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Author: Corcoran, Robin M.

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Common Murre (*Uria aalge*) die-off in the Kodiak Archipelago, Alaska, April 2015–April 2016

Robin M. Corcoran[1]

ABSTRACT—A mass die-off of Common Murres (*Uria aalge*) occurred from spring 2015 to spring 2016 in the northern Gulf of Alaska. Seabird die-offs have been recorded previously in the region, but this event was unique in its long duration and wide spatial extent. In response to the die-off, Kodiak National Wildlife Refuge (NWR) biologists conducted systematic beach surveys along the road system adjacent to the city of Kodiak and compiled reports from local citizens in remote locations throughout the Kodiak Archipelago to document the number of dead birds observed on beaches. Analysis of beached bird records indicated that at least 1,994 dead Common Murres were observed in the Kodiak Archipelago from 4 April 2015 to 26 April 2016. Extrapolating the density estimate, based on carcasses counted on systematic surveys on the Kodiak road system (55 murres/km, SE = 12), to all beaches in the Kodiak road system study region in the same biophysical habitat class based on Alaska ShoreZone coastal mapping, yielded an estimate of 6,305 dead Common Murres (95% CI = 3,522–9,088). In addition to Common Murres, carcasses of another 65 birds representing 15 species were found on beaches on the Kodiak road system during the die-off. The die-off event was preceded by a large-scale inshore movement by marine bird species typically seen offshore (Common Murres and shearwater species), as documented by Kodiak NWR survey data and by local observers throughout the archipelago. Survey data indicate the population estimate for Common Murres in the northeastern region of the archipelago increased from 711 in June 2012 to 31,543 in June 2015 (4,335% increase), and from 5,063 in August 2012 to 64,039 in August 2015 (1,165% increase). *Received 12 June 2020. Accepted 19 May 2021.*

Key words: avian mortality, carcass survey, Gulf of Alaska, marine bird survey, seabird die-off.

RESUMEN (Spanish)—Un evento de mortandad del arao *Uria aalge* tuvo lugar de la primavera de 2015 a la primavera de 2016 en el norte del Golfo de Alaska. Eventos como este se han reportado previamente en la región, si bien esta mortandad en particular fue única por su larga duración y amplia extensión espacial. En respuesta a este incidente, biólogos del Kodiak National Wildlife Refuge (NWR) llevaron a cabo reconocimientos sistemáticos en playas a lo largo del sistema de caminos adyacente a la ciudad de Kodiak y recopilaron informes de habitantes locales en localidades remotas a lo largo del archipiélago Kodiak para documentar el número de aves muertas observadas en playas. El análisis de los registros de las aves encontradas en playas indica que fueron observados al menos 1,994 araos en el archipiélago Kodiak del 4 de abril de 2015 al 26 de abril de 2016. Extrapolando esta estimación de densidad, basada en cadáveres contados en reconocimientos sistemáticos en el sistema de caminos de Kodiak (55 araos/km, EE = 12) a todas las playas en el sistema de caminos de Kodiak en la misma clase de hábitat biofísico, según el mapeo costero de Alaska ShoreZone, la estimación total es de 6,305 araos muertos (IC 95% = 3,522–9,088). Además de araos, durante este evento de mortandad se encontraron cadáveres de 65 aves de 15 especies en las playas del sistema de caminos de Kodiak. Este evento de mortandad fue precedido por movimientos playa adentro de gran escala por especies de aves marinas típicamente vistos mar adentro (araos y pardelas) según fue documentado en los datos de reconocimiento del Kodiak NWR y por observadores locales en todo el archipiélago. Los datos de los reconocimientos indican que la estimación poblacional de araos en la región noreste del archipiélago se incrementó de 711 en junio de 2012 a 31,543 en junio de 2015 (un incremento de 4,335%), y de 5,063 en agosto de 2012 a 74,039 en agosto de 2015 (un incremento de 1,165%).

Palabras clave: Golfo de Alaska, mortandad aviar, mortandad de aves marinas, reconocimiento de aves marinas, reconocimientos de cadáveres.

Un evento de mortandad del arao *Uria aalge* en el archipiélago Kodiak, Alaska, abril 2015–abril 2016

Seabird die-offs have been documented periodically in western Alaska, and Common Murres (*Uria aalge*) are frequently the species most affected during these events (Murie 1959, Bailey and Davenport 1972, Piatt and Van Pelt 1997). Often, large numbers of murres are seen feeding much closer to shore than is typical just prior to the die-off (Piatt and Van Pelt 1997). In most cases, the ultimate

[1] Kodiak National Wildlife Refuge, Kodiak, AK, USA; e-mail: robin_corcoran@fws.gov

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cause of mortality remains speculative; however, die-offs often occur when sea surface temperatures are higher than average or during extreme storms.

