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Research Paper

Seabird bycatch in a Baltic coastal gillnet fishery is orders of magnitude larger than official reports

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ABSTRACT. Bycatch, or the incidental capture of non-target species in fisheries, has been identified as one of the major threats affecting seabird populations worldwide. In the Baltic Sea, a globally important area for wintering seabirds, bycatch in gillnets represents an important cause of human-induced mortality for seabird species whose populations have declined significantly in recent decades. Although countries are required by European law to report official bycatch data, a lack of data on bycatch in small-scale fisheries impedes an assessment of the contribution of bycatch to declines of seabird populations. This study presents data on the total seabird bycatch in the small-scale coastal fishery for an entire country, Lithuania, in the southeastern Baltic Sea, during the 2015–2020 winter period. An average of 19.3% of the total fishing effort in net-meter days (15.5% of fishing days) were observed each winter season, resulting in observations of 909 bycaught birds from 15 species. Two species composed two-thirds of the total bycatch, Long-tailed Duck (*Clangula hyemalis*; 42.1%) and Velvet Scoter (*Melanitta fusca*; 35.4%). Bycatch composition varied with depth, with the majority of bycatch occurring in nets set at depths ≤ 10 m. Adult males dominated the bycatch of benthivorous sea ducks, whereas adult females composed the majority of piscivorous birds caught. Low numbers of juveniles in the bycatch may indicate different wintering sites for young birds. We estimate that between 1500 and 3000 seabirds were bycaught annually in the Lithuanian small-scale coastal fishery in the 2015–2020 period. Because this number is orders of magnitude larger than the bycatch officially reported by the Lithuanian authorities (six birds), our study highlights deficiencies in the country's current bycatch reporting. In contrast to official statistics based on inadequate data, the unintended capture of seabirds in gillnets remains high, despite financial investments to minimize the impact of fisheries on biodiversity.

Les captures accidentelles d'oiseaux aquatiques par la pêche côtière au filet maillant en mer Baltique sont nettement plus nombreuses que ne le disent les rapports officiels

RÉSUMÉ. Les captures accidentelles d'espèces non ciblées par la pêche ont été identifiées comme l'une des menaces majeures pour les populations d'oiseaux aquatiques du monde entier. Dans la mer Baltique, une zone mondialement importante pour les oiseaux aquatiques migrateurs, les prises accidentelles dans des filets maillants représentent une cause importante de mortalité induite par l'homme pour les espèces d'oiseaux aquatiques dont les populations ont nettement décliné depuis plusieurs décennies. Même si les pays sont tenus par la loi européenne de rapporter les données officielles de prises accidentelles, un manque de données sur les captures accidentelles dans les petites pêcheries nuit à l'évaluation de la contribution de ces prises au déclin des populations d'oiseaux aquatiques. Cette étude présente les données concernant le total des captures accidentelles d'oiseaux aquatiques par les petites pêcheries côtières d'un pays entier, la Lituanie, au sud-est de la mer Baltique, pendant l'hiver au cours de la période 2015-2020. On a observé en moyenne 19,3 % de la pêche en activité nette (15,5 % des jours de pêche) au cours de chaque saison hivernale, et constaté que 909 oiseaux appartenant à 15 espèces avaient été capturés accidentellement. Deux espèces représentaient les deux tiers du total des prises accidentelles : la harelde boréale (*Clangula hyemalis* 42,1 %) et la macreuse brune (*Melanitta fusca* 35,4 %). La composition des prises accidentelles variait selon la profondeur, la majorité de ces captures survenant dans des filets placés à des profondeurs < 10 m. Les canards de mer mâles adultes benthivores étaient les plus représentés, alors que les femelles adultes représentaient la majorité des oiseaux piscivores capturés. Le faible nombre de jeunes oiseaux capturés accidentellement pourrait indiquer que les jeunes oiseaux passent l'hiver sur des sites différents. On estime que 1500 à 3000 oiseaux de mer ont été capturés chaque année par les petites entreprises lituaniennes de pêche côtière au cours de la période 2015 à 2020. Comme ce nombre est beaucoup plus élevé que celui des captures accidentelles rapportées par les autorités lituaniennes (six oiseaux), notre étude met en évidence les carences du système de rapport actuel des captures accidentelles dans ce pays. Contrairement aux statistiques officielles basées sur des données inadéquates, la capture involontaire d'oiseaux de mer dans les filets maillants reste élevée, malgré des investissements financiers visant à minimiser l'impact des pêcheries sur la biodiversité.

Key Words: *Baltic Sea; bycatch composition; gillnets; seabirds; sea ducks; small-scale fishery*

INTRODUCTION

Bycatch, or the unintended capture of non-target species, is one of the major causes of mortality for marine animals such as seabirds, sea turtles, and cetaceans (Tasker et al. 2000, Lewison et al. 2014, Northridge et al. 2017). Along with other types of human-induced mortality, bycatch represents a major threat to many different groups of birds (Žydelis et al. 2009, Pott and Wiedenfeld 2017, Dias et al. 2019). For instance, gillnet fisheries are responsible for the drowning of 400,000 seabirds each year globally (Žydelis et al. 2013). The number of birds killed as bycatch annually in gillnet fisheries in the North and Baltic Seas has been estimated at 100,000 to 200,000 (Žydelis et al. 2009), of which an estimated 76,000 birds are killed in the Baltic Sea (Žydelis et al. 2013). This mortality primarily comprises species that are either benthivorous, e.g., sea ducks, or piscivorous, e.g., loons, auks, grebes (Dagys and Žydelis 2002, Österblom et al. 2002, Larsson and Tydén 2005, Tarzia et al. 2017, Marchowski et al. 2020). Such species are susceptible to bycatch because their foraging frequently occurs in shallow waters favored for gillnet fishing (Urtans and Priednieks 2000).

The Baltic Sea is globally important for wintering sea ducks, particularly Long-tailed Ducks (*Clangula hyemalis*) and Velvet Scoters (*Melanitta fusca*). Gillnets remain ubiquitous fishing gear for commercial fishers (ICES 2020a) in the area. Because sea ducks are vulnerable to bycatch, the Baltic Sea coastal fisheries represent one of their most pressing threats (Žydelis et al. 2009). Sea duck population declines of over 50% have been recorded since the early 1990s (Skov et al. 2011, BirdLife International Europe & Central Asia 2019), but the contribution of bycatch to seabird-number declines is unknown, because of a lack of reliable data on the quantity of birds being killed at national levels.

