Severe declines in numbers of male American Common Eiders *Somateria mollissima dresseri* during spring counts over the past two decades in the southwestern Bay of Fundy, Canada

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Abstract

The southwestern Bay of Fundy in New Brunswick, Canada, has traditionally provided important habitat year-round for American Common Eider *Somateria mollissima dresseri*. Numerous anthropogenic stressors from industry and climate change are thought to be having a negative impact on the abundance of *dresseri* eiders wintering and breeding in this region. We analysed trends in the number of eiders breeding in the Bay of Fundy, recorded during dedicated aerial surveys made to count males attending colonies in spring, flown nearly biannually since 1991. A combination of negative binomial generalized additive models (GAMs) and generalized linear models (GLMs) were used to assess changes in eider numbers over the past 30 years across the entire study region and at the scale of smaller spatial sub-units. We found that the number of eiders breeding in the Bay of Fundy began to decline steeply around the year 2000 in all surveyed areas with an overall regional trend of $\lambda = 0.91$ (95% confidence interval = 0.89, 0.92), amounting to a loss of nearly 10% per year over the past two decades. The largest concentrations of nesting eiders continue to be associated with the Grand Manan Archipelago, although numbers have declined there as well. Comparing two years with equal and extensive spatial coverage of surveyed areas, the total number of male eiders counted in the spring in the Bay of Fundy dropped from 8,890 in 1998 to 2,562 in 2017. Altogether, these findings corroborate other evidence that eiders have been declining throughout the Gulf of Maine ecosystem at an alarming rate over the past 20 years, and that distributional shifts are likely occurring across the subspecies' range.

Key words: declines, management, sea duck, trends, waterfowl.

The American Common Eider *Somateria mollissima dresseri* (hereafter *dresseri* eider) is a large, well-recognised sea duck nesting colonially on coastal islands in the northwest Atlantic from Labrador to Massachusetts (Goudie *et al.* 2020). It occupies a high trophic position in their nearshore marine habitat, specialising on benthic inter- and sub-tidal prey, particularly molluscs (Goudie *et al.* 2020). *Dresseri* eiders face numerous stressors from climate regime shifts affecting their marine environment from the cumulative and interactive effects of altered ocean temperatures, chemistry and circulation, changes in species distributions including prey, sea level rise, and increased storm intensity and frequency (*e.g.* Chisholm *et al.* 2021; Pershing *et al.* 2015, 2018; Seidov *et al.* 2021; Sorte *et al.* 2017). In addition to these climate change impacts, *dresseri* eiders face threats from other anthropogenic sources such as coastal development, shipping, offshore energy production, introduced invasive alien species, aquaculture, and commercial exploitation of preferred prey, that may interact to alter habitat quality and prey availability differentially through space and time (Noel *et al.* 2021). They are also vulnerable to the increasing prevalence of predators at breeding colonies, as well as rapid spread of disease, due to their habit of nesting and wintering in high concentrations (Milton *et al.* 2016; Ballard *et al.* 2017). Additionally, aggregations at sea during breeding, moulting or wintering are vulnerable to single events that affect significant numbers of birds, such as disturbance, oil spills or other perturbations. This subspecies is also commonly harvested for sport hunting and food across its entire multijurisdictional range, and there are regional down harvesting programmes in some areas (Rothe *et al.* 2015).

It follows that few species of sea duck are subject to as many uses, threats and jurisdictional authorities as the American Common Eider, requiring coordinated efforts for effective management, including monitoring the subspecies' population trends. Despite not having been monitored over as broad a spatial and temporal scale as other North American waterfowl (Bowman *et al.* 2015; Koneff *et al.* 2017), several lines of evidence indicate that *dresseri* trends vary across the range and at different times of year (Noel *et al.* 2021). One common pattern is however emerging: the number of birds recently breeding and wintering in some areas of Nova Scotia, New Brunswick and Maine is clearly in decline (Bowman *et al.* 2015; Noel *et al.* 2021; Giroux *et al.* 2021; Robertson *et al.* 2021; Gutowsky *et al.* 2023). The drivers of these changes are surely manifold, but significant oceanographic shifts from climate change are suspected to be playing an important role (Noel *et al.* 2021).

