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Seabird beachcast events associated with bycatch in the Norwegian purse seine fishery

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ABSTRACT

Beachcast events, where a large number of seabird carcasses drift ashore, occur with irregular intervals. These events are due to specific situations where mass mortality of seabirds have occurred. Disentangling the cause of these events can provide valuable information on stressors impacting seabird populations. Following several mass mortality events involving gulls in northern Norway, an investigation of the probable cause of death was initiated. In total 75 dead gulls were collected at two occasions and necropsies were carried out. The findings from the necropsy of the gulls were consistent with drowning as the primary cause of death. Bycatch in coastal purse seine fishery was considered a potential cause of the mortality and monitoring of seabird bycatch in this fishery was thus initiated. The monitoring of fishing operations revealed that 10% of 91 fishing events observed led to bycatch, with a total of 32 bycaught seabirds. These bycatch events resulted in a total estimated bycatch rate of 0.356 (95% CI = 0.133–0.949) birds per haul. These findings are consistent with the hypothesis that the registered mortality events were caused by bycatch in the purse seine fishery. The highly episodic and unpredictable nature of these events makes it demanding to achieve solid estimates of the occurrence and extent of bycatch without a very high monitoring effort. Our study shows that systematic investigation following beachcast events can shed light on the occurrence of such extreme events.

1. Introduction

Seabird mass mortalities leading to beachcast events, characterized by stranding of hundreds to thousands of seabird carcasses occur from time to time all over the world. These events can get large public attention, as they often generate a lot of emotions, depending on which species is involved and where the beachcast birds are found. The events also trigger the curiosity and concern of ecologists and managers, as numerous carcasses within a small spatial scale and a short time frame strongly indicates that specific events have resulted in elevated mortality (e.g., Van Pelt and Piatt, 1995; Newman et al., 2007). Although mortality is an omnipresent demographic process, mass mortality events are of particular interest as they might have a profound impact on affected populations (Frederiksen et al., 2008). Especially for small populations and endangered species, it is crucial to address questions concerning why and how often these mortality events occur, and to what degree they affect the population dynamics. Known causes of mass mortality events for seabirds include harmful algal blooms (Jones et al., 2017), oil spill (Munilla et al., 2011), weather anomalies such as heat-waves (Jones et al., 2018; Piatt et al., 2020), storms (Anker-Nilssen et al., 2017), infectious disease (Allison et al., 2015; Strauch et al., 2020), and starvation (Piatt and Van Pelt, 1997; Camphuysen et al., 2002). Even though causal relationships between mass beachcast events and mortality events have been established in some cases (e.g. McKechnie and Wolf, 2010; Jones et al., 2018), others might be hard to disentangle without careful forensic investigations. Furthermore, the beachcast birds may be found far away from the site of the actual mortality event (Flint and Fowler, 1998; Hart et al., 2006), and knowledge about weather, prevailing winds and ocean currents is crucial. Therefore, and as in a crime scene investigation, the applied scientific method to disentangle a probable cause of death must often involve necropsies, measurements of relevant variables in the

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surrounding environment and interviews of possible witnesses.

In Troms, northern Norway (Fig. 1), a large number of beachcast gulls (primarily herring gulls *Larus argentatus* and great black-backed gulls *Larus marinus*) were recorded in November 2015. The event got attention from national media, as dead gulls were washed to shore in the hundreds, close to urban settlements. Four bird carcasses were sent to the Norwegian Veterinary Institute in Oslo for necropsy, and drowning was established as the most probable cause. The unexplained mortality event raised concerns among ecologists, considering the overall decline in many populations of Norwegian seabirds, including herring gulls (Fauchald et al., 2015). In addition, it was regarded as important to perform a thorough investigation to ease public tensions, as speculations flourished about whether anthropogenic activities in the area were to blame. Following the initial mortality event, awareness and commitment was increased on recording observations of dead gulls in the area, and in January 2017, January 2018 and November 2019 similar events were recorded and further bird carcasses collected and examined.

The beachcast events occurred during periods with high availability of Norwegian spring spawning (NSS) herring *Clupea harengus* in the area. The NSS herring is highly migratory, performing seasonal migrations between wintering, spawning and feeding grounds (Dragesund et al., 1997). A large part of the stock overwinter close to the Norwegian coast (Huse et al., 2010). However, it has long been observed that the migration pathways of NSS herring can change, leading to abrupt shifts in winter area use (Huse et al., 2010). In autumn 2010, NSS herring suddenly started entering the fjords of Troms, Northern Norway. This attracted large amounts of top predators such as seabirds (mainly gulls) and whales to the fjords as well as high densities of purse seine fishing vessels targeting herring.

Several probable causes of death leading to the beachcast events were initially suggested, including bycatch in fisheries, mortality associated with aquaculture operations, starvation, intoxication or infectious disease. Bycatch in many of the Norwegian fisheries have been monitored for years, however, there is a dearth of scientific knowledge about the extent of seabird bycatch in the purse seine fishery (but see Oliveira et al., 2015; Norriss et al., 2020). Yet, high numbers of seabirds taken as bycatch in a single fishing event have occasionally been observed in many fisheries in Norway (Fangel et al., 2017; Bærum et al., 2019; Christensen-Dalsgaard et al., 2019), although not in quantities that would likely result in mass occurrence of beachcast birds like the observed events. Nets used at aquaculture facilities (e.g., nets to keep fish from jumping out of the pens and prevent predator access) has been known to unintentionally catch seabirds (Cermaq, 2020), however the extent of this is not described in the scientific literature. Other potential causal factors, perhaps regarded as the most likely ones among the lay public, was an outbreak of an unknown pathogen in the dense crowds of gulls accumulating in the area or a mass exposure to a biological or anthropogenic toxic substance.