Several European Union (EU) regulations address the bycatch of sensitive species, including the Common Fisheries Policy and the Marine Strategy Framework Directive. In 2012 the European Commission (EC) established an action plan for reducing incidental catches of seabirds in fishing gear (European Commission 2012) with the objective to minimize and, where possible, eliminate the incidental catches of seabirds. The action plan calls on member states to estimate fisheries' impacts on seabirds and look for effective solutions to reduce incidental catches. However, most of the actions have never been implemented (ICES 2020b) and seabird bycatch remains an unresolved problem that is difficult to quantify without adequate data.

In most EU member states, bird bycatch data are collected through non-dedicated programs conducted under the data collection framework. However, this approach is not effective in obtaining accurate estimates of the number of birds affected (ICES 2020b). The few dedicated bycatch sampling programs that have been implemented were limited in time and space (ICES 2018). In addition, the total seabird bycatch in EU waters cannot be quantified, because there is no official requirement to collect fishery data from small-scale coastal fisheries (vessels < 12 m length), despite the impact of the large quantity of such fisheries on seabirds (ICES 2018, 2020b). There is therefore an urgent need to quantify bycatch in small-scale coastal fisheries, and to determine the demographic structure of bycaught species to

understand the impact of bycatch on affected long lived seabird populations, because mortality of reproductive-age birds can potentially have large population effects (Koneff et al. 2017).

In the southeastern Baltic Sea, bycatch in the Lithuanian small-scale coastal fleet was described in 2002 and 2009 (Dagys and Žydelis 2002, Dagys et al. 2009, Žydelis 2009) but no recent estimates of the total bird bycatch exist. Despite a reduction in the number of fishers in Lithuania by 50% from 2008 to 2018 (Ložys 2018), and a concomitant decrease in overall fishing effort, bycatch still occurs and its magnitude is poorly known. Approximately 1000 seabirds were estimated to be killed annually in gillnets set by small-scale vessels up to 10 m length in the period 2015–2017 in Lithuania (Tarzia et al. 2017). According to European law, the Lithuanian government, through its data collection framework program, should officially report magnitude of bycaught seabirds. However, it reported no bycatch of birds in 2015 (with no observed effort) and did not submit reports for 2016, 2017, or 2018. In 2019 Lithuania reported six incidents of bird bycatch in its gillnet fishery, three birds in spring and three in autumn (ICES 2017, 2018, 2019, 2020b). Therefore, strong mismatches exist between official and actual bycatch numbers and past estimates, requiring a robust assessment of actual bycatch in Lithuanian waters between 2015 and 2020 to evaluate the accuracy of officially reported statistics. Such assessments are critical to what extent bycatch may impact seabird populations.

In this study, we estimated the seabird bycatch in the small-scale coastal fishery along the entire Lithuanian Baltic Sea coastal zone (92 km) for a five-year period. We collected data on bycaught birds in gillnet and fish-trap fisheries, and extrapolated the observed bycatch rate to the entire annual small-scale fishing fleet in Lithuania. Although not required under the EU Control Regulation (Council of the European Union 2009), fishery data from vessels up to 12 m in length were collected according to Lithuanian national regulations (Council of the European Union 2013). We used these fishing effort data for gillnets and fish traps to extrapolate annual seabird bycatch and compared these estimates with the officially reported number of bycaught seabirds as required by EC legislation (Reg. 812/2004). Collaboration with fishers allowed us to collect detailed information on the depths at which nets were set, and to assess the bycatch composition, including age and sex, of the bycaught birds.

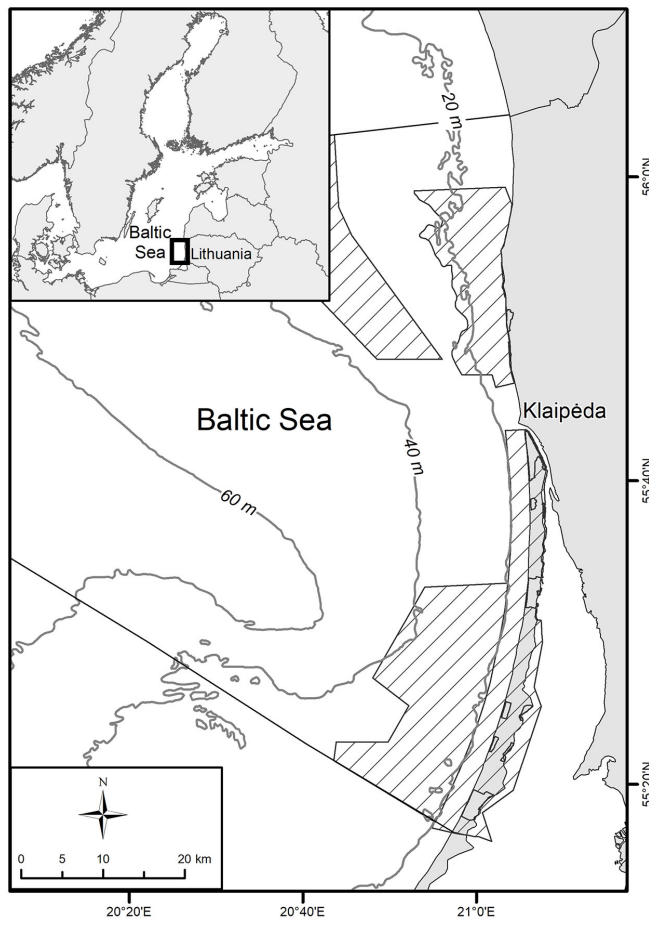
METHODS

Site description

The study area covers the entire Lithuanian coast (92 km) in the southeastern part of the Baltic Sea (Fig. 1). The coastal zone, which includes waters down to 20 m in depth, covers the area out to 2 km from the coastline at the Curonian Spit and out to 9 km from the mainland (Olenin and Daunys 2004). The majority of fishing effort occurs in the coastal zone. However, depending on the target species, fishers may go farther from the coast. The diversity of bottom types determines the diversity of benthic communities (Olenin and Daunys 2004) and influences the distribution of wintering seabirds. From October to May the Lithuanian coastal zone serves as a wintering area for internationally significant concentrations of benthivorous ducks

and piscivorous waterbirds (Durinck et al. 1994, Vaitkus 1999). Natura 2000 sites (Special Protected Areas) designated for protection of Velvet Scoter, Red-throated Loon (*Gavia stellata*), Steller's Eider (*Polysticta stelleri*), Razorbill (*Alca torda*), and Common Merganser (*Mergus merganser*) cover a large proportion of the coastal zone (Raudonikis 2004).