The seabird die-off that occurred in the Gulf of Alaska (GOA) from spring 2015 to spring 2016 was unprecedented in spatial and temporal extent (Piatt et al. 2020). Between May 2015 and April 2016, approximately 45,000 Common Murre carcasses were recorded along 2,500 km of coastline in the GOA, and murre carcass encounter rates on beaches were 10–1,000× higher than normal for 9 continuous months (Jul 2015–Mar 2016; Piatt et al. 2020). The die-off coincided with the largest marine heatwave ever recorded in the northeast Pacific, between winters 2014 and 2015 (DiLorenzo and Mantua 2016). During this period, record sea surface temperatures (SST) were as much as 3 °C higher than average in the GOA and corresponded to low seabird breeding productivity in the region, including widespread breeding failure of Black-legged Kittiwake (*Rissa tridactyla*) and colony abandonment of Common Murre at multiple sites for the first time in over 35 years of monitoring (Dragoo et al. 2016).

This report describes the unusual behavior and deaths of Common Murres observed in the Kodiak Archipelago between April 2015 and April 2016. It is difficult to estimate the total number of birds that die during these events based on the number of carcasses counted on beaches, particularly in Alaska. This is because only a fraction of the birds that die at sea ever wash ashore (Bodkin and Jameson 1991, Van Pelt and Piatt 1995, Flint and Fowler 1998) and because western Alaska is a remote, largely uninhabited region, where systematic and comprehensive beach surveys are rarely logistically feasible. On Kodiak, we had the unique opportunity to conduct systematic beach surveys for dead birds throughout the extended period over which carcass deposition occurred. In addition, as part of the Kodiak National Wildlife Refuge (NWR) avian monitoring program, we conducted nearshore marine bird surveys that quantified large-scale inshore movements of Common Murres preceding and coincident with the die-off.

Methods

Study area

The Kodiak Archipelago is located in the GOA, 50 km east of the Alaska Peninsula and 140 km southwest of the Kenai Peninsula (Fig. 1). The area is characterized by ~4,500 km of rocky irregular coastlines with numerous glacially scoured straits, inlets, bays, and fjords with branching arms. Sea bluffs are generally steep and rocky, and numerous offshore rocks and islets occur along the coast (USFWS 2008).

Two primary factors that could strongly influence the deposition and persistence of dead bird carcasses in the archipelago are high tidal exchange and frequent strong winds. Tidal amplitudes range from 2.5 to 3.4 m on the east side of the archipelago adjacent to the GOA, and from 4.0 to 4.4 m on the west side of the archipelago adjacent to the Shelikof Strait (Plafker and Kachadoorian 1966). The archipelago experiences extreme variability in both the direction and speed of winds. Maximum gusts of over 167 km/h have been recorded, and gusts of over 93 km/h have occurred during each month of the year but are most likely to occur during winter (Alaska Climate Research Center data).

Beaches selected for monitoring throughout the die-off event were located on the Kodiak road system, a network of ~225 km interconnecting the city of Kodiak with outlying communities clustered at the northeastern end of Kodiak Island (Fig. 1). The beaches selected for monitoring were chosen for accessibility and because they were likely to accumulate marine debris, including dead birds, based on topography, exposure, and substrate type. Similar to studies of marine debris accumulation (Eriksson et al. 2013) and oil persistence (Peterson et al. 2002), these beaches were characterized by a combination of shallow to moderate shoreline slope (<5°–30°) and predominance of small-sized sediment substrates, and did not include extensive headlands or regions with steep cliffs. The lengths of beaches surveyed varied from 0.1 to 2.6 km (mean = 0.70, SE = 0.21), and in almost all cases had natural start and end points such as rocky headlands or stream or river outlets.

