten in diesem wichtigen Brutgebiet (welches wahrscheinlich mehr als 80% der isländischen Brutpopulation beherbergt) seit 1974 eine jährliche Zuwachsrate von ca. 1.8% und seit 2009 von 4–5% aufweist. Ein Populationsmodell zeigt, dass die beobachteten Veränderungen der Überlebenswahrscheinlich brütender Weibchen gut mit den Veränderungen in der Wachstumsrate der Population übereinstimmen. Mögliche Ursachen für die Zunahme der mittleren erwarteten Lebensdauer (von 4.1 auf 6.1 Jahre) zwischen 1925–1958 und 2009–2018 könnten ein verändertes Nahrungsangebot und/oder die Reduzierung der Stellnetzfischerei im Mývatn während der letzten 25 Jahre sein, die dazu beigetragen haben, den jüngsten Anstieg der nistenden Weibchen in diesem Gebiet zu erklären. Eine alternative, nicht zwangsläufig exklusive Erklärung für den aktuellen Anstieg der jährlichen Überlebensrate der Weibchen, könnte auch die Verringerung der chronischen maritimen Ölverschmutzung in europäischen Gewässern sein. Auch unter Berücksichtigung der Schwierigkeiten eines Vergleiches der Überlebensraten zwischen zwei Gebieten aus unterschiedlichen Zeiträumen, hat sich die Überlebensrate dermaßen signifikant zwischen diesen zwei Studien verändert, dass sich damit der Anstieg der Abundanz bei Mývatn erklären ließe. Dies könnte darauf hindeuten, dass sich die Überlebensrate der Weibchen in der Population insgesamt erhöht hat. Wir empfehlen dringend ein demographisches Monitoring als einen Beitrag zum Monitoring von Meeresentenpopulationen, da diese Arten schwierig zu zählen sind, und sich jährliche Veränderungen in der Abundanz auch anderweitig nicht einfach auf sinnvolle Weise über große geographische Bereiche erfassen lassen.

Introduction

Populations of long-distance migratory sea ducks winter and stage offshore (often out of sight of land) typically breed in remote areas at low densities, characteristics that present significant challenges to effective monitoring of their distribution and abundance (Bowman et al. 2015). Regular monitoring of sea duck populations is important because they are huntable in some countries along their flyway. Accurate population estimates are vital to ensure that international obligations for sustainable hunting (e.g. under the EU Birds Directive on Wild Birds and the African Eurasian Waterbird Agreement) are met. In addition, sea duck species remain susceptible to many other pressures in the marine environment, such as oil pollution events (Joensen and Hansen 1977; Hughes et al. 1997), disturbance from shipping (Kaiser et al. 2006), displacement from optimal feeding distributions by, e.g. offshore wind farms (Fox et al. 2006) and catch in fishing gear (Zydelis et al. 2013). In the Western Palearctic, recent, very rapid changes in the extent of ice-free marine waters in Arctic and Subarctic regions, due to global climate change, have created new challenges to distinguishing shifts in winter distribution from true changes in population size based on counts to assess winter distribution and abundance (Fox et al. 2018). Against this background, there is an urgent need to implement some form of demographic monitoring of sea duck populations to confirm apparent changes in population size (Boyd et al. 2015).

Numbers of Common Scoter *Melanitta nigra* have been reported declining in one part of the species' wintering range, the Baltic Sea (Skov et al. 2011). Understanding changes in demographic rates over time could help to identify causes of its unfavourable status and guide restorative conservation actions. Unfortunately, we lack long-term perspectives on Common Scoter population status and trends, because the species breeds at low densities over vast areas of the Russian taiga and tundra region, and various breeding populations mix on staging and wintering areas, where they are not counted regularly or (until recently) in any coordinated fashion (e.g. Skov et al. 2011). Ringing recoveries from the Icelandic breeding population of Common Scoter (estimated at 300–500 pairs in 2004, Burfield and van Bommel 2004) showed they largely winter around the coasts of south England, France and the Iberian Peninsula (Petersen 1998). On these winter quarters, they mix with individuals from Eurasian breeding populations, which greatly outnumber Icelandic birds (Wernham et al. 2002). More than 80% of Icelandic Common Scoter are thought to nest at Mývatn, a protected nature reserve and Ramsar site, in the northeast of the country (Kolbeinsson et al. 2019), so annual measures of breeding abundance at this very important site give a good reflection of recent changes in the size of the national population.