Fig. 1. Study site comprises the entire coast of the Lithuanian Baltic Sea coastal zone. Diagonal-striped polygons indicate NATURA2000 sites. Most of the fishing effort of the small-scale fleet occurs in the coastal shallow waters (down to 20 m deep).



The Lithuanian small-scale coastal fishing fleet comprises approximately 54 fishing enterprises, which mostly fish for Atlantic cod (*Gadus morhua*), European Flounder (*Platichthys flesus*), European Smelt (*Osmerus eperlanus*), Baltic Herring (*Clupea harengus membras*), and Turbot (*Scophthalmus maximus*) in autumn, winter, and spring (Ložys 2018). In October the primary target species are Atlantic cod and European Flounder (nets with 40 to 80 mm mesh size), later in the season, from December to April, Smelt and Baltic Herring (15 to 22 mm) are targeted, and then Turbot in April and May (100 to 110 mm).

Data collection

Wintering bird census data were collected by the Lithuanian Ornithological Society during midwinter (January). Bird counts

consisted of standard scan counts of flocks of waterbirds observed from shore-based observation points that were spaced 1 km apart and allowed birds to be recorded up to 2 km out at sea.

Bird bycatch data were collected over a five-year period from October 2015 to May 2020 covering the seabird wintering period from October to May in five consecutive winters. Each winter the data collection covered between six and eight small-scale fishing enterprises using vessels of < 12 m length, and the observed fishing effort is reported in net meter days (NMD) calculated by multiplying the length of the gillnet or the number of fish traps by the soaking time in days (FTD). Both gillnet and trap fisheries were covered and fishermen were contracted to provide bycatch data by completing data collection sheets, or to allow an observer onboard their vessels to collect data. Three fishermen opportunistically reported 35 seabird bycatch events without completing formal datasheets on the associated fishing effort. These data were therefore only used for the description of bycatch composition. Bycaught birds that did not fall back into the sea during hauling of nets were tagged with unique plastic identity tags and kept frozen for further analysis. In addition to data on bird bycatch, we collected information on gear type, gear metrics (net length and gillnet mesh size), bird bycatch depth, soak time, and location for sets in which bycatch was recorded. Bycaught birds were dissected at the Marine Research Institute of Klaipėda University to determine their age and sex following the methodology described by Van Franeker (2004). Although most of the bycaught birds were sexed and aged, several carcasses could not be collected by on-board observers and were only self-reported and/or photographed. Special permission to collect bycaught bird carcasses from fishers was granted by the Environmental Agency of the Lithuanian Ministry of Environment.

Fishing effort data for the entire small-scale coastal fleet for the winter period, October to May, for the years 2015–2020 were received from the Fishery Service under the Ministry of Agriculture. Fishing effort data were combined with the bycatch data to estimate the total number of bycaught birds during the winter season of each year for the different gear types.

Official bycatch data of Lithuania were taken from reports of the International Council for the Exploration of the Sea (ICES) Working Group on Bycatch of Protected Species (WGBYC). Member countries submit reports of bycatch of protected species, i.e., marine mammals, seabirds, reptiles, and fish, to the European Commission.

Data analysis

We examined whether the proportion of seabirds caught in each of the three target fisheries was proportional to the observed effort in the respective fishery using a Chi-squared test. We tested whether bycatch occurred at random or was more intense in a certain fishery, but again caution that the type of fishery includes seasonal, depth, and mesh variation, and the underlying cause of any differences could not be determined in our experimental design.

We examined whether seabirds were caught at different depths by using the non-parametric Kruskal-Wallis or Wilcoxon-rank tests to compare the depth among several or between two similar

Table 1. Recorded numbers of bycaught seabirds in Lithuanian small-scale fisheries (2015–2020).

| Family | Species | IUCN conservation status | Smelt and Baltic Herring (Gillnets 15-22mm) | Cod and Plaice (Gillnets 40-80mm) | Turbot and Plaice (Gillnets 110mm) | Smelt and Baltic Herring (Fish-trap) | Total Number | % |
|-------------------|------------------------|--------------------------|---|-----------------------------------|------------------------------------|--------------------------------------|--------------|------|
| Gaviidae | Black-throated Loon | LC | 4 | 2 | | | 6 | 0.7 |
| | Red-throated Loon | LC | 35 | 16 | | | 51 | 5.6 |
| Podicipedidae | Great Crested Grebe | LC | 8 | 11 | | | 19 | 2.1 |
| | Red-necked Grebe | LC | | 1 | 1 | | 2 | 0.2 |
| Phalacrocoracidae | Great Cormorant | LC | 3 | 2 | 6 | 3 | 14 | 1.5 |
| Anatidae | Greater Scaup | VU | | 1 | | 1 | 2 | 0.2 |
| | Common Goldeneye | LC | 1 | 1 | | | 2 | 0.2 |
| | Long-tailed Duck | VU | 259 | 61 | 2 | | 322 | 35.4 |
| | Velvet Scoter | VU | 187 | 151 | 45 | | 383 | 42.1 |
| | Common Scoter | LC | 43 | 9 | 3 | | 55 | 6.1 |
| | Common Merganser | LC | 2 | | | | 2 | 0.2 |
| | Red-breasted Merganser | NT | | | 1 | | 1 | 0.1 |
| Laridae | European Herring Gull | NT | | 1 | | | 1 | 0.1 |
| Alcidae | Razorbill | NT | | 5 | | | 5 | 0.6 |
| | Common Murre | NT | | 40 | 4 | | 44 | 4.8 |
| | Total Number | | 542 | 301 | 62 | 4 | 909 | |
| | % | | 59.6 | 33.1 | 6.8 | 0.4 | | 100 |

species. These comparisons provide coarse information on the depth at which the different species are primarily caught. We caution, however, that because nets are set at different depths for different target species, and these target species are pursued at different times of the year and with different mesh sizes, two confounding factors exist that may have contributed to observed differences of depth.