Beach surveys and incidental reports

Biologists and volunteers with Kodiak NWR conducted repeated surveys for carcasses and dying birds at 23 beach segments along the Kodiak Island road system from 25 August 2015 to 26 April 2016. From 1 to 3 observers walked the

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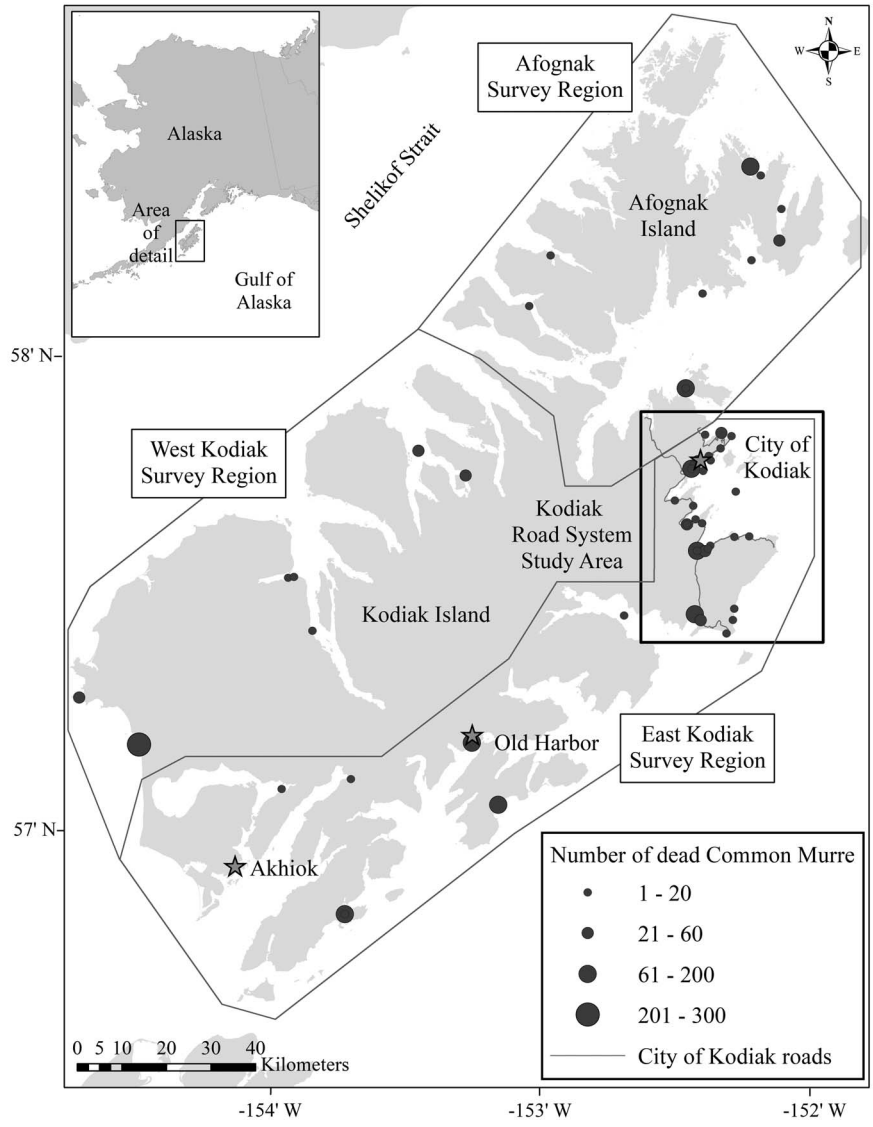

Figure 1. Locations and numbers of dead Common Murres (totaling 1,996 birds) reported in the Kodiak Archipelago, Alaska, from 4 April 2015 to 26 April 2016. The Kodiak road system study area where beaches were systematically searched for Common Murre carcasses is outlined. Regions (East Kodiak, Afognak, and West Kodiak) where Kodiak National Wildlife Refuge conducted nearshore marine bird surveys in June and August 2011–2016 are identified.

beach scanning for dead birds. We made multiple visits to 18 beaches and attempted to visit 7 beaches at least twice monthly. We used 3 methods to distinguish newly deposited birds from those previously counted. First, photographs were taken of each dead bird and each carcass was aged into 1 of 3 categories based on condition: <4, 4–14, and >14 d old. Any carcass fresher than the time interval between the current and previous visit was considered a new deposition. Second, carcasses were individually marked according to Coastal Observation and Seabird Survey Team (COASST; Parrish et al. 2007) program protocols at 3 beaches. Third, carcasses were marked with colored spray paint at 4 additional beaches. Carcasses were periodically collected, frozen, and

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sent to the USGS National Wildlife Health Center, Madison, Wisconsin, for necropsy to determine cause of death.

Biologists at Kodiak NWR compiled additional reports of dead Common Murres along the Kodiak road system and from remote sites including villages, visitors, fisherman, and guides throughout the archipelago. These observations were submitted voluntarily to Kodiak NWR and Alaska Department of Fish and Game.