The southwestern Bay of Fundy at the northern reach of the Gulf of Maine has traditionally provided important wintering habitat for *dresseri* eiders and has also supported significant *dresseri* nesting colonies during breeding (Erskine & Smith 1986; Lock 1986). Indeed, this importance to *dresseri* was one of the key factors in the recent designation of "Sea Duck Key Site 66: Southwestern Bay of Fundy, New Brunswick" by the Sea Duck Joint Venture (Bowman *et al.* 2022). In addition to periodic surveys during the winter, this area has also been subject to comprehensive, systematic survey efforts during the early breeding period; spring aerial surveys have been flown nearly biannually or triennially from 1991 to 2019 to count male eiders attending females around colonies as a proxy for breeding abundance. All male eiders at this time of year in the Bay of Fundy can be presumed to be *dresseri*. Earlier analyses of these survey data indicated that numbers were stable until the late 1990s, followed by a decline of 3.1% per year up to 2012 (Bowman *et al.* 2015). The objectives of this work are to: 1) provide updated trend estimates, and 2) evaluate whether declines have occurred evenly through space and time across the Bay of Fundy, which would suggest that broadscale rather than localised factors are at play.

Methods

Surveys

Aerial surveys of male Common Eiders within the Bay of Fundy in New Brunswick (NB), Canada, have been made in spring by the NB Department of Natural Resources and Energy Development and the Canadian Wildlife Service (Fig. 1) at varying intervals over the period 1991–2019. Male eiders attend females until at least one week after nest initiation; surveys therefore were generally conducted in the second or third week of May, one week following peak nest initiation, covering marine areas close to islands where the eiders are known to nest. Surveys were conducted from fixed-wing aircraft (primarily Cessna 185 in earlier years; Partenavia P86 in more recent years) in good visibility conditions and flown at *c.* 160 kph at an altitude of *c.* 75 m above sea level. Males are highly visible from this height (Chaulk 2009), enabling an observer to count groups or individual males and to record the count and coordinates of the observation.

Data were recorded as georeferenced observations of group size, either on physical maps which were later digitised or directly digitally with a GPS unit (except for 2012, when observation coordinates were not recorded but rather observations were assigned to a "coastal block" in accordance with the standardised Canadian Wildlife Service coastal survey block system, Fig. 1). As this coastal block system is used as a spatial unit for summarising counts and trends, data from 2012 were retained for analyses. Surveys in 1994 were conducted too late in the season (on 27 May) and were not retained. Not all of the blocks were surveyed every year, and those blocks which were surveyed varied among years; however, most blocks were surveyed in 11–15 years during the 1991–2019 study period. Two blocks were surveyed in only two years, and these had < 50 male eiders in total, for both blocks and years combined. Data from these two blocks (blocks 2 & 13)