In this study, we use a trans-disciplinary applied approach to elucidate the etiology of multiple beachcast events involving large numbers of seabirds in Northern Norway from 2015 to 2020. The study reflects the dynamic process of understanding the underlying cause of the beachcast events observed, from having no clear hypothesis of what could have led to the first event, to progressively identifying bycatch in the purse seine fishery as the primary hypothesis to test. We based our investigation on a synthesis of citizen science observations, standardised

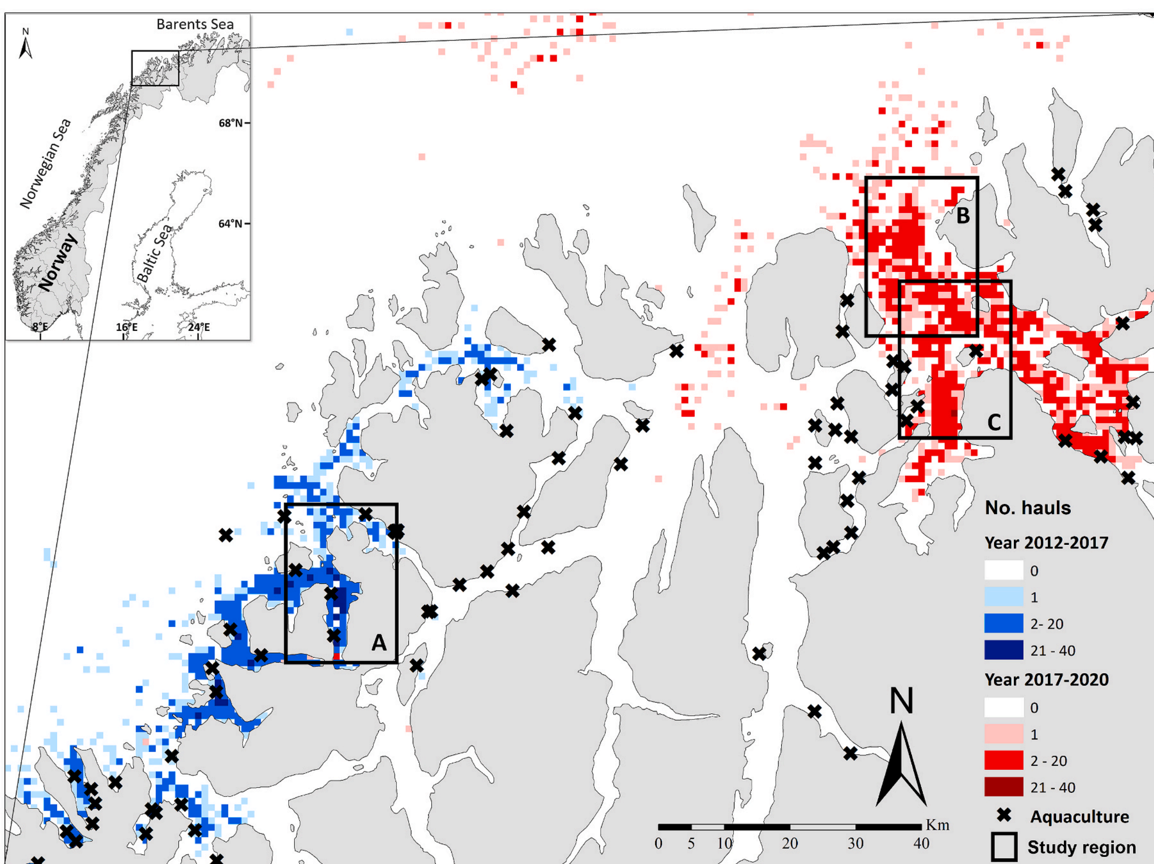

Fig. 1. Map of Norway and overview of the study area. Purse seine activity was carried out in two distinct different areas in respectively 2012–2017 and 2017–2020. Fishing activity given as number of hauls is shown for the period 2012–2020, with blue showing fishing activity from autumn 2012 to spring 2017 and red showing fishing activity from autumn 2017 throughout 2020. Black x indicate aquaculture facilities. Black squares marked with “A”, “B” and “C” are the regions with observed gull mortality (see Fig. 3 for more detailed maps of each region).

and professional necropsies, official records of environmental conditions (from weather stations) and standardised monitoring of bycatch in the purse seine fishery carried out in the area. Based on these data we conclude that purse seine fishery bycatch most probably was a major cause of the mortality events and following this we estimate the potential extent and occurrence of such bycatch.

2. Material and methods

2.1. Data collection from beachcast events

Following the beachcast event in November 2015, monitoring with the aim to record similar cases was initiated by the Norwegian Institute for Nature Research (NINA). Information on beachcast events was obtained through local media (online news feeds), from locals and through notifications on the Facebook group “Whales in Norway”, where many people visiting the area are active. We specifically asked about information on events involving more than ten dead seabirds. When receiving observations, we asked for an estimate of the number of dead birds based on counts in the area. Furthermore, we initiated collection of beachcast carcasses in order to carry out necropsies to identify cause of death. This resulted in the collection of a substantial number of dead birds from two events of high gull mortality, one in January 2017 and one in November 2019. The birds from 2017 were collected and stored frozen until they were packed and sent frozen to NINA in Trondheim. The birds from 2019, were collected and immediately send to the NINA laboratory for necropsy, to avoid freezing artifacts such as accumulation of blood-tinged fluid, formation of pseudo-hemorrhages, subcutaneous pseudo-bruises and changes in texture and discoloration caused by damage to cell membranes, ruptures of blood vessels and increased autolysis and bacterial growth (Roe et al., 2012), and thereby improve diagnostic accuracy.

2.2. Necropsy of beachcast birds

Necropsy was performed according to in-house standard protocols (Ytrehus and Work, 2019). Due to financial limitations, samples for histopathological examination were not processed and serological, bacteriological, virological or toxicological examinations were not performed. The necropsy was performed by a skilled wildlife pathologist and board certified veterinary expert in wildlife population health together with an experienced seabird biologist in 2017, and by the latter in 2019.

In 2017, the carcasses were thawed in room temperature for 24 h before necropsy. In 2019, the carcasses arrived fresh and necropsy was performed within a day after arrival.

