THICK-BILLED MURRES *URIA LOMVIA* AT CAPE PARRY, NORTHWEST TERRITORIES: CORE-USE AREAS, MORPHOMETRICS, AND CHICK DIETS

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ABSTRACT

Paredes, R., Insley, S. J., Luque, S., & Kortsalo, P. (2025). Thick-Billed Murres *Uria lomvia* at Cape Parry, Northwest Territories: Core-use areas, morphometrics, and chick diets. *Marine Ornithology*, *53*(1), 111–122. http://doi.org/10.5038/2074-1235.53.1.1631

Cape Parry is home to the only colony of Thick-billed Murres *Uria lomvia* in the western Canadian Arctic, but ecological information for this small, isolated population is lacking. To address this information gap, we investigated the spatial distribution, diving behaviour, diet, and morphometrics of male and female Cape Parry Thick-billed Murres during the breeding season. We tracked 23 chick-rearing adults (seven females and 16 males) using Global Positioning System (GPS) tags with depth sensors (2021) and collected chick diet data (2021, 2022) using observations and photos. Cape Parry murres foraged relatively close to the colony (4.5 ± 3.3 km) and mostly within the marine boundaries of the Anguniaqvia Niqiqyuam Marine Protected Area (ANMPA). Core-use foraging areas (50% utilization distribution [UD] of dive locations) and diving depths (up to 70 m) coincided with the relatively shallow waters near Cape Parry. There was no difference between sexes in foraging locations, but there was a clear difference between sexes in foraging times, as has been reported in other studies. Dive bouts at night, mostly performed by males, consisted of more frequent, shallower dives compared with daylight diving. Dive bout duration and calculation of murre diving efficacy suggest foraging effort ("time spent feeding") was similar between day and night. Adults delivered fish up to 142 mm in length to their chicks, with a majority (81%–90%) consisting of pelagic Arctic Cod *Boreogadus saida*, benthic Daubed Shanny *Leptoclinus maculatus*, and benthic Sandlance *Ammodytes* spp., with a higher proportion of Artic Cod delivered in 2022 compared to 2021. Morphometric measurements placed Cape Parry females closer to Atlantic than Pacific colonies, and Cape Parry males were positioned between the two geographic groups. In summary, this study provides the first spatial and foraging ecology data for the Cape Parry population of Thick-billed Murres, which is crucial for management and evaluating the adequacy of the ANMPA in supporting this species.

Key words: diving, Cape Parry, diets, foraging, morphometrics, murres, tracking

INTRODUCTION

Cape Parry Peninsula, Northwest Territories, Canada, is home to the only Thick-billed Murre *Uria lomvia* colony in the western Canadian Arctic, and it is more geographically isolated than any other murre colony in the world: Prince Leopold Island is 1,200 km to the east (Atlantic), and Cape Lisburne is 1,500 km to the west (Pacific; Johnson & Ward, 1985; Fig. 1). Given the location of Cape Parry in the Beaufort Sea, this colony was thought to represent the Pacific subspecies *Uria l. arra*, which is larger in body size than the Atlantic subspecies *Uria l. lomvia* (Gaston & Jones, 1998). Genetically, however, the Cape Parry colony appeared to be more closely related to the Atlantic than the Pacific subspecies (Tigano et al., 2015). In 1979, the Cape Parry murre population was estimated at 800 individuals based on counts of the main group at Police Point (Johnson & Ward, 1985). Recent photo surveys that include Police Point and East Point estimated a total population of 1,358 individuals (Hogan & Sidler, 2023). No chicks were reported during these murre surveys (Hogan & Sidler, 2023; Johnson & Ward, 1985). In the 1950s, residents of an Inuvialuit village at Cape Parry, which is no longer in existence, harvested murre eggs for food (J. Ruben, personal communication, 07 August 2021). In 1961, the Cape Parry Migratory Bird Sanctuary (MBS) was established to protect the nesting habitat of Thick-billed Murres. Later, in 2016,

the Anguniaqvia Niqiqyuam Marine Protected Area (ANMPA) was created surrounding Cape Parry to protect offshore marine habitats and wildlife from potential human disturbances—such as commercial fishing, oil and gas development, and shipping—predicted to increase due to climate change (Chambers & McDonell, 2012). The ANMPA marine boundaries were determined based on Ecologically or Biologically Significant Marine Areas (EBSAs) and important habitats for wildlife and local traditional use (Kavik-Axys Inc., 2012). The foraging ranges and diet of Cape Parry Thick-billed Murres are listed as important knowledge gaps for the ANMPA future management plans (Fisheries and Oceans Canada, 2022; Paulic et al., 2012).