Assessment of total seabird bycatch

The bycatch data collected from October to May between 2015 and 2020 were used to extrapolate the total bycatch per wintering season along the Lithuanian coastline (92 km). Our analysis did not examine the spatial variation of fisheries across coastal areas because we used real fisheries data from the whole area of interest. Because of the absence of most migratory waterbirds from May to September, bycatch is infrequent during these months and data were not included in the extrapolation. To extrapolate the total number of seabirds likely caught during the winter season by the Lithuanian small-scale coastal fleet annually, we first calculated the bycatch per unit effort (BPUE) as the number of seabirds (of all species, and separately for the two most common species) bycaught, divided by the net length and the soak time of the net (NMD), or the size and the soak time of the fish trap (FTD), for each observed net or trap deployment. We then calculated 95% bootstrapped confidence intervals around the mean BPUE for each month and for each winter season to account for the different phenology and temporal variation in seabird presence in the Lithuanian Baltic Sea (Field et al. 2019). We randomly drew n samples with replacement from all n observed fishing days in a particular month, and repeated this process 10,000 times to obtain a mean and 95% confidence intervals for the monthly BPUE. We then obtained the total fishing effort and multiplied the BPUE in each month by the total fishing effort to extrapolate the total number of bycaught seabirds in each month. For each winter season we calculated a mean estimate and 95% confidence intervals.

RESULTS

We observed a total of 11,861 gillnet fishing days, which, including net length, resulted in a total of 14,424,666 NMD; and 6690 days where fish traps were used, a total of 5,659,790 FTD between October and May across five winter seasons, 2015/2016 to 2019/2020. In the gillnet fishery the effort targeting Atlantic cod and European flounder was observed for 5,396,145 NMD (26.9%), Smelt and Baltic herring for 13,159,751 NMD (65.5%), and turbot for 1,528,560 NMD (7.6%). The observed fishing effort where bycatch data was available represented on average 19.3% of the total fishing effort (observer coverage) in terms of NMD, and varied slightly among years (19.7% in 2015/2016; 20.1% in 2016/2017; 21.4% in 2017/2018; 17.7% in 2018/2019; and 17.5% in 2019/2020).

Composition of seabird bycatch

In total, during the period 2015–2020, 909 birds were recorded as bycatch, comprising 15 species belonging to six families. In the winter 2015/2016 135 individuals were bycaught, with 211 individuals in 2016/2017, 143 individuals in 2017/2018, 246 individuals in 2018/2019, and 174 individuals in 2019/2020. Of the 909 birds bycaught, gillnets were responsible for catching 905 birds, whereas four birds of two species were caught in fish traps (Table 1). The majority of bycaught birds (59.6%) were recorded in the European Smelt and Baltic Herring gillnet fisheries, with the second largest amount in the cod and European flounder fishery (33.1%; Table 1). Of the fishing trips where bycatch was observed ($n = 251$ trips), five or more birds were caught during 22.7% of these trips ($n = 57$ trips) with a maximum of 41 individuals caught in a single trip. Between one and four birds were bycaught during the remaining trips where bycatch occurred (77.3%; $n = 194$ trips).

The most frequently bycaught seabirds were Long-tailed Ducks (42.1% of the total bycaught birds) and Velvet Scoters (35.4%), followed by Common Scoters (*Melanitta nigra*; 6.1%), Red-

Table 2. Monthly seabird bycatch composition by age and sex for the six most frequently captured seabird species in gillnets during the period of 2015–2020 in the study area.

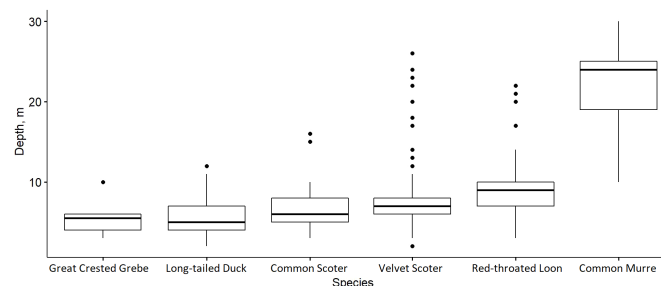
| Species | Sex and Age | Oct. | Nov. | Dec. | Jan. | Feb. | March | April | May | Total | % | |
|---------------------|-------------------|-------------------|------|------|------|------|-------|-------|-----|-------|------|------|
| Red-throated Loon | Female | Adult | | 6 | 7 | | 1 | | | 14 | 27.5 | |
| | | Juvenile/Immature | | 1 | 8 | 2 | | | | | 11 | 21.6 |
| | Male | Adult | | | 5 | | 1 | | | | 6 | 11.8 |
| | | Juvenile/Immature | | 1 | 5 | 1 | | 2 | | | 9 | 17.6 |
| | Unknown | Adult | | 1 | | 2 | | 1 | | | 4 | 7.8 |
| | | Juvenile/Immature | | | 4 | 1 | | 1 | | | 6 | 11.8 |
| | Unknown | | | | 1 | | | | | 1 | 2.0 | |
| Great Crested Grebe | Female | Adult | | 3 | | 1 | 1 | 2 | | 7 | 36.8 | |
| | | Juvenile/Immature | | | | 1 | | | | 1 | 5.3 | |
| | Male | Adult | | | 1 | 1 | 3 | | | 5 | 26.3 | |
| | | Juvenile/Immature | | | | 1 | 1 | | | 2 | 10.5 | |
| | Unknown | Adult | 1 | | | | 1 | | | | 2 | 10.5 |
| | | Unknown | | | 1 | | 1 | | | | 2 | 10.5 |
| Long-tailed Duck | Female | Adult | | 1 | 4 | 25 | 24 | 26 | | 80 | 24.8 | |
| | | Juvenile/Immature | | 1 | 1 | 4 | 11 | 11 | | 28 | 8.7 | |
| | Male | Adult | | 1 | 15 | 37 | 79 | 71 | 3 | 1 | 207 | 64.3 |
| | | Juvenile/Immature | | | | | 2 | 4 | | | 6 | 1.9 |
| | Unknown | Unknown | | | | | 1 | | | | 1 | 0.3 |
| | | Unknown | | | | | | | | | 1 | 0.3 |
| Velvet Scoter | Female | Adult | 1 | 8 | 17 | 51 | 38 | 19 | 1 | 1 | 136 | 35.5 |
| | | Juvenile/Immature | | 1 | 2 | 1 | 2 | 2 | 1 | 7 | 16 | 4.2 |
| | Male | Adult | 2 | 14 | 40 | 75 | 34 | 19 | 12 | 12 | 208 | 54.3 |
| | | Juvenile/Immature | | | 3 | 1 | 1 | | | 13 | 18 | 4.7 |
| | Unknown | Unknown | | | | 2 | 3 | | | | 5 | 1.3 |
| | | Unknown | | | | | | | | | 5 | 1.3 |
| Common Scoter | Female | Adult | | 1 | 1 | | 1 | 1 | | 1 | 5 | 9.1 |
| | | Juvenile/Immature | | | | 2 | 3 | 4 | 1 | | 10 | 18.2 |
| | Male | Adult | | | 2 | | | | | | 2 | 3.6 |
| | | Juvenile/Immature | 1 | 1 | 2 | 4 | 5 | 13 | 1 | | 27 | 49.1 |
| | Unknown | Adult | | | | 2 | 5 | 1 | 1 | 1 | 11 | 20.0 |
| | | Adult | | | | | | | | | 11 | 20.0 |
| Common Murre | Female | Adult | 1 | | | | | 1 | 2 | 4 | 9.1 | |
| | | Juvenile/Immature | 4 | 1 | | | | | | | 5 | 11.4 |
| | Male | Adult | | | | | | | | | 3 | 6.8 |
| | | Juvenile/Immature | 10 | | 1 | | | | 4 | 1 | 16 | 36.4 |
| | Unknown | Adult | | | 4 | | | | 1 | | 6 | 13.6 |
| | | Unknown | | | | | | | | | 3 | 6.8 |
| | Adult | 3 | | | | | | | | 3 | 6.8 | |
| | Juvenile/Immature | | | | | | 2 | | 1 | 3 | 6.8 | |
| | Unknown | | | 1 | | | | | | 1 | 2.3 | |
| | Unknown | | | 2 | | | | | | 3 | 6.8 | |
| | Grand Total | 30 | 35 | 127 | 226 | 214 | 177 | 25 | 40 | 874 | | |