Female survival and emigration are fundamental population parameters to contribute to the modelling of avian population dynamics, yet there is only one historical study of annual female survival and breeding site fidelity in the Common Scoter (Fox et al. 2003). In this analysis, we present estimates of survival from a recent capture-mark-recapture (CMR) study of nesting female Common Scoter at a study site in Aðaldalur, northeast Iceland, the second largest aggregation for the species after Mývatn (supporting 50–60 pairs in recent years). We compare these with the earlier estimates from Mývatn during 1925–1958 to contrast survival from two periods of different population trajectories.

Methods

Capture-mark-recapture of nesting females

Female Common Scoters were caught on eggs during a study in Aðaldalur, Suður-Þingeyjarsýsla, Northeast Iceland (65°58′ N 17°32′ W). Observers walking in a chain searched the breeding area to locate nesting females in suitable habitats covering the same areas to find as many active nests as possible in each year over 14–23 days/year (see Supplementary Material Table S1). All nests were located with a GPS, enabling return visits to the same nest. Incubating females were captured on their nests using mist nets during subsequent visits to the nest site. Birds were marked with standard Icelandic Ringing Scheme stainless steel rings. Eighty-eight individual females were caught during annual catches in June of 2009–2017, leading to 154 recapture events during 2010–2018, as well as 5 birds found dead in or near the study area (no other ringed birds were reported dead to the Icelandic Ringing Scheme during the study). We defined June of each year as the recapture period, and estimated annual survival probability using simple Cormack–Jolly–Seber models in MARK 8.2 (White and Burnham 1999). Goodness-of-fit was tested in U-CARE 2.3.4 (Choquet et al. 2009), and model selection used $QAIC_c$ to adjust for lack of fit (Burnham and Anderson 2002). Including information from the five dead recoveries did not change estimates of survival (results not shown).

Spring counts at Mývatn

Numbers of Common Scoter in Mývatn, Suður-Þingeyjarsýsla, Iceland (65°35′ N 17°00′ W, 45 km SSE of Aðaldalur) have been consistently monitored from 1974 (males) and 1975 (females) until 2018. Experienced observers conducted annual total counts from pre-defined vantage points in late May to estimate numbers of birds settling to breed at the site (Gardarsson 1979; Gardarsson and Einarsson 1994, 2004). Mean annual finite population growth rates (λ) for both sexes were calculated using linear regression of natural log transformed counts, back-transformed to the real scale.

Population modelling

To assess whether changes in female survival could explain observed changes in population growth rate during 1925–1958 and 1975–2018, we constructed a simple female-only matrix population model in R (R Core Team 2016, script reproduced in Supplementary Material). Annual fecundity was estimated as the mean ratio between the number of fledged young observed in late August and the number of females counted in late May in Mývatn during 1975–2018 (Gardarsson and Einarsson 2004, Á. Einarsson unpubl. data): 1.12 young/female. Pre-breeding survival and age of first breeding were unknown, but values of these demographic variables in the model were iteratively adjusted to fit the observed finite rate of increase (λ) of the population during 1925–1958 (0.98). Subsequently, the recent survival estimate was substituted into the model, and λ predicted for the recent period.

Results

Survival estimates of nesting females

The goodness-of-fit test indicated some lack of fit in all test components (overall test: $\chi^2_{28} = 51.2$, $P = 0.005$). The ratio between the test statistic and the number of degrees of freedom was similar (1.5–2) for all test components. We estimated the overdispersion factor $\hat{c}$ as 51.2/28 = 1.83 and used this value to adjust model selection and variances. The best model had constant survival and recapture probabilities over time ($\Delta QAIC_c = 11.2$ to nearest model with time-dependent parameters). The estimated annual apparent survival probability was 0.848 (95% Confidence Limits = 0.775–0.901), while the estimated annual probability of recapture (i.e. for a female still alive that has not permanently emigrated) was 0.553 (0.455–0.648).