Seabird tracking provides useful information for identifying potential Marine Protected Areas (MPAs; LeCorre et al., 2012) and for delineating and managing existing MPAs (Thaxter et al., 2012). This includes information on species-specific home ranges and habitat preferences. Tracking studies are also used to identify areas of potential conflict between seabirds and human development activities such shipping traffic (Gaston et al., 2013), oil and gas (Hedd et al., 2018), and wind farms (Green et al., 2023). Miniaturized bird-borne data loggers that simultaneously collect location and time-depth data are useful to identify the most likely feeding locations or core-use areas of diving seabirds

Fig. 1. Location of the Cape Parry Thick-billed Murre *Uria lomvia* colony (center) in relation to Atlantic colonies to the right and Pacific colonies to the left (Google Earth Pro 7.3.6, October 10, 2024).

(e.g., Harding et al., 2013; Linnebjerg et al., 2015; Orben et al., 2015). Thick-billed Murres can dive to a 200 m depth and fly up to 185 km from their breeding colonies (Gaston & Jones, 1998; reviewed in Patterson et al., 2022). Foraging ranges appear to be directly related to colony size (Patterson et al., 2022), and consequently, Cape Parry murres were expected to forage near the colony. Variability in local conditions may also influence home ranges; murres can make extensive foraging trips to access suitable feeding habitats in years of reduced food availability (Eby et al., 2023; Kokubun et al., 2018; Paredes et al., 2015). In addition to increased foraging effort, murres can change diets and nutritional stress level in response to environmental changes (Piatt et al.; 2007; Regular et al., 2014; Will et al., 2020). For example, since the 1980s, a significant decrease in the availability of high-energy prey in murre chick diets, specifically Arctic Cod *Boreogadus saida*, has coincided with the early melt of sea ice in the Hudson Bay region (Mallory et al., 2010). Similarly, a reduction in key forage fish in the diets of murre chicks from the Pribilof Islands, along with elevated corticosterone levels, has coincided with the timing of sea-ice melting in the Bering Sea continental shelf (Kokubun et al., 2018). Monitoring murre chick diets through feeding watches is a relatively inexpensive and non-invasive method to continually assess changes in marine ecosystems (e.g., Harris et al., 2022; Mallory et al., 2010).

Thick-billed murre males and females may have different foraging strategies (e.g., Elliott et al., 2010; Paredes et al., 2008) and, therefore, may respond differently to changes in local conditions (e.g., Young et al., 2015). Although sex differences in diet and spatial distribution are not observed in all colonies, male and female murres consistently segregate in the times of day when they forage or attend the colony (reviewed in Huffeldt et al., 2021). It is unclear, however, why males forage at night in some colonies and during the day in others (Elliott et al., 2010; Huffeldt et al., 2021; Paredes et al., 2008). Shallow diving of the male or female foraging at night has been attributed to the diel vertical migration (DVM) of prey in some low-Arctic colonies (Paredes et al., 2008; Young et

al., 2015). Interestingly, temporal patterns between the sexes persist in colonies with 24 h daylight despite the lack of DVM of prey as suggested by murre dive depths (Huffeldt et al., 2021). Differences in temporal patterns in foraging or nest attendance between the sexes have been attributed to parental roles and male-only care in the Alcini tribe (Paredes et al., 2006; Young et al., 2015), prey specialization (Elliott et al., 2010), and a combination of social and ecological factors (reviewed by Huffeldt et al., 2021). The slight sexual size dimorphism of Thick-billed Murres, mostly in bill and head measurements (Gaston & Jones, 1998; Stewart, 1992), has been proposed as a possible explanation for foraging differences between the sexes (Elliott et al., 2010), and for male-biased agonistic behaviour and breeding site defence (Jehl & Murray, 1986; Paredes et al., 2006). Further studies in colonies, including Cape Parry, help to shed light on the factors responsible for sex differences in foraging behaviour and attendance patterns.

In this study, our main goal was to determine the core-use areas of male and female Cape Parry Thick-billed Murres (henceforth murres) during the chick-rearing season. Our first objective was to determine the spatial distribution and primary feeding areas of murres, and to compare this to the ANMPA boundaries (Paulic et al., 2012). To do so, we used short-term deployments of single miniaturized global positioning system (GPS) data loggers with time-depth sensors to obtain diving locations of murres. Our second objective was to characterize diving behaviour to investigate sex differences in patterns of night and day foraging and colony site attendance (reviewed in Huffeldt et al., 2021). Our third objective was to assess provisioning diets by conducting feeding watches and photographing prey delivered to chicks, which provided insights into foraging behaviour and the availability of key forage fish, such as Arctic Cod. Finally, we used morphometrics to compare the body size of Cape Parry murres to published accounts of those from Atlantic and Pacific murre colonies. We expected Cape Parry murres to be smaller in body size than Pacific birds given that they are more closely related to Atlantic murres (Tigano et al., 2015).