throated Loons (5.6%), Common Murres (*Uria aalge*; 4.8%) and Great Crested Grebes (*Podiceps cristatus*; 2.1%). Occasionally, Black-throated Loons (*Gavia arctica*), Razorbills, and Common Mergansers were also recorded as bycatch. The distribution of bycatch depths for the most frequently bycaught seabird species varied significantly (Kruskal-Wallis, $p < 0.001$; Fig. 2). The depths at which Great Crested Grebes (5.2 ± 1.7 m) and Long-tailed Ducks (5.5 ± 1.9 m) were caught were similar (Wilcoxon test, $p = 0.6$). Bycatch depths of Common Scoters and Velvet Scoters were significantly deeper than those of Long-tailed Ducks (Wilcoxon test, $p = 0.0001$ and $p < 0.001$, respectively) reaching mean depths of 6.8 ± 2.5 m and 7.7 ± 3.6 m, respectively. Bycatch depths of Red-throated Loons (9.7 ± 5.2 m) and Common Murres (22.2 ± 4.3 m) were significantly deeper than the above-mentioned species (Wilcoxon test, $p < 0.001$).

Long-tailed Duck bycatch was dominated by males (66.1% of the total), and 1.9% of these were juvenile and immature birds, whereas 8.7% of females were juvenile birds (Table 2). For Velvet Scoters, bycatch of males represented 59%, of which 4.7% were juveniles, similar to the proportion of juvenile or immature females (4.2%). More than 50% of juveniles of both sexes were

bycaught in May. In contrast, the demographic composition of piscivorous birds was dominated by females. Red-throated Loon males constituted just 29.5%, with juveniles representing 17.6%, whereas juvenile or immature females represented 21.6% of all bycaught females (Table 2).

Fig. 2. Depths of bycaught birds in the small-scale coastal fishery. Species were sorted in order of increasing mean depth.



More than 50% of juveniles of both sexes were

Table 3. Extrapolated total numbers with bootstrapped 95% confidence intervals for Long-tailed Ducks, Velvet Scoters, and all seabirds bycaught in gillnets in winters 2015–2019 in the Lithuanian coastal zone. Note that 13 other species were captured at lower frequency in addition to the two specified duck species. Only the starting year of a given winter season is shown, i.e., “2015” starts in October 2015 and ends in April 2016. International Waterbird Census (IWC) data reflect the maximum number of individuals during the midwinter counts; due to imperfect detection and seasonal turnover these counts may underrepresent the total number of birds using the Lithuanian coastal zone, thus leading to unrealistic bycatch proportions (> 100%).

| Season | Species | IWC | Mean extrapolated bycatch | Lower 95% bycatch | Upper 95% bycatch | Proportion of observed wintering birds in bycatch (%) |
|-----------|------------------|-------|---------------------------|-------------------|-------------------|---|
| 2015-2016 | All seabirds | 9579 | 2998 | 48 | 7965 | 31.3 |
| | Long-tailed Duck | 1004 | 499 | 3 | 1339 | 49.7 |
| | Velvet Scoter | 6045 | 2247 | 46 | 6291 | 37.2 |
| 2016-2017 | All seabirds | 7257 | 3212 | 431 | 7787 | 44.3 |
| | Long-tailed Duck | 470 | 804 | 67 | 1942 | 171.1 |
| | Velvet Scoter | 4024 | 2200 | 19 | 5659 | 54.7 |
| 2017-2018 | All seabirds | 9397 | 819 | 98 | 1769 | 8.7 |
| | Long-tailed Duck | 247 | 415 | 51 | 1017 | 168.0 |
| | Velvet Scoter | 6912 | 172 | 0 | 499 | 2.5 |
| 2018-2019 | All seabirds | 10491 | 2633 | 227 | 6827 | 25.1 |
| | Long-tailed Duck | 292 | 1902 | 87 | 5213 | 651.4 |
| | Velvet Scoter | 5762 | 376 | 3 | 952 | 6.5 |
| 2019-2020 | All seabirds | 10302 | 1074 | 272 | 2045 | 10.4 |
| | Long-tailed Duck | 991 | 494 | 59 | 1108 | 49.8 |
| | Velvet Scoter | 5063 | 478 | 44 | 1137 | 9.4 |

Lithuania officially reported no bycatch of birds in 2015 (with no observed effort) and did not submit reports for 2016, 2017, or 2018. In 2019, Lithuania reported six incidents of bird bycatch in its gillnet fishery, three birds in spring and three in autumn (ICES 2017, 2018, 2019, 2020b).