During necropsy the birds were thoroughly inspected for external lesions and skinned to allow examination for signs indicative of trauma. The body cavity was opened and all organs examined. The mouth, oropharynx, trachea and esophagus were opened and examined, and the cranium split to allow examination of the cranial cavity and the brain. The birds were sexed following methods described by Van Franeker (2004) and Camphuysen et al. (2007). Based on plumage, the appearance of the sexual organs and absence, presence and eventual size of bursa of Fabricius, the age group of each bird was characterized as juvenile/immature or adult (Van Franeker and Meijboom, 2002). The body condition of the birds was determined based on the overall condition score ranging from 0 to 9 (with 0 being very cachectic and 9 extremely good body condition) (Van Franeker, 2004).

2.3. Diagnosis of drowning

Finding carcasses of seabirds stranded on a beach does not necessarily mean that the birds have drowned, but rather that they died at sea or were disposed there. As such, drowning is a difficult diagnosis to substantiate, and presumptive evidence of drowning relies on exclusion of other causes of death that could have occurred before the animal was immersed in water (McEwen and Gerdin, 2018). Analyses that can provide corroborative evidence in humans and dogs, for example the diatome test (Piegari et al., 2019), are not validated in seabirds and hence not recommended (Simpson and Fisher, 2017). In addition, postmortem changes occurring during submersion, as for example dilution of haemorrhages, osmotic effects of salt water and trauma occurring in the surf, may create new and change lesions that were present before death.

In humans, drowning is defined as “the process of experiencing respiratory impairment from submersion/immersion in liquid” and drowning outcomes classified as “death, morbidity and no morbidity” (Van Beeck et al., 2005). It is recommended that this terminology also is adopted by animal health professionals (McEwen and Gerdin, 2018). Use of previous terms that were used to classify drownings as dry, wet, passive, active, silent and secondary, are now discouraged (Idris et al., 2003; Van Beeck et al., 2005; McEwen and Gerdin, 2018). Much of our knowledge of the pathogenesis of drowning comes from gruesome experiments performed on dogs (For a review, see McEwen and Gerdin 2018). In short: An animal immersed or submersed in water will initially hold its breath voluntary. This will rapidly cause oxygen depletion. Furthermore, presence of only small amounts of water in the larynx induce a reflective spastic closing of the airways, lasting up to 2 min. During this period, hypercarbia ensues and acidosis develops while the animal struggle and swallow water due to heavy respiratory movements. If the animal then loses consciousness, the laryngeal muscles relax and water is aspirated. If the animal still is conscious, it will gasp and consequently also aspirate water. Death normally occurs between five and 10 min after submersion.

2.4. Environmental conditions

The direction of wind and water current plays an important role in where the stranding of carcasses occur in relation to the site where the animals died (Flint and Fowler, 1998; Hart et al., 2006). This makes it challenging to backtrack where the carcasses found originated from. To take the probable area of origin of the dead birds into account and compare this area with the distribution of purse seine fishery activities and aquaculture facilities, we considered the prevailing direction of wind and water current in the area.

As the carcasses included in our study were all characterized as mildly to moderately autolytic, we assumed that the mortality-event happened less than three days before the stranding, and used a three day cut-off for wind data. Information on average wind speed and direction at hourly intervals during the three day period prior to each stranding event was downloaded from the nearest meteorological stations (available from Norwegian Meteorological Institute, https://seklima.met.no/). As wind speed and direction are two components of the same quantity, i.e., wind is a vector with both magnitude and direction, the average wind speed and the resultant vector average wind direction was calculated by converting speed and direction to an east-west- and the north-south vector using the R package *openair* (Carslaw and Ropkins, 2012).

To take into account the current in the study area, the prevailing currents were assessed from Norwegian coastal current modelling website (http://www.havstraum.no, accessed August 13, 2021). In addition, the current in the study area is strongly influenced by the direction of the tide, with the tide-induced current going inwards in the fjords during flood and going outwards doing ebb tide.

2.5. Fisheries data

The beachcast events included in the study all occurred within enclosed fjord systems. The fishing in these areas is regulated by the Norwegian harvesting regulation (J-21-2022 https://lovdata.no/dokument/SF/forskrift/2021-12-23-3910/KAPITTEL_17#%C2%

A774), prohibiting vessels ≥15 m in overall length to fish within the fjord lines. Exceptions are, however, made for specific vessel groups in specific areas for a specific period of time, for instance allowing purse seine fishery vessels >15 m targeting NSS herring to fish within the fjord line. Consequently, the fishery in the study area consisted primarily of some small gillnet boats targeting cod and saithe, and purse seine boats targeting NSS herring. Gillnets are known to take surface feeding seabirds as bycatch (Bærum et al., 2019). Nonetheless, we considered it unlikely that the limited number of gillnet-vessels active in the area could result in the substantial number of gulls killed, and focus was put on the purse seine fishery.

The purse seine fishery is an active fishery where a ringed net is set around the shoals of fish. After the fish have been surrounded, the bottom of the net is closed, which prevents the fish from escaping. When the bottom has been closed, the vessel starts hauling in the net, to increase the density of fish in the net, by reducing the volume of the net bag. When the density is high enough, a fish pump is deployed and the fish is pumped onboard. The time spend pumping fish onboard is highly dependent on the size of the catch, but can take as much as 60 min.

The purse seine fleet targeting NSS herring consists primarily of small vessels between 20 and 40 m in length and large vessels that are between 60 and 80 m in length. The latter primarily operating offshore (Mul et al., 2020). All Norwegian fishing vessels exceeding 15 m are subject to electronic reporting of catch, activity and position data. This information from purse seine fishing boats was made available by the Directorate of Fisheries (www.fiskeridir.no). Since fishing vessels remain relatively stationary while hauling the net, we assigned a position to each fishing event. To explore the overall distribution of purse seine fishing activity in the area, we created 1 × 1 km grids of the area and summed the number of fishing events per fishing season (November–January) within these grids. There was a clear shift in distribution of fishing activity between the 2016–2017 and the 2017–2018 fishing season, with boats moving their activity to the Kvænangen area in the fall of 2017. Hence, an average number of hauls per winter season per 1 × 1 km grid was calculated for the period 2012–2017 and 2017–2020 respectively.