Estimation of total number of dead Common Murres

We used Alaska ShoreZone Habitat Mapping (http://www.shorezone.org/) to generate an estimate of the total number of dead Common Murres that might have washed ashore on beaches in the Kodiak road system region. ShoreZone is a coastal habitat mapping and classification system in which georeferenced aerial imagery is used to interpret and integrate geological and biological features of the intertidal zone and nearshore environment. Post hoc analysis of beaches selected on the Kodiak road system for carcass surveys identified 20 of the 23 beaches (15.6 of the 16.1 km surveyed) in 4 ShoreZone habitat classes: semi-exposed mobile substrate, semi-protected mobile substrate, semi-protected partially mobile substrate, and protected partially mobile substrate. We excluded the habitat classes of 3 segments from the analyses because of the small percentage of beach surveyed in these categories.

We used a polyline shapefile from ShoreZone habitat mapping in a Geographic Information System (GIS) to calculate the total length of coast in the Kodiak road system region, and the length of coastline in the 4 habitat classes. We calculated the density of dead Common Murres per kilometer of beach for each of the 23 beaches surveyed on the Kodiak road system using the total number of new carcasses found during visits from 25 August 2015 to 13 April 2016 (the last survey when we recorded new carcasses) divided by the length of the surveyed beach. We calculated the mean density of dead birds and corresponding standard error for the 23 surveyed beaches and extrapolated the results for all beaches in the 4 habitat classes to estimate total number of dead Common Murres in the Kodiak road system region.

Marine bird surveys

Kodiak NWR biologists surveyed nearshore marine birds in June and August 2011–2016. The survey design consisted of both nearshore-intertidal transects (mean high tide line to 400 m offshore) and offshore transects (0.5–5 km offshore). Transects were systematic from a random start point with approximately 20% of the nearshore and 4–10% of the offshore regions surveyed. Surveys were conducted from a 6 m skiff traveling at 6–9 km/h, and all birds seen within 300 m of the skiff were recorded. The survey crew typically consisted of 2 observers, a skiff operator, and a data entry person. Data were entered on a ruggedized laptop with GPS using dLOG3 software designed for bird surveys (Ford 2009). In 2011 and 2014 East Kodiak Island was surveyed, and in 2013 and 2016 West Kodiak Island was surveyed (Fig. 1). In both 2012 and 2015, the northeastern end of the Kodiak Archipelago including Raspberry, Afognak, and Shuyak islands was surveyed (Fig. 1), allowing comparisons between years with and without a seabird die-off.

We used transect densities (birds/km^2) to calculate mean density and standard error (SE) for each region and survey, and we used a ratio estimator (Cochran 1977, Williams et al. 2002) to estimate population sizes and variances (Agler et al. 1994, Klosiewski and Laing 1994). The difference in mean density in the nearshore and offshore survey zones was analyzed with a paired *t*-test with the null hypothesis that the difference in density was 0.

Results

Beach surveys

We completed 160 surveys along 23 beach segments along the Kodiak Island road system from 8 May 2015 to 26 April 2016. Dead murres were found on every beach searched with one exception. We recorded 786 carcasses representing 16 bird species along the Kodiak road system (Table 1). The vast majority of carcasses (92%) were Common Murre, followed by Crested Auklet (*Aethia cristatella*, 3%), a species that regularly winters in offshore waters of the Kodiak region. Crested Auklets were first sighted in the nearshore zone in December 2015, and the first auklet

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Table 1. Total number of dead birds by species recorded on beaches in the Kodiak Archipelago, Alaska, from 4 April 2015 to 26 April 2016. Beaches ($n = 23$) along the road system adjacent to the city of Kodiak were regularly searched for carcasses from 25 August 2015 to 26 April 2016. The total number of dead birds reported to Kodiak National Wildlife Refuge from both remote sites and the road system in the Kodiak Archipelago are also summarized.