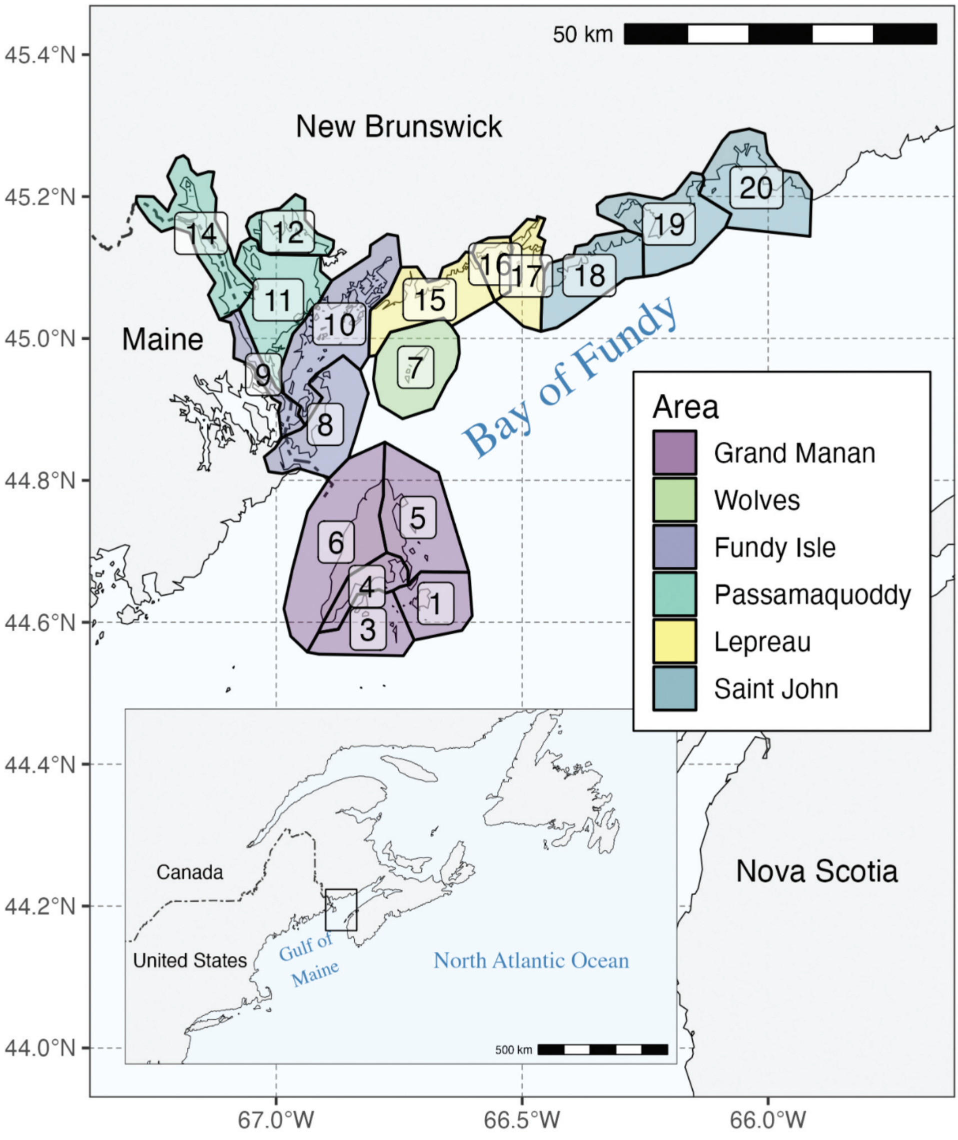

Figure 1. The 18 Canadian Wildlife Service coastal survey blocks for overlapping spring aerial surveys of male American Common Eiders in the Bay of Fundy, New Brunswick, Canada. Block numbers are shown as numeric labels while six assigned "areas" for each block are shown as unique colours. Two blocks (2 & 13) were surveyed in only two years and < 50 male eiders were present, so were not included in the analysis. Inset indicates the extent of the study area.

therefore were not retained, leaving the 18 coastal survey blocks shown in Figure 1 for analyses. Each block was assigned to one of six larger spatial units or "areas" (Fig. 1).

Analysis

Visual data exploration indicated likely non-linear relationships in the number of eiders counted on aerial surveys over time as well as highly variable counts across blocks and areas (Fig. 2), thus we implemented a generalized additive model (GAM) approach to assess consistency in temporal patterns in counts across surveyed areas (Wood 2006). We fitted a negative binomial GAM with a log-link function to annual total counts summed for each of 18 blocks as the response and random smooths for year by both block area and block to account for the nested structure of the data, in R (v.4.2.3, R Core Team 2023) using R package 'mgcv' (Wood *et al.* 2016). This analysis indicated that all block areas showed consistent temporal patterns after 2000; thus, we estimated a recent regional trend for the Bay of Fundy using data from all survey blocks over the period 2000–2019. We fitted a generalized linear model (GLM; Zuur *et al.* 2009) with a negative binomial distribution, log-link function, and a year (trend) effect on annual total counts with block as a fixed effect to account for uneven numbers of eiders in each block and uneven sampling of blocks across years using R package 'MASS' (Venables & Ripley 2002). We first considered a Poisson distribution but overdispersion was pervasive, while the negative binomial addressed the extra variance and fit the data well. Trend was derived as mean population change per year (λ) from the year β coefficient on the response scale (*i.e.* exponentiated, where $\lambda = e^{\beta}$), reported with 95% confidence intervals (95% CI = lower confidence limit, upper confidence limit). To visualise and summarise past and recent abundance and distribution, geo-referenced count estimates were summed on a 0.025° grid for the earliest (1998) and most recent (2017) survey years with near-complete spatial coverage across survey blocks (all blocks except for block 8 were surveyed in both 1998 and 2017).