Extrapolation of total annual seabird bycatch

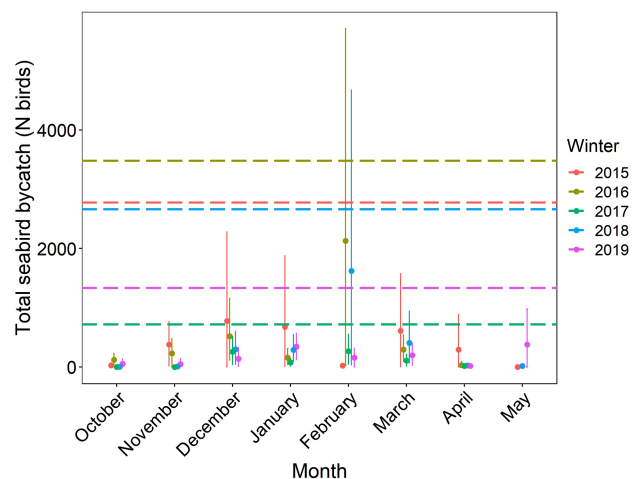
Out of the total of 909 bycaught birds, 874 birds were reported during 18,551 fishing days covering the five winter seasons (between October and May), whereas the remaining 35 birds were reported anonymously by fishermen as bycatch without fishing effort data and are therefore excluded from the extrapolations below. The mean BPUE in each month ranged from zero (in May 2015, October 2017, and November 2017) to 3.7 birds/1000 NMD (February 2018). Monthly total fishing effort ranged from 80,510 NMD (October 2019) to 1,619,775 NMD (May 2015). Bycatch in fish traps was lower, with four out of 90 observed fish trap deployments (4.4%) resulting in bycatch (a single individual in all four cases).

Although the overall fishing effort was largest in the smelt and herring fishery (54.1% of NMD), the proportion of bycatch was disproportionately higher than would be expected based on the distribution of fishing effort alone. By contrast, bycatch in the cod and flounder (35.2% of NMD) and in the turbot and flounder (10.6% of NMD) fisheries was lower than expected, based on fishing effort (χ^2 test = 74.68, $p < 0.001$).

The extrapolated total number of seabirds bycaught per month in gillnets ranged from zero to more than 1600 (in February 2017 and 2019; Fig. 3). The total number of bycaught birds per winter clustered into two groups, with two winters (2017/2018 and 2019/2020) totaling around 1000 birds, and the other three winters totaling around 3000 birds (Fig. 3). Given the large uncertainty in BPUE, the 95% confidence intervals of the total extrapolated

number spanned two orders of magnitude (Table 3). Although our extrapolations are solely based on gillnets, the low bycatch rate of birds in fish traps would only increase the total bycatch in the Lithuanian Baltic by around zero to 50 birds in any given winter, which is an order of magnitude lower than the error margin in the bycatch estimates from gillnets alone.

Fig. 3. Extrapolated total number of seabirds bycaught in gillnets in each of five successive winters from 2015–2019 in the Lithuanian Baltic Sea coastal zone. Dashed horizontal lines indicate the mean total for each winter season, whereas points show the monthly total number with bootstrapped 95% confidence intervals. Note that only the starting year of a given winter season is shown, i.e., “2015” starts in October 2015 and ends in April 2016.



The total seasonal bycatch of the two most frequently caught species (Velvet Scoter and Long-tailed Duck) ranged from 172 to 2247 individuals (Table 3). Monthly BPUE ranged from zero to 3.4 Long-tailed Ducks / 1000 NMD and from zero to 1.8 Velvet Scoters / 1000 NMD in different months and years. The monthly total bycatch ranged from zero to 1538 (95% confidence interval: 14 to 4,432) for Long-tailed Ducks and from zero to 1736 (95% CI: zero to 4650) for Velvet Scoters, highlighting the temporal variation in seabird bycatch in the gillnet fishery.

Comparing the mean seasonal extrapolated bycatch with data from the international waterbird census data for the Lithuanian Baltic Sea reveals that between 8.7 to 44.3% of wintering birds may be bycaught annually in the Lithuanian coastal gillnet fishery (Table 3). The numbers of bycaught Long-tailed Ducks were significantly higher than the recorded number in midwinter counts and depending on the year varied from 49.7% to 651.4%. Much lower numbers were estimated for Velvet Scoters of between 2.5 to 54.7% of the birds recorded during midwinter counts.

DISCUSSION

Despite EU legislation to reduce the bycatch of seabirds, bycatch remains an important threat in the Baltic Sea. Our study shows that annual seabird bycatch by the Lithuanian small-scale coastal fleet, based on data covering five winter seasons, has not decreased from a previous estimate from 2005 to 2009 (Dagys et al. 2009) despite a 50% reduction in the size of the fishing fleet. We estimated that every winter ~1000 to 3000 seabirds are killed as bycatch in Lithuanian fisheries alone, whereas the level of bycatch formally reported by Lithuanian authorities to the EU is orders of magnitude lower. Bycatch remains high despite financial investments to minimize the impact of fisheries on biodiversity, and the dramatic declines in the number of seabirds wintering in the Baltic Sea may be one of the consequences of bycatch in gillnet fisheries.