Species	Scientific name	Kodiak road system	Remote sites and additional reports
Common Murre	*Uria aalge*	721	1,275
Crested Auklet	*Aethia cristatella*	24	
Black-legged Kittiwake	*Rissa tridactyla*	15	
Marbled Murrelet	*Brachyramphus marmoratus*	7	
Pelagic Cormorant	*Phalacrocorax pelagicus*	4	
Tufted Puffin	*Fratercula cirrhata*	3	
Northern Fulmar	*Fulmarus glacialis*	2	
Red-necked Grebe	*Podiceps grisegena*	2	
Sooty Shearwater	*Puffinus griseus*	1	
Cassin's Auklet	*Ptychoramphus aleuticus*	1	
Glaucous-winged Gull	*Larus glaucescens*	1	
Horned Grebe	*Podiceps auritus*	1	
Horned Puffin	*Fratercula corniculata*	1	
Long-tailed Duck	*Clangula hyemalis*	1	
Bufflehead	*Bucephala albeola*	1	
White-winged Scoter	*Manitta fusca*	1	

mortality was reported on 29 December 2015. Examining the mean number of carcasses found on a monthly basis, there appeared to be 2 peaks in deposition; the first, in September 2015 when carcasses averaged 21.6 birds/km (SE = 8.0, $n =$ 21 surveys, 14 beaches), followed by a second in December 2015 when carcasses averaged 16.2 birds/km (SE = 10.0, $n = 20$ surveys, 11 beaches) (Table 2).

In total, 52 carcasses of birds (86% Common Murre) collected from June 2015 to March 2016 were submitted to the USGS National Wildlife Health Center from the Kodiak Archipelago. Emaciation was a consistent finding in all but one of the birds examined.

Table 2. The mean number of dead Common Murre carcasses recorded on a monthly basis on beaches on the road system adjacent to the city of Kodiak, Alaska, from July 2015 to April 2016. SE = standard error; n = sample size.

Month and year	Mean (SE)	n (surveys, beaches)
Jul 2015	0.3 (0.3)	(4, 2)
Aug 2015	1.0 (0.7)	(13, 7)
Sep 2015	21.6 (8.0)	(21, 14)
Oct 2015	5.4 (2.0)	(18, 14)
Nov 2015	4.6 (2.5)	(17, 11)
Dec 2015	16.2 (10.0)	(20, 11)
Jan 2016	4.6 (1.6)	(27, 9)
Feb 2016	4.1 (1.2)	(13, 8)
Mar 2016	2.0 (0.8)	(16, 8)
Apr 2016	0.4 (0.2)	(8, 8)

Incidental reports

Local residents reported dead murres on beaches of the Kodiak road system starting in early April 2015. Coincident with reports of dead murres, there were also many spring and summer observations in nearshore areas of seabird species that are highly pelagic and normally occur offshore (Common Murre and mostly Sooty Shearwaters [*Ardenna grisea*]) foraging within 100–200 m of shore and at the heads of bays. In mid-August several residents along the Kodiak road system noted unusual Common Murre behaviors, primarily individual or small groups of birds hauled out on rocks or beaches. As the month progressed more local residents noted sick and dead murres on many beaches. Reporting peaked between 21 August and 7 September 2015.

In total, 1,275 dead Common Murres were observed incidentally (outside regular surveys) in the Kodiak Archipelago (Table 1). Most (68%) of the 44 incidental reports were from remote locations throughout the archipelago, suggesting the murre die-off was widespread (Fig. 1). Seven observations exceeded 100 dead birds on a single occasion, including an estimated 300 dead murres

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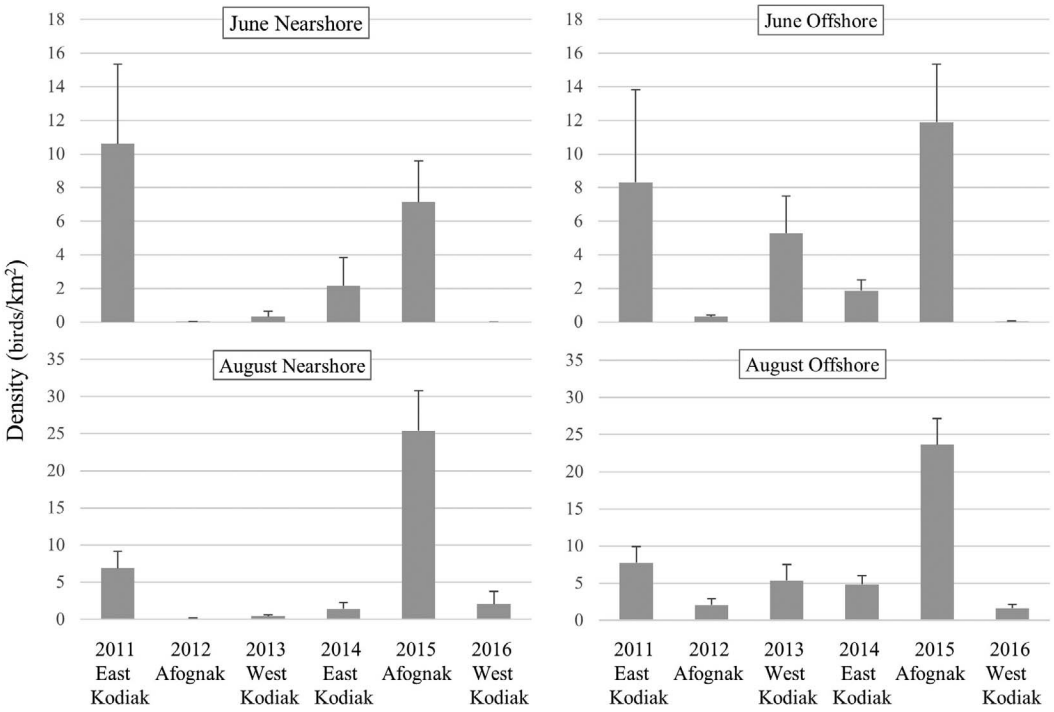