To assess the amount of fishing activity in the focal area of each beachcast event, we applied the three days cut-off described above, and used data on location of purse seine hauls from the three days prior to the beachcast event. To further delimit the study area we focused on the anthropogenic activities within a 10 km radius of the area where dead birds were observed.

2.6. Data collection on bycatch

Based on the results from the first necropsy suggesting drowning being the cause of death and as the beachcast events co-occurred with an ongoing purse seine fishery close by, a causal relationship was suggested. During this fishery, a coast guard vessel and/or a fishery control vessel from The Directorate of Fisheries are present at all times, carrying out fishery inspections. Inspections from The Directorate of Fisheries are usually not completely random and can depend on for example number of vessels in the area conducting fishing operations, area of the fishing operation (e.g. close to or within closed areas for fishing), risk assessment for the vessel (a priori assessed), or the size of the catch of the target species. This means that the same vessel can be inspected several times. In addition to the inspectors from The Directorate of Fisheries, we placed external observers on a coast guard vessel observing the fishery during January 2017. Subsequent monitoring of the purse seine fishery was carried out in three following fishing seasons (2018/2019, 2019/2020, and 2020/2021). The monitoring of the purse seine fishery gathered data through three main channels, 1) dedicated seabird bycatch researchers traveling with fishery patrol vessels, 2) fishery inspectors utilizing customized fill-in forms for registration of seabird bycatch, and 3) fishery inspectors reporting through general purpose inspection forms (no customized columns for seabird bycatch). All the three observations processes were composed of both observations from the fishing patrol vessel and observations from onboard the fishing vessels. In total, these sampling processes did not follow a strict random sample processes, but rather represented a sample of the nearby vessels with a likely bias towards sampling situations based on prior knowledge of the inspectors. In total, the sample included registrations from 40 different identified vessels and 49 entities where the vessel identities were unknown.

2.7. Bycatch rate estimates

Seabird bycatch rates were calculated as the number of birds per observed seine-haul rate. The 91 observed seine hauls comprised nine seabird bycatch events, with a total of 32 seabirds registered as bycatch, and 82 zero-bycatch events. Numbers of seabirds taken per bycatch event ranged from one to ten. We thus used a negative binomial generalized linear mixed effect model to account for non-normal data. As we had rather few observations, we did not explore possible trends in the data, but rather constructed an intercept only model to estimate an expected mean bycatch value per haul. The datapoints were collected across three different years/seasons, but as we had no reason to believe there should be any obvious differences between years, we neither considered this in the model (i.e., each fishing event could be considered a random sample across all years). However, the observations could be considered as nested under three different observations processes, and we thus included type of observation (i.e. originating from observing researchers (N = 17), fishery inspectors with dedicated bycatch schemas (N = 23) or from general fishery inspection observation (N = 50) as a random intercept in the model. Thus, in a general notion, seabird bycatch (Y) on seine-haul j within observer process i was modelled according to:

$$Y_{ij} \sim NB(\mu_{ij}, k)$$

$$E(Y_{ij}) = \mu_{ij} \text{ and } var(Y_{ij}) = \mu_{ij} + \frac{\mu_{ij}^2}{k}$$

$$\log(\mu_{ij}) = \alpha + b_i + \varepsilon_{ij}$$

where α the is the coefficient (intercept) under estimation, b_i is the random observer process-specific intercept (assumed to be independent and identically distributed as $N(0, \sigma^2_{Observer\ process})$), and ε_{ij} is the random residual variation. The model was specified using the *glmmTMB* library (Brooks et al., 2017) in the statistical software R (R Core Team 2021).

3. Results

3.1. Documentation of beachcast events

In total three beachcast events and one event with dead birds observed floating on the water were documented in the period November 2015–November 2019 (Table 1). Two of these events were reported directly to the project group and the remaining two we were made aware of through local newspaper articles. In addition, throughout the study period we got several reports from tourists and researchers in the area who had observed <10 dead gulls floating in the fjords.

Beachcast event one and two was documented in the Lyfjord and Bellvika area (Fig. 1, box A) in fall 2015 and winter 2017. In both events, a number of dead gulls were observed washed up on the beach by locals using the area for recreational purposes. In the event in 2015, 43 dead gulls were counted on shore and based on dead birds counted on the water the local observers estimated that approximately 200 gulls died. In the 2017 event more than 350 dead gulls were observed on the shore, and based on the number of dead birds observed in the water it was assumed that as much as 1000 birds could have died during the event. From event two, 35 dead gulls were opportunistically collected for

Table 1
Description of beacatch events registered in the period November 2015–November 2020.

Event	Date of event	Area	Description	Source	Dead birds collected
1	6th nov. 2015	A: Lyfjord/ Bellvika (Kvaløya, Troms)	Local hikers observed 43 birds dead gulls on the shore in Lyfjord. An estimate of at least 200 dead birds was given.	Nordlys 2015a, Nordlys 2015b	4[a]
2	8th Jan 2017	A: Lyfjord/ Bellvika (Kvaløya, Troms)	More than 350 dead gulls were observed on the shore in Bellfjord by a local biologist. He estimated that more than 1000 birds had probably died in the event.	Own communication with observers, Nordlys 2017, NRK 2017	35
3	6th Jan 2018	B: Seglvik (Kvænangen, Troms)	Local inhabitant has found dead gulls on the shore over the last days. On the day reported he found 25 dead gulls, but states that this is just a small part of the dead birds	Nordlys 2018	0
4	12-13th Nov 2019	C: Reisafjorden (Troms)	NINA was contacted directly with reports of dead seabirds floating in the Reisafjorden on both days. Between 250 and 500 gull carcasses were observed. None of the birds seem to have reached shore.	Own communication with observers	40