METHODS

Study site and species

The study took place at Police Point, Cape Parry MBS (70°10′59″N, 124°45′27″W; Fig. 2A). The murre colony is located on 20–30 m (above sea level [asl]) limestone cliffs of Silurian and Ordovician origin facing the Amundsen Gulf in the Beaufort Sea. The murres nest mostly on bare ledges, with some also nesting inside small caves and crevices (Johnson & Ward, 1985; this study). Data were collected between 01–12 August 2021 and 26 July–09 August 2022. We studied two murre groups, located 0.5 km apart; Johnston & Ward (1985) referred to our main study group as Group #4, and the group at Cow's Point as Groups #1

and #3, with 152 and 90 active sites, respectively. A breeding site was considered active if the adult had an egg or chick or was sitting in a prone rather than an upright position (Derksen, 1977). The Police Point murre colony is located ~2 km from the Cape Parry Distant Early Warning (DEW) station, which was operational during the study. Aircraft transporting personnel or supplies occasionally flushed nesting murres by flying too close to the colony. Ambient temperatures were colder in 2021 (range, mean ± standard deviation [SD]: 0.2–13.6 °C, 4.2 ± 4.1 °C, n = 12 d) than in 2022 (4.4–12.8 °C, 7.7 ± 2.3 °C, n = 15 d; https://climate.weather.gc.ca/). Pack-ice was present nearshore only in 2021, during which sea temperatures ranged between −1.5 and 4 °C (1.9 ± 1.2 °C, n = 205,095 records) during dives, based on time-depth recorders.
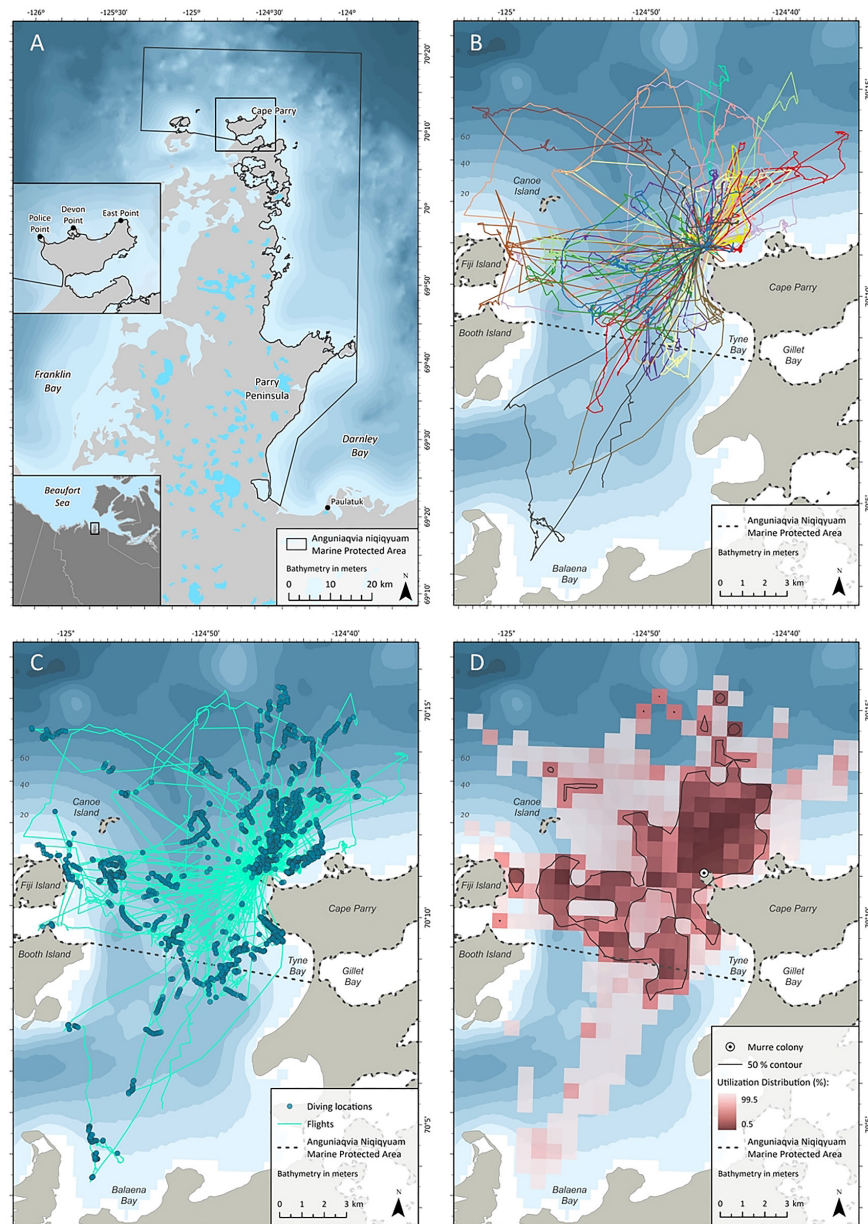

Fig. 2. Spatial distribution of Cape Parry Thick-billed Murres *Uria lomvia* rearing chicks during August 2021. (A) Cape Parry Anguniaqvia Niqiqyuam Marine Protected Area (ANMPA) boundaries, (B) GPS tracks (n = 23 birds; 148 trips), (C) GPS tracks with diving locations (green dots), and (D) kernel density of dive locations showing the total foraging areas (99.5% utilization distribution [UD]) and core-feeding areas (50% UD).