The bycatch recorded during this study was based on observations covering an average of 19.3% of total fishing days over a five-year period in the small-scale coastal fishery during the winter season, and thus a fairly high proportion of the overall fishing effort. Nonetheless, given the extremely skewed distribution of episodic bycatch events, a very high proportion (~70%) of fishing trips would need to be monitored to adequately quantify the levels of bycatch in a fishery (Glemarec et al. 2020). Lithuania has not followed the Data Collection Framework under Regulation (EU) 2019/1241, submitting only two annual reports to the European Commission during our five-year study period. These reports indicated no bycatch in 2015–2018 and six birds in 2019, whereas our data show that during the same period at least 909 individual birds were bycaught in just eight small-scale fishing enterprises. In each of the reports submitted by Lithuania it is stated that there is no scheme of sensitive species bycatch monitoring. Thus, the level of seabird bycatch that occurs every winter in Lithuania is grossly misrepresented by formal reports to the European Commission. This lack of accurate data on the occurrence and level of bycatch greatly impedes the implementation of solutions to address the problem. To minimize the effect of bycatch on seabirds it is necessary to improve the collection of data from small-scale fisheries, including data on the bycatch of sensitive species such as seabirds, and for more precise counts of wintering birds in order to interpret bycatch rates in the context of changes

to fishing effort and populations (Tuck 2011). If our results are representative of similar situations in neighboring countries whose coastlines are longer and where fishing effort is correspondingly larger, this could represent a significant additional mortality. If annual bycatch removes more than 5 to 7% of a population (Koneff et al. 2017), the mortality from bycatch can lead to population declines of sensitive species (Bellebaum et al. 2013).

We extrapolated that ~1000 to 3000 birds were bycaught annually during the winter seasons from 2015 to 2020 in the Lithuanian small-scale coastal Baltic Sea fishery, but because of the skewed distribution of bycatch events these extrapolations are surrounded by considerable uncertainty. The estimated bycatch in winters 2017–2018 and 2019–2020 was much lower than in the other three winters covered by our study, likely because of much lower fishing effort in those winters. Despite the large uncertainty and annual variation, our extrapolations are comparable to the estimate of 1000 to 1500 birds bycaught in 2015–2017 in a subset of the fleet (Tarzia et al. 2017), and lower than the estimate of 3000 to 5000 birds from 2009 (Dagys et al. 2009) when the abundance of birds was two to three times higher than during our study period (Šniaukšta 2015, 2018). The lower abundance of wintering seabirds in the southern Baltic (Skov et al. 2011) may explain the declining number of bycatch victims, but more data would be required to assess the proportion of populations that are killed annually: our census data indicated that a very large proportion (> 40%; Table 3) of observed Long-tailed Ducks may be killed, which could have population-level consequences for the species (Koneff et al. 2017). The International Waterbird Census is carried out once per wintering season and therefore only captures a snapshot of bird abundance wintering in coastal areas. In this study, we analyze bycatch during the whole wintering period, during which birds are mobile and the numbers of wintering birds change depending on the month or weather conditions (storms, ice cover in northern Baltic sea parts). Although the Velvet Scoter is more or less sedentary along the Lithuanian coast, Long-tailed Duck numbers fluctuate from a few hundred in December to January, to thousands in February to March, when large numbers appear at the start of spring migration. The bycatch numbers we estimate are realistic and reflect the phenologically changing abundance of birds that is not captured during the midwinter counts.

Three of the bycaught species, i.e., Long-tailed Duck, Velvet Scoter, and Greater Scaup (*Aythya marila*), are classified as Vulnerable on the IUCN Red List (IUCN 2019). The two most frequently bycaught species, i.e., Long-tailed Duck and Velvet Scoter (77.5% of the total), were caught in similar proportions in Poland (71.3%; Stempniewicz 1994) and in a previous Lithuanian study (70%; Žydelis 2002). Bycatch of large numbers of Long-tailed Ducks were also recorded in Latvia, Sweden, and Germany (Urtans and Priednieks 2000, Larsson and Tydén 2005, Bellebaum et al. 2013). Numbers of wintering Long-tailed Ducks in Lithuania vary annually, but do not reach more than 7% of the total number of wintering birds in each year (Šniaukšta 2018). However, our data might underestimate the number of individual birds using the Lithuanian Baltic because of seasonal turnover of individuals. Nonetheless, the high proportion of Long-tailed Ducks in our bycatch data highlights this species' vulnerability to bycatch in gillnets. Bycatch was mentioned as one of the threats

and possible causes of decline for Long-tailed Ducks in Germany (Bellebaum et al. 2013), and may have contributed to the population decline of 80% over the past decades (Skov et al. 2011).

Most species recorded as bycatch do not breed in the Baltic Sea in large numbers, but use the area as a wintering or passage area (Svensson et al. 2010, Loshchagina et al. 2019, Quillfeldt et al. 2021). Of the 40 Common Murres found in fishing nets in this study, 16% had rings indicating that they were from Swedish colonies. A tracking project has shown that sea ducks and loons that are likely suffering from bycatch in the Baltic breed in the Russian Arctic (Dorsch et al. 2019, Karwinkel et al. 2020, Quillfeldt et al. 2021). Therefore, the negative effects of the Lithuanian fishery are manifested in breeding areas in other countries.

The majority of seabirds (99.6%) in our study were bycaught in gillnets, whereas only few individuals were recorded in fish traps. Even though fish traps are becoming more popular among fishermen in Lithuania, they prefer to use gillnets because of the shorter setting time, which is more convenient during the short periods of favorable weather conditions typical in winter. We therefore conclude that at present the threat from fish traps to seabird populations is considerably lower than the threat from gillnets.

We also found considerable differences among fisheries targeting different fish species, but those comparisons are confounded by several factors: fishermen use different mesh sizes, at different depths, and in different seasons to catch different target fish species, and we therefore cannot attribute either of those factors alone to a higher or lower incidence of bycatch. The intermediate mesh size nets of 40 to 80 mm used to catch cod and flounder in shallow depths in early winter were the most dangerous for birds, but our bycatch rate was less than half of that recorded in a previous study (Dagys and Žydelis 2002, Dagys et al. 2009). The fishing quota for cod in the Baltic Sea was reduced annually from 2014 until 2019 when the moratorium on the cod fishery was applied, which likely led to lower cod fishing activities. Another reason for the discrepancy between earlier and current bycatch rates is that bird numbers have declined by about 50% (Skov et al. 2011) and this could explain the reduction (Dagys and Žydelis 2002). In addition, seabird mortality in gillnets with a mesh size of 15 to 22 mm may be higher than recorded because some birds might be entangled by a toe or by the beak in the small mesh and fall back into the water before the net is hauled (J. Morkūnas, *personal communication* with fishers and observers). In our study the fishing effort by NMD for smelt and Baltic herring gillnets was 3.5 times higher than for cod and flounder gillnets, and a proper assessment of seabird's vulnerability to different mesh sizes would require a designated study design to overcome confounding factors.