Nordlys 2015a: https://www.nordlys.no/maker/maser/fugleliv/ida-gjorde-sjokkfunn-fant-over-40-dode-maker-i-fjara-i-tromso/s/5-34-283535. Nordlys 2015b: https://www.nordlys.no/maker/dodsfall/tromso/na-er-konklusjonen-klar-etter-sjokkfunnet-i-fjara/s/5-34-335899. Nordlys 2017: https://www.nordlys.no/var/fiskeri/fugler/fant-over-350-dode-fugler-pa-stranda-i-tromso-det-er-trist/s/5-34-545411. NRK 2017: https://www.nrk.no/tromsogfinnmark/_-jeg-vasset-i-dode-maser-pa-stranda-1.13311870. Nordlys 2018: https://www.nordlys.no/kvanangen/make/dod/store-mengder-dod-fugl-er-skylt-i-land-aldri-sett-maken-til-dette/s/5-34-762082.

[a] Birds were sent to the Norwegian Veterinary Institute for necropsy and are therefore not included in this study.

necropsy. At both events it was observed that the dead birds were only present on the coast for a limited period of time. Following the subsequent high tide, most of the birds had disappeared from the shore.

Beachcast event three and four took place in northern Troms (Fig. 1, box B & C) in 2018 and 2019. Event three was reported by a local resident who over a period of some days observed dead gulls washing up on the local beach in Seglvika. He did not provide an exact number, but claimed that the 25 carcasses found in the 6th January was just a small proportion of what he had observed. The fourth event was reported directly to our project by local researchers, who observed and estimated 250–500 gull carcasses floating in the fjord (pers. comm. Eve Jourdain). Notably, no beachcast birds were reported in connection to this event. In total 40 carcasses were collected for necropsy.

3.2. Necropsies

From the beachcast event in 2017, 35 gulls were examined. Most of the birds were classified as adults (86% in 2017 and 83% in 2019). All the birds were in moderate (n = 9, 26%) to good (n = 26, 74%) condition and the necropsies revealed consistent lesions. The autolytic changes were moderate, considering that the birds had been frozen and thawed. The birds had pale conjunctiva and oral mucosa and their eyes lied deep in their orbits. A few of the birds were scavenged. The examinations did not reveal any findings consistent with contamination or trauma, for example oil in the plumage, external wounds, burns, hemorrhages or fractures. When the hind part of the birds was lifted and slight pressure applied to the abdomen, moderate amounts of watery fluid was seen in the cervical part of the clavicular air sac. The lower parts of trachea and the bronchi contained large amounts of blood-tinged, watery fluid. In some birds, moderate amounts of watery and blood-tinged fluid were present also in the abdominal air sacs (Fig. 2). The lungs were consistently severely congested and edematous, with blood-tinged watery fluid oozing from cut surfaces. In some birds, mild enlargement of the spleen and mild congestion in the kidneys was observed. The proventriculus and the gizzard were either empty or contained small remnants of fish scales and -bones.

From the beachcast event in 2019, 40 relatively fresh carcasses of gulls were examined. Most of the birds were classified as adults (83%). Overall, the findings were relatively similar to those observed in 2017, but since the carcasses were fresh, we observed that a majority of them smelled intensely from herring and many had silvery fish scales in their plumage. In addition, the fluid in the trachea, bronchi, air sacs and lungs frequently contained large amounts of foam (Fig. 2). In addition, all the birds were in excellent condition with large fat deposits, and their livers were consistently yellowish and had decreased texture (indicative of hepatic steatosis).

3.3. Fishery activity and environmental conditions

During the study period, the distribution of the purse seine fishery in the region shifted northeastwards, and there were two distinct areas of fishery, specifically the fjords of central Troms (October 2012–February 2017) and the Kvænangen/Reisafjorden area in northern Troms (November 2017–February 2020) (Fig. 1).

We considered the fishery and aquaculture activity within a 10 km radius of all the mortality events to assess likely sources of mortality. Within this radii there was purse seine fishery activity with the numbers of hauls ranging from 14 to 51 in the three days preceding each event (Fig. 3, Supplementary Material Table A2). Aquaculture facilities are widespread in the whole region, being primarily placed in sheltered areas (Fig. 1). Within the 10 km radius of the different events, there were between 0 and 6 aquaculture facilities (Fig. 3, Supplementary Material Table A2).

The average wind strength ranged from 5.8 m/s – 9.72 m/s, with the wind direction and speed being event specific (Supplementary Material Figure A1 and Table A2). In all beachcast events the direction of the

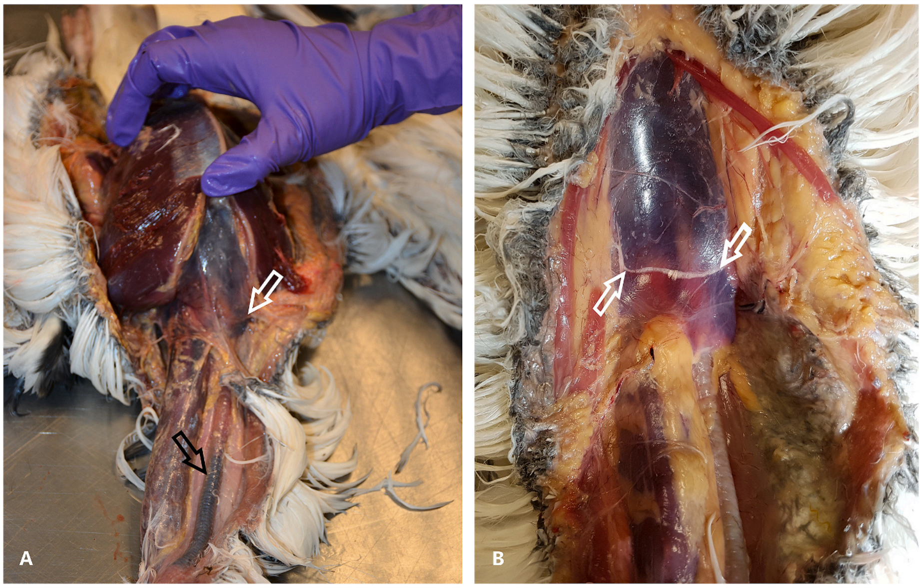

Fig. 2. Water in the cranial air sac was a consistent finding in the necropsied gulls. The images are taken from the head of the bird in a caudal direction during skinning of the neck. A shows one of the frozen and thawed carcasses from 2017. Blood-tinged fluid without foam is present in the trachea (black arrow) and the cranial air sac (white arrow). B shows one of the fresh carcasses from 2019. The cranial air sac is partly filled with clear fluid covered with small amounts of whitish foam (white arrows). Notice the large amount of yellow subcutaneous fat. Photo: Signe Christensen-Dalsgaard.