Spring counts at Mývatn

Systematic standardised counts at Mývatn showed a mean annual growth rate λ of 1.019 for males during 1974–2018 and of 1.017 for females during 1975–2018 (Fig. 1). For the period 2009–2018, when the mark-recapture study took place, the observed λ was 1.051 for males and 1.043 for females. Counts of males and females were highly correlated over time (Pearson correlation test, $r_{44} = 0.93$, $P = 7 \times 10^{-20}$).

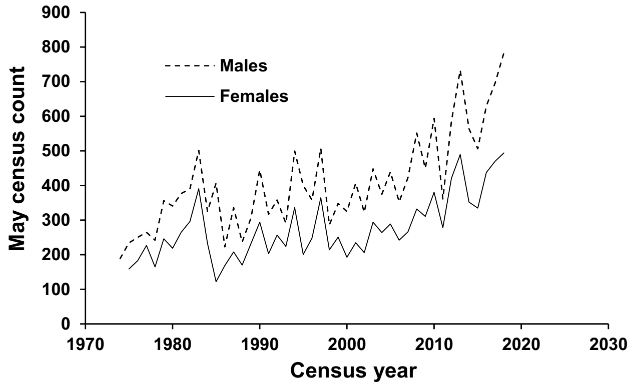

Fig. 1 Annual counts of Common Scoter males (1974–2018) and females (1975–2018) at the Mývatn-Laxá study area, northeast Iceland. Data courtesy of Mývatn Research Station

Population modelling

Outputs from the model showed that the observed λ during 1925–1958 (0.98) could be reproduced by assuming that all female Common Scoter start breeding at age 3, that first-year survival from August is 0.54, and that second-year survival is 0.80, values that seem biologically realistic. Substituting the recent estimate of adult female survival into this model led to a predicted λ of 1.038, which is remarkably close to the observed value for the 2009–2018 period (1.043).

Discussion

This is the first study designed to estimate annual survival of nesting female Common Scoter, which we believe generates an estimate robust to most of the potential biases involved in mark-recapture estimation of survival. Birds were marked with stainless steel rings, so marker loss can be considered negligible, and the goodness-of-fit test failed to indicate major heterogeneity in the data set. Random (non-Markovian) non-breeding and temporary emigration of females would only affect the estimated recapture probability and, thus, not cause bias in the estimate of survival. Permanent emigration from the study area would still lead to a negative bias in estimated survival, but no information was available from dead recoveries outside the breeding season to estimate the level of site fidelity.

Our estimate of annual survival probability (0.848, 95% CL 0.775–0.901) was higher than that based on historical (1925–1958) live and dead encounter data from Mývatn (0.783, 95% CL = 0.715–0.839; Fox et al. 2003). These estimates translate into a mean expected breeding lifespan (calculated as -1/ln(survival)) of 6.1 years in the present study compared to 4.1 from Mývatn in the period 1925–1958. Given that our current estimate did not take permanent emigration from the study site into account (whereas the earlier estimate of Fox et al. (2003) did), the actual difference in survival and, thus, life span may have been even larger. Conditions differing between the two sites and/or the two study periods could potentially contribute to this substantial difference in female breeding Common Scoter survival rate. The earlier study was based on recaptures of birds bearing aluminium rings (albeit frequently replaced during recapture events), so the switch to stainless steels leg rings could contribute to the difference in survival estimates. However, the study of Fox et al. (2003) found no sign of a strong age-specific decline in adult female survival, which would be apparent if there was a problem with ring loss of this nature in that study.