There was a significant difference in the depth at which birds were bycaught in this study, indicating that different species preferentially forage at different depths. Long-tailed Ducks bycaught in the cod gillnet fishery from 2000 to 2002 in Swedish waters in South of Gotland were hauled from 20 to 30 m depths (Larsson and Tydén 2005). In contrast, in our study, and in studies in neighboring Latvia (Urtans and Priednieks 2000), Long-tailed

Ducks were bycaught in shallower waters, which may reflect the distribution and abundance of their prey along the depth gradient. This also reflects the area where fishing occurs, which depends on the target species. According to Skabeikis et al. (2019), following a strong decline of Blue Mussels (*Mytilus edulis*) in the Lithuanian coastal zone, Long-tailed Ducks mostly foraged on soft-bottom prey items and migratory European Smelt in shallow coastal areas (Forni et al. 2022). Diving ducks choose similar habitats during the whole wintering period (Žydelis et al. 2006) because they rely on benthic organisms whose distribution does not change rapidly (Olenin and Daunys 2004). By contrast, piscivorous birds follow target fish species to areas of high abundance and can be found closer to shore, where more intensive fishing effort targeting European Smelt occurs (Lok et al. 2012). The distribution of piscivorous birds is therefore temporally more variable and their exposure to gillnet fisheries is mostly affected by the distribution of their target species.

Piscivorous species differed by their bycatch depth, which may reflect the vertical distribution of their prey. The target prey for the Common Murre in the Baltic Sea is pelagic sprat (Lyngs and Durinck 1998) and other pelagic fish, whereas Red-throated Loon prey on pelagic species and European Smelt, and Great Crested Grebes prefer benthic fish (Morkūnė et al. 2016). European Smelt is abundant in shallow coastal waters, whereas pelagic fish such as herring and sprat are much more abundant and reachable for loons and Common Murres offshore (Österblom et al. 2002). Benthic prey might be successfully caught by grebes in shallow waters (Morkūnė et al. 2016), and this could be the reason why Crested Grebes were mostly bycaught in shallow coastal waters. Considering data of bird distribution at other sites, Red-throated Loons were choosing depths up to 20 m in the Baltic Sea (Dorsch et al. 2019). In general, the bycatch depth of different bird species depends not only on species-specific feeding preferences, but also on fishing depths and local specificities of prey distribution. Therefore, it is important to study the depths at which bird bycatch occurs on a local scale to understand which species are most vulnerable to bycatch.

The dominance of adult male birds in the bycatch during the wintering season in this study showed that the Lithuanian coast is predominantly used by adult birds, assuming that birds get bycaught in gillnets at random and in proportion to their abundance. The dominance of adult birds in bycatch has also been recorded in Poland (Stempniewicz 1994), whereas other studies have reported similar numbers of adult and juvenile/immature birds (Koneff et al. 2017). Our study showed that adult male birds are more frequently taken as bycatch compared to females, which may indicate a larger wintering male population in Lithuania. This could be explained by lower survival of females in sea duck populations and a male-biased sex ratio (Lehikoinen et al. 2008). Uncertainty regarding the population structure of different species prevents a proper understanding of the anthropogenic impacts on their populations (Koneff et al. 2017). Many sea ducks have a life history in which variable and generally low productivity is compensated by relatively high adult survival and long reproductive life spans (Goudie et al. 1994, Koneff et al. 2017). Therefore, the elimination of adult individuals with high natural survival probability may exacerbate the population level effect of bycatch (Marchowski et al. 2020).

In this study the majority of seabird bycatch occurred in winter from December to March. This is in accordance with previous studies in the southeastern Baltic Sea (Stempniewicz 1994, Dagys and Žydelis 2002, Dagys et al. 2009, Bellebaum et al. 2013). We also found that higher proportions of juveniles of some seabird species were bycaught in spring than in winter. Juvenile Velvet Scoters constituted ~60% of the total bycatch of this species in May (Table 2). Similar results in March and April were obtained in Poland, where 54 to 66% of bycatch were juveniles (Stempniewicz 1994). Juveniles and immature Long-tailed Ducks made up 11–13% of bycatch in February and March in Lithuania, similar to Poland (Stempniewicz 1994). A noticeable finding is the mismatch in the proportion of adult and juvenile Long-tailed Ducks between male and female birds; juvenile males accounted for only 1.9% of bycatch whereas juvenile females accounted for 8.7%, in contrast to the proportion of adult birds (64.3% male versus 24.8% female; Table 2). Because most sea ducks form pairs in wintering grounds and during migration (Alison 1975), immature males could be excluded from preferred habitats to minimize competition between adult males for females. This aggressive behavior was observed in breeding grounds, where territorial males with mates chase away other adult and immature males from breeding ponds (Alison 1975; J. Morkūnas, *personal observation* in Kolgūjev). This behavior may explain the low number of juvenile sea ducks wintering in the Lithuanian coastal zone, because they are excluded from high-quality habitats used by adult birds.

CONCLUSION

In summary, the data that have been reported by the Lithuanian authorities to the European Commission grossly underrepresent the actual magnitude of seabird bycatch, and our data highlight the inadequacy of the current national strategy to report bycatch. The bycatch of 1500 to 3000 seabirds each winter in gillnet fisheries along the relatively small coastal waters of Lithuania should be a strong signal to European institutions regarding member countries' compliance with bycatch related regulations. The Lithuanian coastal zone constitutes a small stretch of the Baltic Sea, and even though it is an important wintering area for seabirds, the number of bycaught birds might be small in comparison to the overall Baltic population. However, the same type of fishery is ubiquitous elsewhere in the Baltic and our study in Lithuanian coastal waters might be representative of bird bycatch in gillnets across the entire Baltic Sea. In most countries, the collection of bycatch data has been primarily opportunistic, whereas dedicated monitoring programs are needed to understand and eventually mitigate the bycatch problem. Alongside improved data collection, effective ways to mitigate seabird bycatch should be developed, starting from alternative fishing gear (O'Keefe et al. 2021) and/or using technical mitigation measures (Field et al. 2019, Rouxel et al. 2021).

Responses to this article can be read online at:
<https://www.ace-eco.org/issues/responses.php/2153>

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