wind was consistent with mortality occurring at the same location as the purse seine fishery and that the carcasses had drifted into the areas where they were observed. The two events in respectively 2015 and 2017 happened in close vicinity of two aquaculture facilities, and based on prevailing wind and current, the birds could have died there. However, this was not the case in the last two events, where no aquaculture facility was present (event 3) or the prevailing wind direction made in unlikely that the birds originated from any facility (event 4).

3.4. Qualitative observations of bycatch events and quantitative seabird bycatch rates

In total, we obtained a sample of 93 observations of hauling in the purse seine fishery from the period November 2018–January 2021. Of these, two were qualitative observations made by inspectors at a coast guard vessel and a photographer on board a fishing vessel. They respectively described a bycatch event with an estimated range between 35 and 40 birds taken as bycatch and a series of bycatch events during an afternoon of fishing where bycatch of up to 50 gulls were observed in three out of four hauls.

The remaining 91 observed fishing events was recorded by observers using standardised quantitative protocols, where information regarding seabird bycatch were recorded for each event. The registered bycatch consisted of 13 common gulls (*Larus canus*), nine herring gulls, six great black-backed gulls and four gulls of undetermined species. Based on the GLMM, the mean bycatch rate per purse seine operation (including everything from setting to pumping of the herring from the purse seine into the boat) was estimated to approximately 0.356 birds per haul, with a 95% confidence interval between 0.133 and 0.949.

Based on own and reported observations, gulls appear to be at risk of getting caught within the purse seine during the late part of the hauling, when the upper and outer parts of seine are hoisted above the water and towards the boat. If gulls are present within the seine in large numbers during this situation, the gulls might not be able to escape and thus risks drowning in the seine. The observations indicated that once the birds landed in the densely packed herring in the purse seine, some of them were pushed down among the fish and subsequently drowned. When the seine was opened after the pumping of herring was completed, the dead and injured birds floated away from the boat. The fate of the birds that still were alive after being released is not known.

4. Discussion

Large beachcast events of seabird carcasses are concerning as they might represent mass mortality events of unknown size and origin. In a management and conservation perspective, it is thus crucial to get inference on the cause and frequency of such events. In this study, we used a combination of scientific methods to disentangle the probable cause of death following several mass mortality events among gulls in northern Norway. By performing necropsies to collect data on macroscopical findings, together with thorough investigation of plausible environmental and anthropogenic factors, we found that bycatch during the purse seine fishery is the most likely cause of the observed mass mortality events.

4.1. Indices from necropsies

Based on the consistency in findings between the individual carcasses, it is most likely that the birds in each of the two beachcast events were killed by the same mechanism within a short period of time. The overall good condition of birds excludes starvation as a plausible cause of death. Together with the absence of macroscopic pathological findings indicative of trauma, sepsis or acute intoxication, the consistent observation of water in the air sacs and the severe lung congestion and edema indicate that the birds died from drowning (Simpson and Fisher, 2017).

Notably, the lung anatomy and physiology of birds is very different from mammals (Ewbank et al., 2020). We have not found any scientific experimental descriptions of the pathogenesis of drowning in seabirds, and relatively few reports describe pathoanatomical lesions associated with drowning. Most of the recent reports describe entanglement of diving birds in fishing nets (Vanstreels et al., 2016; Simpson and Fisher, 2017; Ewbank et al., 2020), while some reports describe drowning of anatids during storms (Miller et al., 1986; Springer et al., 1989).

The consistent finding of moderate amounts of water in the clavicular air sac and smaller amounts in the more caudal air sacs, is compatible with findings described in other reports of presumed drowning (Vanstreels et al., 2016; Simpson and Fisher, 2017). Vanstreels et al. (2016) suggest that inhalation of water into the intrapulmonary bronchi may cause such an increase in flow resistance that the negative inhalation pressure not is sufficient to draw the liquid through the lungs and into the caudal air sacs. Simpson and Fisher (2017), however, regard the finding of water in air sacs as