Results

GAM results indicated consistent nonlinear patterns (effective degrees of freedom of the smooth for year by area was 20.4) in the number of male eiders counted on aerial surveys for five of six surveyed areas, with clear declines beginning around the year 2000 (Fig. 3). Three blocks in the most eastern survey area, Saint John, had relatively low but highly variable numbers of eiders in the 1990s (Fig. 2), causing the different temporal patterns in counts across blocks in this area, although abundance still declined after 2000 (Fig. 3). An overall trend for the southwestern Bay of Fundy over the period 2000–2019 was derived with a GLM from all surveys with block as a fixed effect and showed a decline of $\lambda = 0.91$ (95% CI = 0.89, 0.92) over the past two decades. Comparing the earliest and most recent survey years with near-complete spatial coverage across survey blocks (1998 and 2017, when all but block 8 were surveyed), the number of male eiders was *c.* 6,000 fewer in 2017 compared to 1998, a drop

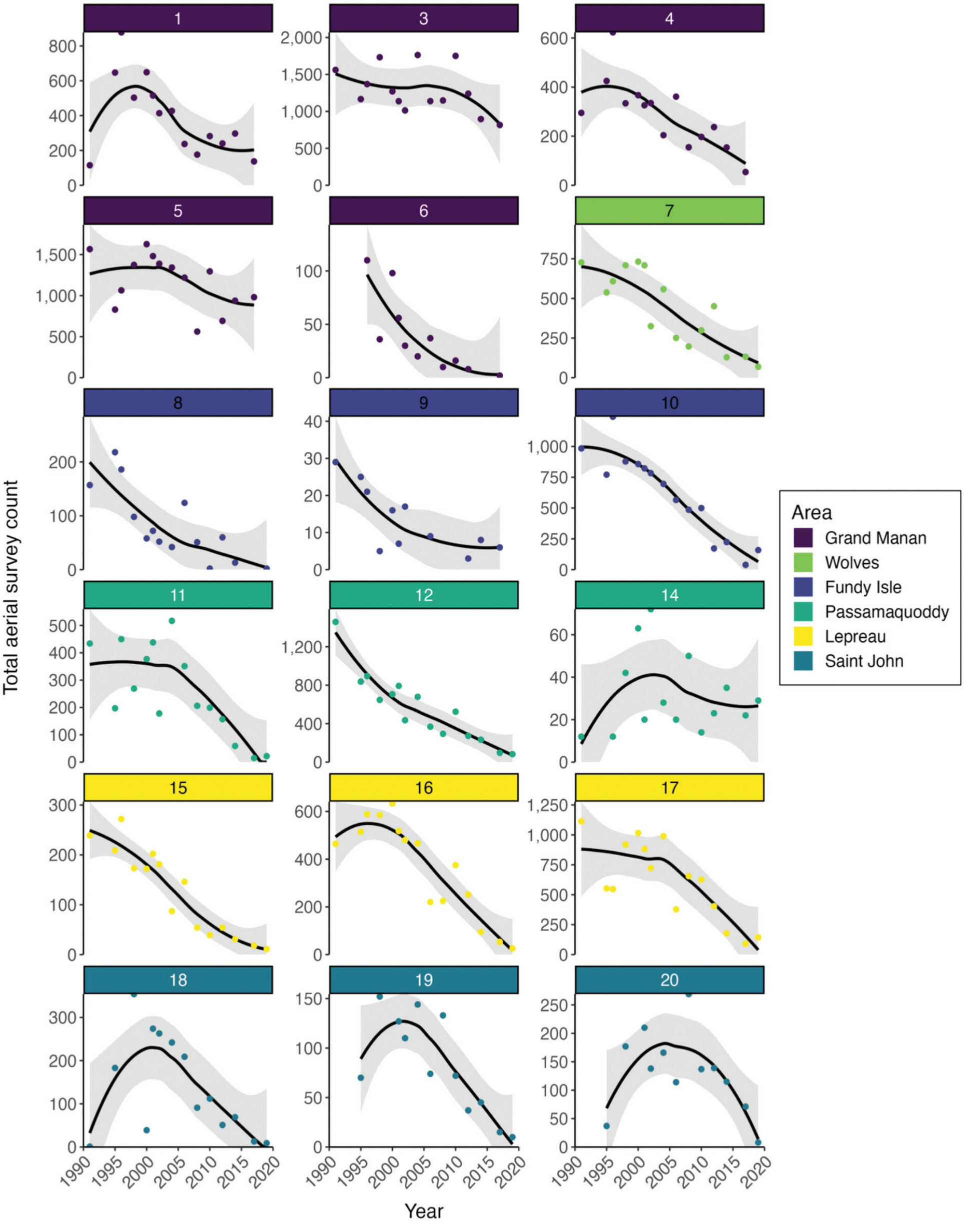

Figure 2. Number of male American Common Eiders counted during aerial surveys flown in spring over the Bay of Fundy, New Brunswick, Canada between 1991–2019. Raw counts are shown as closed circles coloured by area, with numbers indicating survey blocks within each area (see Fig. 1). The line and shaded area depict a LOESS smoother and 95% confidence intervals.

from 8,890 total males counted in 1998 to 2,562 males in 2017 (Fig. 4). Including birds from block 8 is unlikely to have altered these totals significantly because block 8 birds showed a similar pattern of decline to those other blocks (Fig. 2), with 98 males counted in 1998 and 2–60 recorded in the four survey years between 2008–2014. Overall, the largest concentrations continue to be associated with the Grand Manan Archipelago (Fig. 4). The number of male eiders observed in spring along the entire mainland coast and in the Wolves Archipelago has seemingly plummeted since 2000 based on trends at the block-level and area-level (Figs. 2 & 3), and when comparing distributions from earlier with more recent survey years (Fig. 4).

Discussion