In 2021, most murres had eggs hatching at Police Point on 01 August. In 2022, most murres had eggs hatching on 27 July, and first chicks were observed on 31 July. A fledgling was first observed departing from Cow's Point on 15 August 2021. Two pairs of Common Murres *Uria aalge* were also observed breeding at Police Point; one had a chick, and both pairs were part of the Thick-billed Murre colony. This supports the small numbers (two adults) reported at sea by Johnson & Ward (1985), and the incorrect report of 200 birds by Taylor et al. (2015). The primary aerial predators were Glaucous Gulls *Larus hyperboreus*, with seven individual birds and one nest containing chicks observed.

Data collection

Foraging location, diet, and morphometrics

Thirty-two adult murres were outfitted with Axy-trek GPS data loggers (Technosmart, Inc.; Rome, Italy). We used a single unit rather than multiple units to minimize potential instrument effect on birds' behavior (Evans et al., 2020). Each bird was captured at the nest site using noose poles (6–8 m long), weighed with a Pesola balance (± 1 g; ITM Instruments; Toronto, Canada), color-marked with livestock markers, fitted with a GPS data logger, and released after 5–8 min. The GPS with pressure and temperature sensors (external antenna, 45×20×8 mm, 12 g; or internal antenna, 40×20×10 m, 14 g) was attached to the lower back feathers using Tesa tape and two cable ties. The total weight of the GPS and attachment material (14–18 g) was 1.4%–1.8% of the mean body mass (984 g, $n = 53$) of captured murres. GPS tags were set to record location every 1–3 min, and pressure (resolution of 0.2 m and accuracy of ± 0.1 m), temperature (resolution 1 °C and accuracy of ± 2 °C), and wet-dry every 1 s. Birds were recaptured for GPS retrieval 24–48 h later, at which time they were weighed, measured (culmen length, tarsus, wing cord, head and bill), and banded with a permanent metal band (Bird Banding Laboratory, United States Geological Survey [USGS]). Chest feathers were also collected for eventual determination of sex at the Cri Genomics Laboratory, New Brunswick University. An additional 28 birds were captured once for morphological measurements, banding, and feather sampling.

Observers used binoculars (10×42 magnification) to identify prey delivered to chicks. In 2021, prey identifications were confirmed opportunistically with cameras (Nikon DSLR with a 400 mm lens; iPhone, max. 10× magnification) between 10h00–22h00. In 2022, identifications were confirmed during dedicated feeding watches (30–120 min/d) between 10h30–20h00. The Live Mode of the iPhone camera often helped to capture a three-dimensional view of each prey. Prey were identified to the genus and species level, when possible, using a laminated field guide prepared in advance based on *Marine Fishes of Arctic Canada* (Coad & Reist, 2018). Fish lengths were estimated using the murre gape length (62 mm; this study) as a reference and recorded as larger, same, or smaller gape in both years.

Data analysis

Foraging location and diving behaviour

We used GPS and diving data to determine foraging trip, dive, and dive bout characteristics, to characterize temporal foraging patterns, and to determine differences between the sexes. The diving data were analyzed using the "diveMove" package (version 1.6.1; Luque, 2007) in R (R Core Team, 2021, and the spatial data analyzed using NAD 1983 UTM Zone 10N projection in ArcGIS Pro 2.8.2.

Pressure signals from Axy-Trek loggers were transformed to water depth and corrected for their zero-offset and drift from the expected surface measurement using a recursive filtering method (Luque & Fried, 2011). For consistency with other studies (Elliott et al., 2010; Linnebjerg et al., 2014), dives were identified as departures greater than 3 m below the surface ($n = 5,087$). To examine diel differences in foraging behaviour, frequencies of "day" or "night" dives were calculated based on sunrise (03h47–05h07) and sunset (00h56–23h37, https://nrc.canada.ca/en/research-development/products-services/software-applications/sun-calculator/). Because sunrise/sunset times vary substantially throughout the summer, each dive was classified individually as day or night based on the calendar date when it occurred.