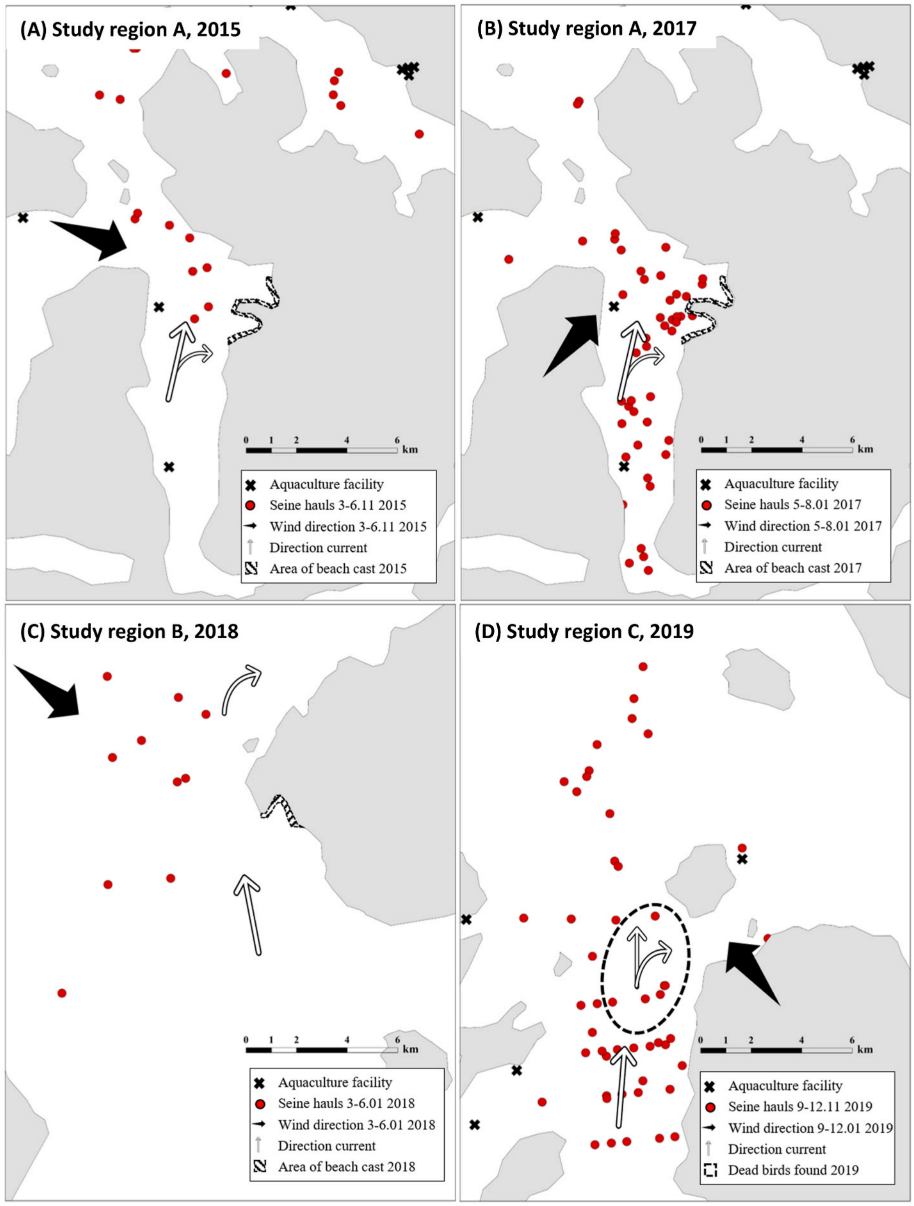

Fig. 3. Map depicting fishing activity, aquaculture facilities and prevailing wind direction during the four events involving dead birds getting washed on shore (A) 2015, (B) 2017 and (C) 2018) and being observed floating (D) 2019.

pathognomonic for drowning, but describes presence of water also in the caudal air sacs. They argue that the water first reaches the cranial air sacs after being exhaled from the caudal air sacs through the secondary bronchi. Water in the air sacs was not described in the reports of Miller et al. (1986) or Springer et al. (1989), who described findings in beachcast geese and swans.

Our interpretation of the current necropsy findings in the gulls, is that they are consistent with drowning as the primary cause of death. Compared to the descriptions of changes in diving birds entangled in nests below water, the gulls in our study showed relatively mild congestion. We suspect that this may indicate a more rapid death in the gulls, which not to that degree should be expected to be physiologically adapted to diving. These findings are consistent with the hypothesis that the mortality events were caused by the gulls being taken as bycatch. Bycatch in aquaculture nets could also potentially have led to some of the same findings in carcasses, but would most probably have been accompanied by traumatic lesions characteristic for entanglement. In addition, it seems unlikely that the carcasses then had showed such consistent lesions and that the birds had died so simultaneously. Other factors, such as the distribution of aquaculture facilities and the observations of bycatch in purse seine nets, adds to make it unlikely that bycatch in aquaculture facilities was the ultimate cause of the events.

Notably, the changes were much easier to interpret in fresh carcasses, while freezing and thawing created artifacts, for example accumulation of fluid in tissues that made evaluation of congestion and water in lungs and air sacs difficult, and disappearance of the characteristic foam in the airways. To perform necropsies on fresh carcasses instead of frozen ones, hence facilitates a correct diagnosis of drowning in beachcast events.

4.2. Seabird bycatch

The necropsies performed after the first beachcast event in 2017 indicated that the birds initially were healthy, but had drowned simultaneously. There are few events that can cause such a thing to happen, and the suspicion of most plausible cause of death pointed to bycatch in fisheries. Following this, monitoring of bycatch in the areas was initiated. As the purse seine fishery targeting herring is the major fishery in the area during the period in question, focus was put on this fishery.

Seabird bycatch is in general characterized by low levels of bycatch interspaced with episodic events of high bycatch numbers (Piatt and Nettleship, 1987; Bærum et al., 2019). This pattern was also evident in coastal purse seine fishery for herring in Norway in our study, and seem to be a trend observed in other purse seine fisheries as well (Hedd et al., 2016; Norriss et al., 2020). In our sample of fishing operations, most fishing events resulted in zero bycatch, but the few bycatch events registered were noteworthy and resulted in the fairly high estimated bycatch rate in total. This high rate was somewhat surprising given that the Norwegian purse seine fishery has been regarded as having a low bycatch risk, based on interviews of fishers (Christensen-Dalsgaard et al., 2008; Fangel et al., 2011). However, given the distinct bycatch distribution containing mostly zero bycatch, it is perhaps not surprising that the fishers do not have the impression that the type of fishery is of any special concern in terms of seabird bycatch. Observations and dialogue with the fishers revealed that, although the bycatch events are rare in general, gulls do sometimes get caught within the purse seine during the late part of the haul. As there often are very high densities of gulls around the fishing vessels in this type of fishery, the number of gulls potentially trapped in the seine can be substantial. When the seine is opened after the fish have been pumped onboard the fishing vessel, the dead and injured birds just float away from the boat and thus never reach the deck of the boat. Hence, if no dedicated observers are onboard, bycatch events might go unnoticed or neglected, especially when fishing takes place in periods with little daylight. Of the mass mortality events, two occurred in the beginning of the fishing season in November and two at the start of the year when the boats had new quotas to fish. There might thus be higher likelihood of such bycatch events in the start of the fishing season, as well as after breaks within the season. This pattern could be related to birds being more hungry and therefore aggressive after periods with less fishing activity. The proventriculus and gizzard of the bycaught birds contained either no or very little remnants of fish scales and -bones, indicating that the birds getting caught were the ones that were actively foraging for herring in the purse seine. However, we did not obtain enough observations to test these indices within the data.