As expected, the number of male *dresseri* eiders in the Bay of Fundy in New Brunswick showed severe declines during the spring nesting period over the past 20 years, and these declining trends were consistent across all surveyed areas. The nonlinear temporal patterns in abundance over the full three decades of monitoring aligned with earlier analyses of these survey data; numbers were stable until the late 1990s (Mawhinney *et al.* 1999) followed by declines (Bowman *et al.* 2015). However, these declines have accelerated from 3% per year up to 2012 (Bowman *et al.* 2015), to nearly 10% per year up to 2019. Our findings corroborate multiple lines of evidence that eiders have been struggling in the southwestern Bay of Fundy over the past two decades (Ronconi & Wong 2003) and in the Gulf of Maine more broadly (Allen *et al.* 2019; Robertson *et al.* 2021; Gutowsky *et al.* 2023; Tomlik *et al.* 2023), where recent, rapid hydroclimatic changes (Pershing *et al.* 2015, 2018; Gonçalves Neto *et al.* 2021; Seidov *et al.* 2021) are contributing to significant changes in the abundance and distribution of species across trophic levels of the ecosystem from zooplankton to fish to seabirds to whales (*e.g.* Pinsky *et al.* 2013; Pershing *et al.* 2015, 2021; Morse *et al.* 2017; Meyer-Gutbrod *et al.* 2021).

Courting eiders in spring and duckling crèches in early summer are ubiquitous hallmarks of the coastline and coastal islands of the Bay of Fundy. The loss of breeding eiders from nearly all areas with colonies in the southwestern Bay of Fundy signals a significant ecological shift since around 2000. While frequent poor years of breeding and considerable interannual variation in nesting success are known demographic features of eider life history (Ronconi & Wong 2003), the consistent and steep declines of males attending colonies in spring clearly indicates a long-term trend despite expected fluctuations. Low eider duckling survival rates on Grand Manan, coupled with increasing numbers of gulls *Larus* sp. which depredate ducklings, has been suggested to explain decreases in eider numbers around Grand Manan (Mawhinney *et al.* 1999). Declines in Maine have also been attributed in part to the prevalence of avian and mammalian predators including gulls but also Bald Eagles *Haliaeetus leucocephalus*, American Mink *Neovison vison* and North American River Otters *Lontra canadensis* (Allen *et al.* 2019). Predators could be reducing productivity (Allen *et al.* 2019), and