Figure 2. Common Murre density (birds/km^2) on nearshore and offshore transects surveyed June and August on East Kodiak Island (2011 and 2014), Afognak Island (2012 and 2015), and West Kodiak Island (2013 and 2016) in the Kodiak Archipelago, Alaska. Bars = 1 standard error.

along a 5 km stretch of beach at the mouth of the Ayakulik River at the western end of Kodiak Island in mid-August 2015. Several observers (21%) who reported dead murres also noted seeing higher than normal murre abundance in nearshore areas including heads of bays.

Estimation of total number of dead Common Murres

Based on Alaska ShoreZone Habitat Mapping, the total shoreline length in the Kodiak road system region in the 4 primary habitat classes of beaches searched was 114 km (~29% of the 390 km of road system coastline). The mean density of dead Common Murres was 55 birds/km (SE = 12) at the 23 beaches surveyed on the Kodiak road system from 25 August 2015 to 13 April 2016. Expanding the density estimate across all beaches in the 4 habitat classes in the road system region yielded an estimate of 6,305 dead Common Murres (95% CI = 3,522–9,088).

Marine bird surveys

Common Murre density in both the nearshore and offshore survey zones in 2015 was among the highest recorded in surveys conducted from 2011 to 2016 in the Kodiak Archipelago (Fig. 2). While nearshore density was highest in June 2011 on the east side of Kodiak Island, this may have been due to the fact that the largest existing Common Murre colonies in the archipelago fall in this region, and the largest is located on a nearshore transect at Inner Right Cape Islets, Kiliuda Bay. Comparison of 2012 and 2015 nearshore marine bird surveys revealed striking differences in Common Murre distribution at the northeastern end of the archipelago. Occurrence of Common Murres increased from 6% of nearshore transects (≤400 m from shore) in 2012 to 57% of transects in 2015. Correspondingly, Common Murre densities on the nearshore transects increased significantly from 0.02 birds/km^2 in June 2012 to 7.13 birds/km^2 in June 2015 (t-test = 2.89, df = 44, P = 0.006). Increases in density were mirrored in August, with