Globally, incidental bycatch of seabirds in fishing gear has been identified as one of the key factors that can have detrimental effects on seabird populations (Dias et al., 2019). The population of herring gulls in Northern Norway has decreased significantly during the last decades (Fauchald et al., 2015), and the species is now listed as "vulnerable" on the Norwegian red list (Artsdatabanken, 2021). The periodic high availability of NSS herring in the area most likely attract herring gulls from the whole northern part of Norway (https://seatrack.seapop.no/map/), and consequently bycatch in the purse seine fishery can affect the breeding populations of gulls from a large region. Given the severity of the declines of the herring gull population in the region it is crucial to identify functional and effective mitigation measures that can be applied in the fishery. Most of the knowledge on seabird bycatch stems from longline fisheries (Anderson et al., 2011; Melvin et al., 2019), which is thus naturally also the type of fishery where the most mitigation toolboxes has been developed (e.g., Løkkeborg 2011; Melvin et al., 2014; Jiménez et al., 2020). However, other fisheries such as gillnet-fishery (Žydelis et al., 2013; Christensen-Dalsgaard et al., 2019), trawl fishery (Watkins et al., 2008) and purse seine (Norriss et al., 2020) might also pose a risk to seabird species as bycatch rates can be substantial. Implementing effective mitigation measures in these fisheries is not always simple (Martin and Crawford, 2015), and the effect of applied measures range from promising (Bielli et al., 2020; Da Rocha et al., 2021; Rouxel et al., 2021) to rather small (Field et al., 2019). To our knowledge, there has not been a large focus on mitigation measures to prevent seabird bycatch in the purse seine fisheries, with the exception of some trials with varying success (Suazo et al., 2019; Oliveira et al., 2020). Our findings indicate that the extreme bycatch events usually takes place during a specific part of the fishing operation, namely when the purse is very close to the vessel. This makes the type of fishery a good candidate for implementing specific and effective mitigations actions such as scaring the scavenging birds away from the purse seine in critical times of the fishing operation (e.g., when the purse is lifted slightly from the surface and towards the boat). Further studies are warranted to investigate variations in the likelihood of bycatch, and to find effective and easy implementable scaring devices.

4.3. Using beachcast events to infer on bycatch events

Data on seabird stranding's and mass mortality events have previously been used to identify bycatch of seabirds (Hamel et al., 2009; Simeone et al., 2021). As argued by Žydelis et al. (2006), beached birds have a limited value in determining bycatch rates. However, investigating beachcast events can be crucial in identifying the existence of bycatch that was previously not known, which is an important first step in mitigation. The highly episodic and unpredictable nature of bycatch events makes it very data demanding to achieve solid estimates on the occurrence and extent of bycatch. Consequently, beachcast events can shed light on the occurrence of extreme events.

It is, however, important to note that the absence of beachcast events is not necessarily indicative of no mortality. The direction of the wind and ocean currents plays an important role in where the stranding's of carcasses occur, and when animals die at sea, it might only be a small fraction that wash up on shore (Flint and Fowler, 1998; Hart et al., 2006). For instance, Boor and Ford (2019) estimated an overall beaching probability of 0.14 for carcasses released in the ocean. Indeed, following the qualitative observations of bycatch events involving a large number of dead birds, no carcasses were washed ashore. Similarly, at the event in 2019, dead birds were just observed floating in the ocean but never reached shore, and would not have been discovered had there not been people out on boats in the area. It is therefore likely that what has been reported considerably underestimates the frequency of such events occurring.

5. Conclusions

Investigation of beachcast events with unknown cause is complicated and should ideally include thorough histopathological examination and testing for a wide range of potential microbial and toxicological agents (Wobeser, 2007; Work, 2015). However, systems or financial funds to examine sudden beachcast events of multiple birds rarely exists to get in depth knowledge of probable causes, as was also the case for the observed events in this study. Yet, the bycatch observations together with the environmental factors, the findings of large number of birds that has died more or less simultaneously and has consistent findings of water in the air sacs and absence of other macroscopic changes, provide compelling evidence for drowning in purse seines as the cause of death. These extreme bycatch events are likely rare, but might involve a large number of gulls given the high bird density commonly accumulating close to the fishing vessels. Although we never observed bycatch events that resulted in hundreds of birds being caught in one fishing operation, observations indicated up to 40–50 gulls being caught simultaneously. During very high seabird densities, and subsequent feeding frenzies for the gulls within the seine, it is likely that this number could potentially be higher. There might also be special conditions of which will increase the likelihood of extreme bycatch events for multiple vessels in the same area, resulting in an accumulation of seabird mortality events within a small spatial and temporal scale. More data and further investigations are needed to get inference on how the likelihood changes according to different variables and how preventive measurements and awareness can mitigate this problem.

CRediT authorship contribution statement

Signe Christensen-Dalsgaard: Conceptualization; Methodology; Investigation; Writing - original draft; Visualization; Project administration. **Bjørnar Ytrehus:** Conceptualization; Methodology; Investigation; Writing - original draft. **Magdalene Langset:** Investigation; Data Curation; Writing - review & editing. **Jørgen Ree Wiig:** Investigation; Writing - review & editing. **Kim Magnus Bærum:** Conceptualization, Methodology; Formal analysis; Data Curation; Writing - original draft; Project administration; Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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