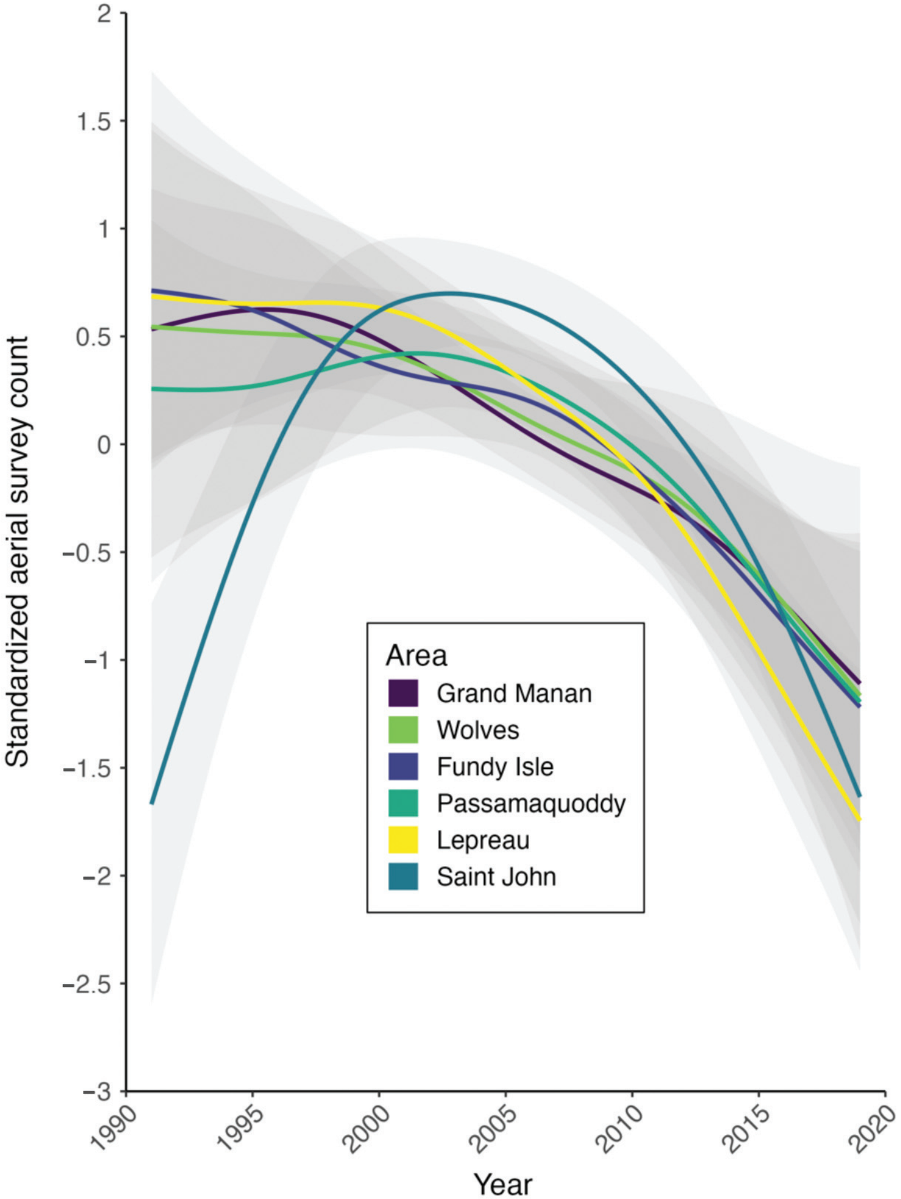

Figure 3. Estimated smoothing functions (solid lines) with 95% confidence intervals (grey shaded areas) of the number of male American Common Eiders counted during aerial surveys flown in spring over the Bay of Fundy, New Brunswick, Canada from 1991–2019. Smooths were estimated by area (see Fig. 1) from a negative binomial GAM including random smooths for both area and block, to account for the nested structure of the data.