Numbers of commercially collected Common Scoter eggs at Mývatn declined dramatically from peaks during 1907–1918 until the late 1950s (Guðmundsson 1979). At the Grimsstaðir farm (the origin of data used by Fox et al. 2003), numbers of Common Scoter eggs gathered per year during 1925–1957 fell by 2% per annum (based on data in Guðmundsson 1979). Assuming the annual number of eggs collected was a reflection of the numbers of nesting females present in each year (i.e. reflecting constant search effort between years, as was thought to be the case), the Mývatn Common Scoter population was declining during 1925–1957 in the period for which Fox et al. (2003) estimated adult breeding female survival. American Mink *Neovison vison* escaped from fur farms, reaching Mývatn in 1955, post-1960, a road was built around Mývatn, diatomite was mined from the lake and increased fishing effort drowned many female ducks and ducklings at the site (Skírnisson and Petersen 1980), all suggesting that conditions for the species locally were unlikely to have been improved in years after 1957.

Annual spring counts at Mývatn show that numbers settling to breed there have increased since 1974/5 at c. 2% per annum. Reproductive success of Common Scoter (measured as produced young per female) at Mývatn fluctuates with the invertebrate food supply and shows no significant trend over the same time period (Gardarsson and Einarsson 2004, Mývatn Research Station unpublished data). Hence, current levels of female survival seem sufficient to support an increasing spring population (and likely nesting abundance), exceeding the female survival rates during 1925–1958, at a time when nesting numbers were known to be declining. However, without contemporary CMR survival estimates from this specific site, we cannot reject the alternative hypothesis that numbers at Mývatn are currently maintained by immigration. Only around 100 pairs of Common Scoter are thought to nest away from Mývatn within Iceland, with no clear trend (Náttúrufræðistofnun Íslands 2000, Kolbeinsson et al. 2019). While it remains plausible that females from elsewhere in Iceland and/or further afield could recruit to

Mývatn, this seems highly unlikely given the high levels of nesting site fidelity of the species (Fox et al. 2003) and the fact that more than 80% of the Icelandic population breeds at this important site.

We lack historical population survey data and survival estimates from the Aðaldalur study area, but there were some signs of a modest increase in breeding Common Scoter abundance during 2004–2018 (Kolbeinsson et al. 2019). Because we lack long-term multi-site CMR data, it is difficult to distinguish between site-specific and temporal explanations for the difference in survival of breeding adult female Common Scoter between the two sites during the two study periods. For this reason, we cannot exclude the possibility, for example, that female survival at Aðaldalur was always higher than at Mývatn, although that would still require that survival at Mývatn had increased since the earlier study to explain the population trajectory there. As a result, we tend to favour a temporal explanation for these differences over between-site differences (given their close proximity) and contend that the Iceland breeding population of Common Scoter is likely a relatively isolated but homogenous one, and that the Mývatn element has contributed predominantly to overall national breeding numbers. The striking results from our simple model suggest that, given no major changes in reproductive success, the difference in observed nesting female survival rate between the two periods was enough to explain the contemporary difference in population trajectories.

It is well demonstrated that the production of Common Scoter young at Mývatn correlates with chironomid abundance, and reproductive performance in year t at the site was correlated with subsequent changes in spring nesting bird densities in year $t+3$ (Gardarsson and Einarsson 1994, 2004). However, long-term monitoring of emergent midges at the site shows no evidence of overall increases in food supply, so it seems highly unlikely that reductions in gill-net fishing in the last decade (Á. Einarsson pers. obs.) have affected trophic relationships in the lake. The gill-net fishery was, however, reported to be responsible for drowning between 1.9% (1968), 2.3% (1960) and 18.2% (1969) of the annual nesting population of Common Scoter at the lake (Gardarsson 1961; Bengtson 1972), so in those years potentially had a substantial effect on the mortality of the species at the site. The number of nets set per night per annum (as a measure of fishing intensity) at Mývatn fluctuated annually but was frequently between 12,000 and 18,000 during 1978–1994, falling to 1000–9000 during 1995–2012, and less than 900 in all seasons since (Guðni Guðbergsson, Iceland Marine and Freshwater Research Institute, in litt., see also Guðbergsson 2004). Removal of more than 95% of this potential source of drowning mortality is likely to have affected female Common Scoter annual survival at this site, whilst potentially not affecting that at Aðaldalur (where we lack information about potential changes in fishing intensity).