Using "diveMove" package in R, we estimated maximum depth, duration, dives per hour, and dive bout parameters (bout duration, dives per bout) to characterize day and night foraging behaviour. Dive bouts were defined as successive dives interrupted by a relatively longer post-dive period. Bout duration is used as an indicator of the time spent within a prey patch (Ford et al., 2015; Mori, 1998), and the number of dives per bout is used as an index of the size of the prey patch (Boyd, 1996; Sommerfeld et al., 2015). We used the absolute difference between successive post-dive intervals (PDI, the time between the end of one dive and the beginning of the next) to examine the temporal structure of diving. We modeled the distribution of sequential differences in PDI as a mixture of two random Poisson processes, fitted using maximum likelihood (Luque, 2007). The dive bout ending criterion was derived from model parameters separating the two processes. We calculated dive efficiency as the proportion of bottom time over a complete dive cycle (dive duration + PDI; Ydenberg & Clarke, 1989) and used it as an indicator of "time feeding". Pursuit or prey-catching behaviour in murres, which mostly occurs during the bottom phase of a dive, was shown by Chimienti et al. (2017). Herein, we use the term dive efficacy, instead of dive efficiency, to account for the uncertainty of energy intake. PDI values > 140 s, which are double the dive depth duration (< 8% of dives), were excluded from this analysis. We compared these dive and dive bout parameters using separate generalized mixed linear models (GMLM) with gamma distribution and log link function, with time of day (day and night) or sex (male and female – day only) as dependent variables and individual as a random factor. The bout duration was modeled using linear mixed models (LMM) after log-transformation, with time of day as a dependent variable and individual as a random factor.

Only GPS locations with diving data were used to determine the foraging trip parameters: maximum trip distance (straight distance to furthest point), trip duration, and total traveled distance. First, the start and end of a trip were determined using two buffers with 50 m and 10 m radii around a center point of each nest site, using density-based clustering tools. Dives were then merged to the nearest GPS location by time to the start of a dive, as determined by activity data using a python 3.6 pandas-library and its *merge_asof* function with the *near* variable. A dive started when "dry" changed to "wet," and the next dive started only if it was followed by a "dry" stage. For six birds without correct activity data, we used the time difference between each dive feature, and the start time of a dive was identified if the time difference between two features was greater than 1 s. Using these two methods, we obtained 5,000 dive locations (98%

of the total number of dives) and identified 98 foraging trips out of 141 total trips. Non-foraging trips (trips without dives) were significantly shorter (0.63 ± 0.06 km, $n = 43$) than trips with dives (4.36 ± 3.2 km, $n = 98$ trips, $F_{1,144} = 131.705$; $P < .001$). Trip parameters were modeled using LMM, using sex as a fixed factor and individual as a random factor.

To summarize the spatial distribution of murre diving effort, we used Brownian Bridge animal movement models to estimate their utilization distribution (Horne et al., 2007), accounting for autocorrelation of positions. Two smoothing parameters were required for this purpose; one to account for the imprecision of location estimates, which was set at 20 m, and the other to account for animal speed, which was determined via maximum likelihood (Horne et al., 2007). The kernel was evaluated over a grid with a total size of 30 × 40 km. We weighed the resulting kernel density by the number of locations per individual per pixel to avoid unduly biasing the combined utilization distribution (UD) towards any specific individual. Therefore, the 95% UD and 50% UD represent the total and core-use areas, respectively.

Diet

We calculated the percent occurrence of identified prey group or species delivered to chicks based on the total number of items per year. We also compared the estimated prey size frequencies between years, categorized according to gape length: larger, same size, or smaller. These categorical prey size estimates were made qualitatively on site for both years. Frequency of occurrence of prey species, and categorical size, were compared between years using chi-square tests. In addition, pictures taken in 2022 were used to provide more detailed prey length measurements (continuous data) to calculate energy content based on Elliott et al. (2008). Note that prey length in 2022 covered the early chick-rearing period when most chicks were small.

Morphometrics

We compared the body mass, culmen length, wing length, tarsus length, and head and bill length measurements of male and female Cape Parry murres using *t*-tests with Bonferroni correction for multiple tests. Sexual size dimorphism (SSD) was calculated for each variable using the following formula: SSD = [(male–female)/female]×100. We used published means of body mass and

measurements for colony comparison, with sample sizes ranging from 10 to 156 individuals; most samples were > 29 individuals (68%, $n = 82$ measurements). We plotted culmen length vs. wing length (Gaston & Jones, 1998) and culmen length vs. body mass to visually compare body size across colonies.

Statistical analysis

Statistical analysis was carried out using SPSS Statistics (version 29.0). Residuals of the GLMs and LMM (i.e., trip parameters and dive bout duration) met the assumptions for homogeneity and normality. Models were estimated with restricted maximum likelihood and Satterthwaite approximation for degrees of freedom. Bout duration data was log-transformed before analysis. Morphological measurements were compared using *t*-tests, and frequencies were compared using chi-squared tests (i.e., prey type). Means are expressed ± SD. All comparisons are two-tailed, and differences were considered significant when $P < .05$. Bonferroni correction was used for multiple tests: diving behaviour ($P < .006$) and morphometrics ($P < .008$).

RESULTS

We recovered 23 of 32 deployed GPS tags, and all devices recorded data. All recaptured birds, and most birds that were not recaptured (7/9), were observed attending chicks. On average, the mass of tagged birds decreased by 26.5 ± 56.5 g/d ($n = 22$) during GPS deployment. Seven birds gained mass, and one bird exhibited no mass change.