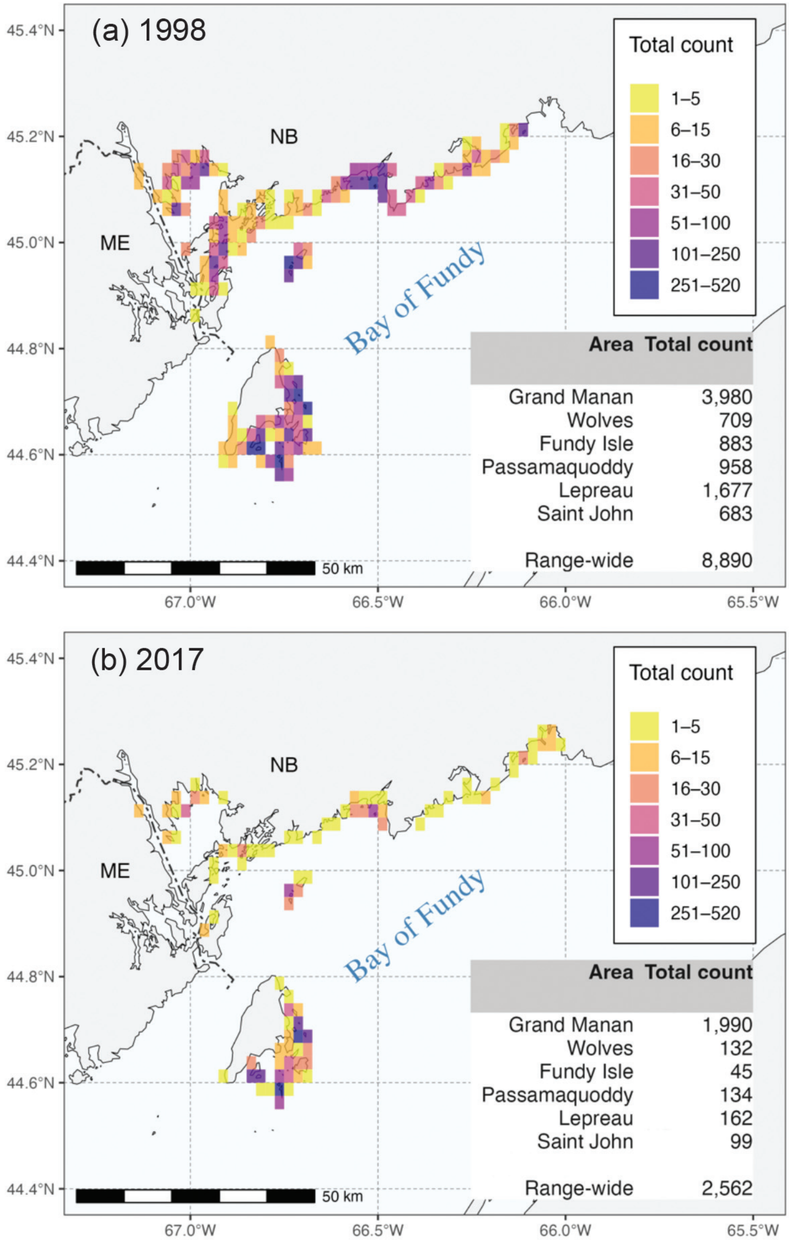

Figure 4. Distribution and abundance of male American Common Eiders recorded during spring aerial surveys over the Bay of Fundy, New Brunswick, Canada: (a) in the past (1998) and (b) recently (2017). Counts are shown summed on a 0.025° grid, and inset tables show total counts by area (see Fig. 1) and across the full survey ("range-wide").