However, greater female mortality during 1925–1958 compared to 2009–2018 could equally likely have occurred outside of the breeding period. The reasons for this could be manifold but could relate to the former greater importance as a huntable quarry species, especially in the United Kingdom where the majority of these birds are thought to pass through on migration and to winter. On the other hand, by the early 1980s, Harradine (1985) estimated that less than 0.1% of just under 500,000 ducks shot annually in the United Kingdom were Common Scoter. The species was never a popular quarry species because of its inaccessibility and unattractiveness to wildfowlers, so this seems a highly unlikely explanation for changes in abundance in Iceland during this time.

Common Scoters aggregate in large flocks in shallow offshore waters making them vulnerable to oil pollution events (e.g. Joensen and Hansen 1977; Vauk et al. 1989; Hughes et al. 1997; Banks et al. 2008; Chrastansky et al. 2009). Intentional and unintentional oil spills events were likely higher during 1925–1958, when washing of oil tanks into the sea was regular and completely unregulated, likely peaking during and after the Second World War, when 14.5 million tons (3500 vessels) of merchant shipping were sunk in the North Atlantic, together with 222 warships and 800 submarines (White 2008). Although we lack complete statistics for the United Kingdom, 120 reported oil spills per annum during 1978–1981 (Stowe and Underwood 1984) give some idea of the chronic marine oil pollution problem of that time. Belgian beached birds surveys in the 1960s showed virtually all (> 90%) swimming seabirds washed ashore were oil-contaminated, yet contemporary rates are negligible, despite the increasing intensity of shipping and size of vessels, indicating a major decline in chronic oil pollution following enactment of legislation (Stienen et al. 2017). Similar declines in beached Common Scoter occurred along Danish North Sea and Skagerrak coasts during 1984–2005 (Larsen et al. 2007). Globally, levels of major tanker oil spills in the marine environment have declined from 79 per decade in the 1970s to less than 10 at present (ITOPF 2018), potentially benefitting Common Scoter. Interestingly, the trend in breeding scoters (combined Surf *Melanitta perspicillata*, White-winged *M. fusca* and Black Scoter *M. americana*) generated by the North American Waterfowl Breeding Population and Habitat Survey based on aerial survey transects of the breeding areas show decreases from 1980s to early 2000s and then an increase since 2004 (Bowman et al. 2015). This may suggest a contemporary recovery in those species in recent years along Pacific and Atlantic coasts in that continent. However, we readily accept the weakness of evidence for reductions in chronic oil pollution affecting Common Scoter survival at the two sites in Iceland. We urge prudence in comparing survival rate estimates from two separate but adjacent breeding sites over a period of several decades and linking these differences to general reduction in chronic oil spill rates on the winter quarters, but concede reduction in such a regular source of mortality could potentially contribute to overall reductions in survival.

Our inability to conclude definitively that recent apparent increases in numbers of Common Scoter breeding in Iceland are the result of elevated female survival rates returns us to the starting concern about our general inability to monitor sea duck populations effectively. The combination of shifting wintering distributions in response to food supply and global change (including climate), as well as the challenging environments they inhabit, creates particular difficulties in generating reliable annual indices of non-breeding abundance. Their typically low-breeding densities over vast areas of inaccessible breeding habitat (Hagemeijer and Blair 1997) make them difficult to census anywhere other than at unusual breeding aggregations, such as at Mývatn and Aðaldalur, described here. Nevertheless, the robust and unique results of these analyses underline the value of such an approach for species that otherwise present us with major monitoring challenges. In particular, we require more information about female survival outside the breeding season and the factors affecting parameter. For this reason, the establishment of capture-mark-recapture nesting female studies to generate annual survival (despite their inevitably limited geographic scope) is especially attractive as a vital supplementary source of demographic data that can enlighten our understanding of population change in otherwise cryptic species, such as Common Scoter.

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