Foraging location and diving behaviour

Murres made short foraging trips, mostly north and northwest of the Police Point colony and Balaena Bay (Fig. 2B). On average, the maximum trip distance was 4.5 ± 3.3 km (max. 15.84 km, $n = 48$ trips), the total distance traveled per trip was 14.1 ± 11.5 km (max. 58.8 km), and trip duration was 3.7 ± 3.1 h (max. 16.9 h). Both sexes travelled to similar areas, with no differences in their foraging trip parameters ($P > .05$).

Cape Parry murre diving was relatively shallow, as expected by the bathymetry (20–80 m depth) of their foraging range. The maximum recorded dive depth and duration was 70 m and 177.6 s, respectively (see Table 2).

TABLE 1
Dive and dive bout parameters of Cape Parry Thick-billed Murre *Uria lomvia* males
categorized by day and night (mean ± standard deviation)[a]

	Day	Night	Total	F	df	P
Dive depth (m)	**21.3 ± 11.0**	16.5 ± 5.9	20.0 ± 10.0	130.2	5,085	**< .001**
Dive duration (s)	**72.8 ± 27.9**	60.3 ± 16.5	69.3 ± 25.9	158.2	5,085	**< .001**
Bottom time (s)	**27.1 ± 16.7**	23.2 ± 12.8	26.0 ± 15.8	45.9	5,085	**< .001**
Post-dive interval (s)	**27.7 ± 12.4**	23.8 ± 9.6	26.5 ± 11.8	156.1	4,657	**< .001**
Number of dives/h	13.1 ± 10.4	**17.8 ± 11.2**	14.3 ± 10.7	8.54	358	.004
Dive efficiency	0.26 ± 0.13	0.27 ± 0.13	0.27 ± 0.13	0.445	4,212	.505
Dive bout duration (s)	676 ± 2.81	851 ± 2.88	707.9 ± 2.84	2.535	372	.112
Dives per bout	5.5 ± 8.6	**9.03 ± 12.23**	6.5 ± 5.3	16.48	828	**< .001**

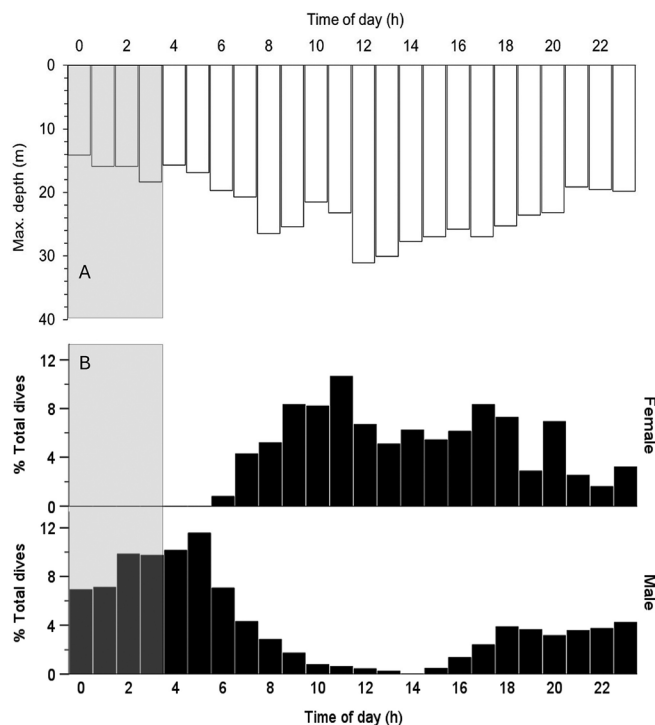[a] Significant differences are shown in bold after Bonferroni correction ($P < .006$).

Fig. 3. Temporal differences in diving behaviour of Cape Parry Thick-billed Murres *Uria lomvia* during a 24-h period. (A) Mean maximum dive depth and (B) percentage of dives by sex. The grey rectangle indicates the night period.

There was a consistent and sex-specific temporal pattern of diving behaviour (Fig. 3A). Females dove primarily during the day between 06h00 and 23h00 (99%, n = 864 dives). Males also dove during the day, between 03h30 and 08h00 (66.8%, n = 4,223 dives), but also at night, between 23h30 and 03h30 (33.2%; Fig. 3A). Dives were deeper and longer during the day than during the night ($F_{1,5085}$ = 120.2, P < .001), which likely explains the deeper mean dive depths of females compared to males ($F_{1,5085}$ = 4.165, P = .041; Fig. 3B). There were no differences in dive depth between males and females during the day ($F_{1,3675}$ = 2.097, P = .148). Males, foraging at night, made more dives per hour and per diving bout than those foraging during the day. However, the dive bout duration and diving efficacy of murres did not differ between day and night foraging (Table 1).