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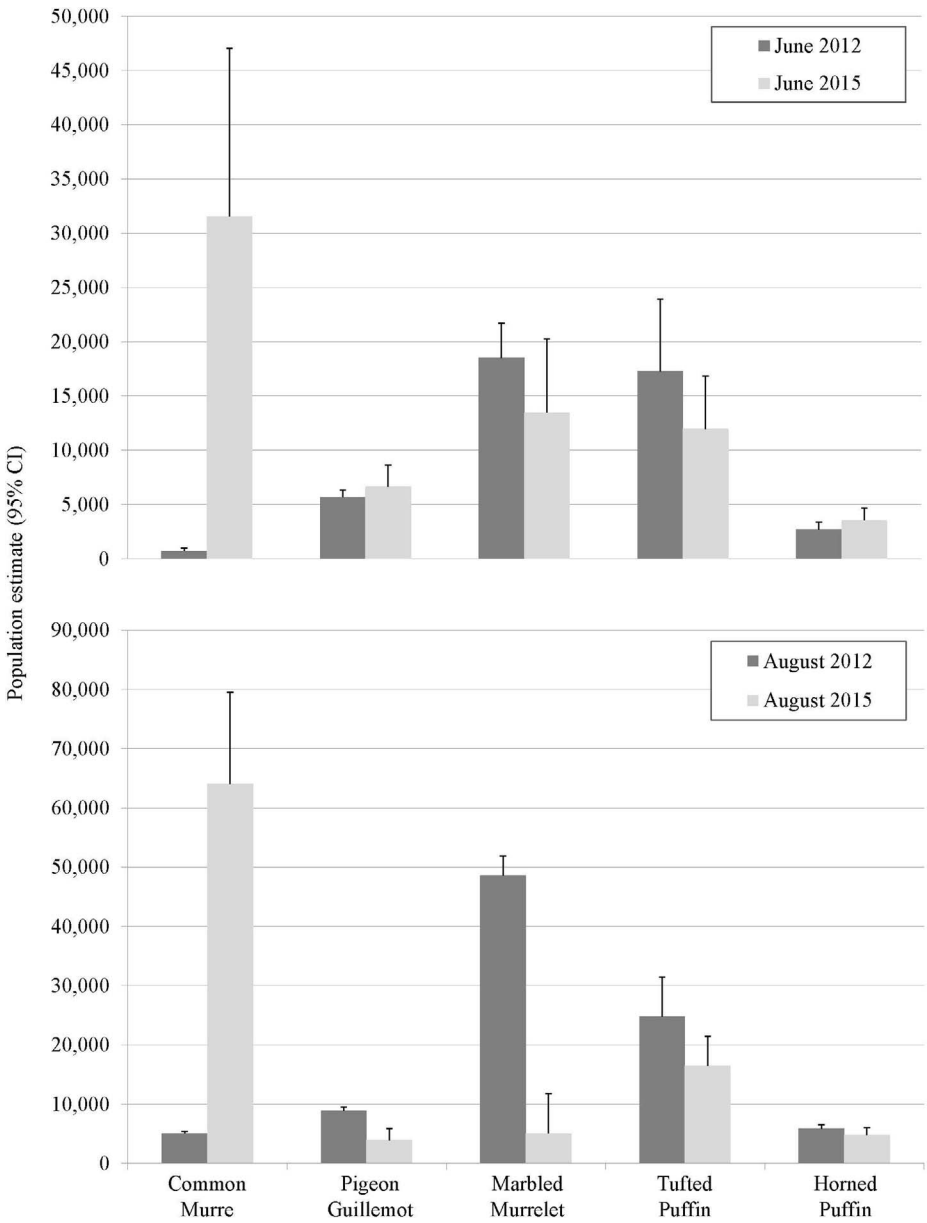

Figure 3. Means and 95% confidence intervals (CI) of population estimates of the most common breeding alcid species in the Kodiak Archipelago, Alaska, in June (top) and August (bottom) 2012 and 2015. Results are based on nearshore marine bird surveys conducted on the northeast end of the archipelago.

density on nearshore transects increasing significantly from 0.13 birds/km^2 in 2012 to 25.4 birds/km^2 in 2015 (t-test = 4.69, df = 42; $P < 0.001$). The corresponding population estimate for Common Murre in the northeastern region of the archipelago increased from 711 in June 2012 to 31,543 in June 2015 (4,335% increase), and from 5,063 in August 2012 to 64,039 in August 2015 (1,165% increase) (Fig. 3).

Comparison of June 2012 and 2015 survey data indicated no significant differences in population estimates of the other common breeding alcids

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(Marbled Murrelet [*Brachyramphus marmoratus*], Pigeon Guillemot [*Cepphus columba*], Tufted and Horned puffins [*Fratercula cirrhata* and *F. corniculata*]) in the northeastern Kodiak Archipelago (Fig. 3). However, in August, Marbled Murrelet and Pigeon Guillemot population estimates declined significantly from 2012 to 2015 (*t*-tests, both $P < 0.05$; Fig. 3). Marbled Murrelet population estimates declined 90% from 48,624 in August 2012 to 4,998 in August 2015, and Pigeon Guillemot population estimates declined 56% from 8,811 in August 2012 to 3,893 in August 2015 (Fig. 3).