could also be depressing adult survival, particularly for females as suggested by lower survival rates in females than males in Nova Scotia (Milton *et al.* 2016). In the Baltic/Wadden Sea flyway of the European Common Eider subspecies *S. m. mollissima*, reduced adult female survival from high natural mortality due to the combined effects of predation by mink and White-tailed Sea Eagles *Haliaeetus albicilla*, cholera outbreaks and mass starvation events has also been attributed as a driver of population declines beginning around 2000, as well as a male-biased sex ratio (Tjørnløv *et al.* 2019). In contrast, Allen *et al.* (2019) found lower survival rates in males in Maine, possibly due to higher harvest pressure. Allen *et al.* (2019) also suggested that many of Maine's coastal islands are now unsuitable for nesting because of excessive human disturbance and loss of necessary nesting habitat. Similar suggestions have been made about habitat suitability on breeding islands in Nova Scotia, where changes in vegetation, in some cases facilitated by the formation of cormorant *Phalacrocorax* sp. colonies, may reduce available protective cover and increase vulnerability to predation (Tomlik *et al.* 2023). The marine foraging environment has also undergone significant changes, including large, long-term declines in Blue Mussels *Mytilus edulis* (Canadian Wildlife Service Waterfowl Committee 2017; Sorte *et al.* 2017), the eiders' preferred prey. Disentangling the relative contributions of various factors explaining the severely reduced number of eiders returning to breed in the southwestern Bay of Fundy may not be possible, but the signal is clear that eiders are stressed throughout the Gulf of Maine, and that broadscale factors are at play.

Spring aerial surveys have proven a viable approach for monitoring eider breeding populations in the Bay of Fundy, capturing changes on a spatial and temporal scale that would be otherwise challenging to document. We are confident in the use of spring counts of males as a proxy for breeding abundance in the Bay of Fundy, as previous work has shown a close correlation between ground-based estimates from nest counts and aerial estimates of breeding numbers, where the ratio of adult males to nests was 1.04:1 at colonies in the Grand Manan Archipelago (Ronconi & Wong 2003). The survey protocol may not work as well in other parts of the breeding range. Earlier attempts to evaluate feasibility in the Gulf of St. Lawrence in Quebec showed low repeatability in counts among days, likely due to much higher overall numbers of nesting birds and higher day-to-day flux in local numbers of males (Gilliland & Lepage 2013). In Nova Scotia, a pilot spring survey observed high numbers of males around islands without suitable nesting habitat, suggesting that migrating birds headed to more northern breeding areas with later nesting phenology are likely mixed in with local Nova Scotia breeders (M. English, Environment and Climate Change Canada, unpubl. data). The feasibility of surveying only around islands with known colonies requires further assessment. Regardless, for New Brunswick, these surveys are a critical monitoring scheme. We suggest that continued investment in spring eider surveys in the Bay of Fundy is highly warranted, as it provides a key index of the status of American Common Eiders in the southern part of their breeding range and of the broader ecosystem.

The Grand Manan Archipelago remains a stronghold for nesting *dresseri* eiders in the southwestern Bay of Fundy, although both nest counts (Ronconi & Wong 2003) and aerial surveys (Mawhinney *et al.* 1999; Bowman *et al.* 2015; this study) show that significantly fewer birds nest there now compared to 30 years ago. The relatively low abundance of eiders across the Bay of Fundy in general will inevitably have ecosystem consequences given their position in the trophic food web as important predators and prey (Hamilton 2000) and will also have societal and cultural impacts given their traditional importance for subsistence and sport hunting. The Sea Duck Joint Venture has taken a crucial step in designating "Sea Duck Key Site 66: Southwestern Bay of Fundy, New Brunswick" as an area critical to sea ducks which should be prioritised for habitat conservation and protection efforts (Bowman *et al.* 2022), an area that falls nearly entirely within the extent of our aerial surveys. Our findings emphasise the urgency of this prioritisation as well as the importance of continued monitoring, and that the Grand Manan Archipelago is a key area in which to focus management efforts and further research. This empirical evidence of declines and current distribution should play a role in informing the conservation, harvest or habitat management decisions of waterfowl managers in New Brunswick and more broadly, across the international range of the subspecies.

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Photograph: Male (white) and female (brown) American Common Eiders during spring aerial surveys over the Bay of Fundy, New Brunswick, Canada in 2006, by Scott Gilliland.