Most diving activity (94% dive locations, n = 5,000) was concentrated within the ANMPA boundaries. Some diving (6%) occurred southeast of Police Point as far as Balaena Bay (Fig. 3C).

The total feeding area, determined by kernel density analysis of diving locations, was approximately 113.86 km² (99.5% UD; Fig. 3D). The core feeding areas (50% UD; 47.59 km²) were primarily located to the northwest and were relatively close to the colony (Fig. 3D). Some diving was also concentrated off the coast of Devon Point, to the west side of Fiji Island, and to the north of Booth Island.

Diet

Adult murres mainly delivered three fish species: pelagic juvenile Arctic Cod, benthic Daubed Shanny *Leptoclinus maculatus*, and Sandlance *Ammodytes* spp. (2021: 81%, n = 42; 2022: 90%, n = 116; Fig. 4). A higher proportion of juvenile Arctic Cod (61%, n = 116), and a lower proportion of Daubed Shanny (20%) and Sandlance (9%), were delivered in 2022 than in 2021 (χ^2_2 = 14.909, n = 105, P = .0005). Larger fish were more frequent than smaller fish in 2021 (64% vs. 13%) compared to 2022 (45% vs. 33%; χ^2_1 = 12.002, n = 155, P = .0005). The estimated fish sizes (length ± SD) and energy density of fish species observed in 2022 are shown in Table 2.

Morphometrics

Female and male murres differed significantly only in the length of their culmen and tarsus, and head and bill length (P < .008; Table 3). Both the body size indices—using culmen length vs. wing length, and body mass vs. culmen length—placed Cape Parry females closer to murres at Atlantic colonies than those at Pacific colonies; males were intermediate between the two geographic groups (Fig. 5A, B). The body size index using body mass vs. culmen length placed Cape Parry males closer to Cape Thompson murres in the Pacific than the other colonies (Fig. 5B). These results were mostly driven by male culmen size. Cape Parry murres had one of the highest SSD values for culmen length (Appendix 1, available online).

DISCUSSION

Cape Parry is one of only a small number of Thick-billed Murre colonies that support < 10,000 birds. The small foraging ranges of Cape Parry Thick-billed Murres support density-dependent predictions (< 27.5 km) associated with colony size (Gaston et al.,

TABLE 2
Estimated length, mass, and energy density of fish delivered by Thick-billed Murres *Uria lomvia*
at Cape Parry in 2022 (mean ± standard deviation)

| Common name	Scientific name	n	Length (mm)	Mass (g)[a]	Wet energy (kJ)[a]
Arctic Cod	*Boreogadus saida*	34	71.6 ± 33.8	3.8 ± 3.7	17.7 ± 17.6
Daubed Shanny	*Leptoclinus maculatus*	10	97.0 ± 36.1	3.3 ± 2.0	16.4 ± 9.9
Sandlance	*Ammodytes* spp.	8	93.2 ± 29.9	2.3 ± 1.5	11.7 ± 7.9
Sculpin spp.	*Myoxocephalus* spp., *Triglops* spp.	7	85 ± 29	5.8 ± 4.1	25.2 ± 17.9
Fish Doctor	*Gymnelus viridis*	2	124	5.46	22.3
Capelin	*Mallotus villosus*	1	130.2	11.3	40.7

[a] Estimation based on Elliott et al. (2008)
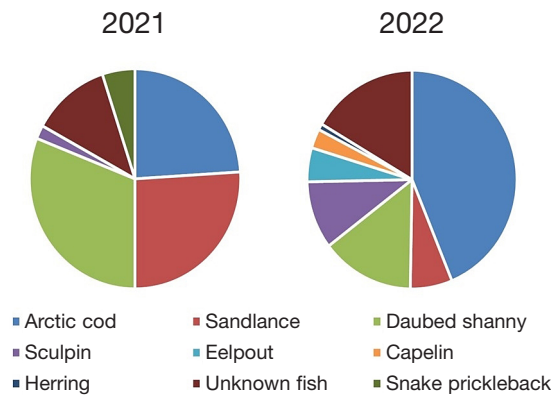
Fig. 4. Chick diet of Cape Parry Thick-billed Murres *Uria lomvia* in 2021 (*n* = 42) and 2022 (*n* = 116), showing percent occurrence of total prey items. See Table 2 for scientific names of prey items. Note that temperatures in 2021 were colder than in 2022.