Discussion

Seabird die-offs have been documented periodically in western Alaska, but this event was unique in its long duration and wide spatial extent (Piatt et al. 2020). Observations during the Common Murre die-off in the Kodiak Archipelago in 2015–2016 were consistent with previous mass mortality events in the region (Nysewander and Trapp 1984, Piatt et al. 1998, Drovetski et al. 2012). First, Common Murres, and to a lesser extent other offshore marine bird species, were increasingly observed inshore preceding the die-off, perhaps indicating that food resources offshore were not sufficient to meet their needs. In the Kodiak Archipelago nearshore (<5 km from shore) populations of Common Murres increased 44-fold in June and 13-fold in August between 2012 and 2015. Based on seabird colony records, Common Murres nest at 37 sites in the archipelago (Corcoran 2013). Both historical data and recent counts indicated that the largest colonies did not exceed 700 individuals, and the mean number of murres per colony was 71 (SE = 23) from 2001 to 2011. Because there were no large breeding colonies of Common Murres in the Kodiak Archipelago, birds could have moved into the area from large nesting concentrations outside the archipelago.

Widespread breeding failure was documented at large colonies within the GOA including East Amatuli and Chowiet Islands (Dragoo et al. 2016, Piatt et al. 2020). Once inshore, the birds exhibited unusual behaviors like sleeping while swimming or hauled out onshore, and many had worn and ragged plumage (pers. obs.). Despite the high number of murres tallied during surveys in Kodiak in June and August, we recorded very few dead birds, and it appears mass mortality did not begin in the region until September. This timing coincided with the post-breeding molt, putting an additional energetic strain on the birds while they were flightless (Guillemette et al. 2007, Dunn et al. 2020) and unable to travel long distances in response to changes in forage fish availability. However, there appeared to be at least 2 peaks in carcass deposition, first in September 2015 and second in December 2015 (Table 2). Consistent with reports of previous die-offs, there was no evidence of widespread disease or contaminant exposure (Piatt and Van Pelt 1997), and all but one necropsied bird from the archipelago were emaciated suggesting starvation as the cause of death.

During a die-off event the number of carcasses recorded on beaches depends on the rate and pattern of deposition, persistence rates, and detection probabilities of observers (Byrd et al. 2009). All 3 of these processes vary depending on beach type, currents, winds, tides, weather, carcass size, and degree of scavenging (Bodkin and Jameson 1991, Van Pelt and Piatt 1995, Fowler and Flint 1997). Modeling these processes across 23 beach segments over a 9 month period was beyond the scope of this project. We did however try to control for these factors by marking and ageing carcasses to avoid double counting, and only extrapolating the density estimate to beaches in the same habitat class as those searched. Similar to a study conducted on Unalaska Island following the wreck of the M/V *Selendang Ayu* (Byrd et al. 2009), carcass persistence rates appeared to be low on the Kodiak road system with marked birds resighted on 24 of 160 surveys. Potential reasons for low persistence rates include high tidal exchange, frequent storms, and numerous resident scavengers, including red foxes (*Vulpes vulpes*), Common Ravens (*Corvus corax*), Bald Eagles (*Haliaeetus leucocephalus*), and Glaucous-winged Gulls (*Larus glaucescens*).

Many of the previous die-off events in western Alaska occurred in association with warm SST. The die-off of 2015–2016 occurred during the largest recorded marine heatwave in the northeast Pacific, during which record SSTs were as much as 3 °C higher than the mean in the GOA (Bond et al. 2015, DiLorenzo and Mantua 2016, Oliver et al. 2018). Although forage fish abundance and

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distribution data in the GOA are limited, availability of these fish is believed to decline in response to warm SST (Bailey et al. 1995, Anderson and Piatt 1999).

The "ectothermic vise" hypothesis proposes that prolonged warm SST reduced phytoplankton biomass and restructured zooplankton communities resulting in lower–energy rich species while at the same time increasing food demands of ectothermic forage fish (Piatt et al. 2020, Arimitsu et al. 2021). In addition, large ectothermic groundfish that feed on forage fish increased metabolic demand due to prolonged warm SST resulting in increased competition with seabirds (Piatt et al. 2020). While other marine bird species would also have been impacted by changes in forage fish availability, Common Murres may have made up the vast majority of carcasses found on beaches in Kodiak because they were the most common species on surveys, outnumbered only by Black-legged Kittiwakes. Murres also were observed in protected waters, foraging in the surf zone, and walking ashore before dying—factors that likely increased their detection on and from beaches.

The use of high resolution ShoreZone imagery in this study to quantify beaches with characteristics that were amenable to carcass deposition could have wider applications. As of 2018, ShoreZone imagery and associated habitat classification was available for most of the Alaska coast (NOAA Fisheries 2018). Coupled with imagery, the habitat classification can be used to identify potential survey sites in remote regions of Alaska to assess future die-off events. Calculating carcass encounter rates based on beach topography, exposure, and substrate type could improve estimates of carcass deposition over large areas of coastline.

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