2013; Patterson et al., 2022). The lack of spatial sexual segregation during foraging, the close proximity of core feeding areas, and the fact that chick diet was composed exclusively of fish (e.g., Arctic Cod, Daubed Shanny, Sandlance) suggest that food conditions near Cape Parry were suitable for murres. In the Pribilof Islands, male and female Thick-billed Murres partially segregate in years of poor prey abundance (Young et al., 2015), but they forage in the same shelf areas in good years (Kokubun et al., 2018). Lower energy-density prey, such as squid, which is commonly fed to chicks in other Pacific and Atlantic colonies (Elliott & Gaston, 2008; Harding et al., 2012; Paredes et al., 2015), was not observed despite its apparent availability at Cape Parry (Gardiner & Dick, 2010). However, invertebrates cannot be discounted because early morning feeding observations were not possible. Maximum dive depths of Cape Parry murres (up to 70 m) coincide with bathymetry at which juvenile Artic Cod is found at Cape Parry (McNichol et al., 2020; Walkusz et al., 2013). The apparent availability of this key forage fish at Cape Parry, particularly in 2022, contrasts with its decline in chick diets in eastern Canadian murre colonies (Mallory et al., 2010) and in Black Guillemots *Cepphus grylle mandtii* in the western Beaufort Sea (Divoky et al., 2021). At Cape Parry, the warmer conditions in 2022 compared to 2021 may explain the higher occurrence of juvenile Arctic cod in chick diets: an earlier ice breakup and warmer spring/summer sea surface temperature correlate with increased biomass of juvenile cod in the Canadian Arctic (Bouchard et al., 2017). The Arctic Cod observed in 2022 were smaller and likely lower in energy density (18 kJ) compared to

those reported in the diets of murres from eastern Canadian colonies (Elliot & Gaston, 2008), and their energy density was similar to that of benthic species like Daubed Shanny (Table 2). Changes in prey quality and quantity, driven by changes in sea-ice extent (Mallory et al., 2010), can negatively affect Arctic bird populations and are a primary concern with respect to climate change-induced population impacts (e.g., Divoky et al., 2021). Whether or not the Cape Parry murre population is increasing is worth further investigation; since the 1980s, the population at Police Point appears relatively unchanged (Hogan & Siddler, 2023). Continued monitoring of Cape Parry murre chick diets would help to detect broader changes in the food web in the Amundsen Gulf, a key area in the western Canadian Arctic, providing valuable insights into population dynamics.

We found that Cape Parry murre core-use areas during the chick-rearing period are primarily within the ANMPA boundaries, suggesting that these boundaries are currently adequate for the conservation of this species during the chick-rearing stage. These results, however, should be taken with caution because murre foraging ranges and habitat usage can vary among years (e.g., Kokubun et al., 2018) and breeding stages (Gaston et al., 2013; Gee et al., 2024). During incubation, for example, murres are known to make longer trips (e.g., Paredes et al., 2006) and have larger foraging ranges (Gaston et al., 2013; Gee et al., 2024). Furthermore, in open-water years such as 2022, which are becoming more frequent, access to foraging areas is not limited by sea pack ice. The core-feeding areas north and northwest of Police Point, as well as near Devon Point and Fiji Island, suggest productive and predictable nearby marine habitats. In addition, the diel differences in dive depth and frequency suggest that murres had different foraging conditions (e.g., prey patch size, Boyd, 1996; Sommerfeld et al., 2015) during day and night near Cape Parry. The shallower and frequent diving during night bouts suggest murres, mainly males, were feeding on DVM prey or, alternatively, that light intensity was insufficient to access deeper depths. This diel diving behaviour was, however, much more attenuated than that observed in low-Arctic murre colonies (Jones et al., 2002; Paredes et al., 2008; Young et al., 2015). The similar dive bout duration and diving efficacy, however, suggests that murres at Cape Parry spend similar amounts of time foraging during day and night, but that foraging occurs at different depths and possibly targets different prey (Elliott et al., 2008). In contrast, murre dive depths do not appear to vary across the 24-h period in colonies with continuous daylight and an apparent absence of DVM (Huffeldt et al., 2021; Mehlum et al., 2001). Interestingly, the temporal segregation in foraging or the opposite colony attendance pattern between the sexes persists at Kippaku,

TABLE 3
Morphometrics and sexual size dimorphism (SSD) of Cape Parry Thick-billed Murre *Uria lomvia* males (*n* = 37) and females (*n* = 16)[a]

	Female	Male	SSD	Total	*t*	*df*	*P*
Body mass (g)	994.7 ± 72.0	978.8 ± 70.0	-1.59	983.6 ± 6.2	0.746	27.85	.342
Culmen (mm)	35.7 ± 1.9	37.5 ± 2.4	5.04	36.9 ± 2.4	-2.89	36.97	**.003**
Gape (mm)	61.2 ± 2.3	62.3 ± 2.3	1.79	61.9 ± 2.3	-1.605	28.33	.110
Head + bill (mm)	103.4 ± 2.2	106.3 ± 2.8	2.80	105.5 ± 2.9	-3.93	32.68	**.001**
Tarsus (mm)	44.9 ± 1.3	46.6 ± 1.8	3.78	46.1± 1.8	-3.51	37.46	**.001**
Wing cord (mm)	212.6 ± 6.3	214.5 ± 6.1	0.89	214 ± 6.2	-1.04	27.75	.305

[a] Values are mean ± standard deviation. Significant differences are shown in bold after Bonferroni correction (*P* < .008)
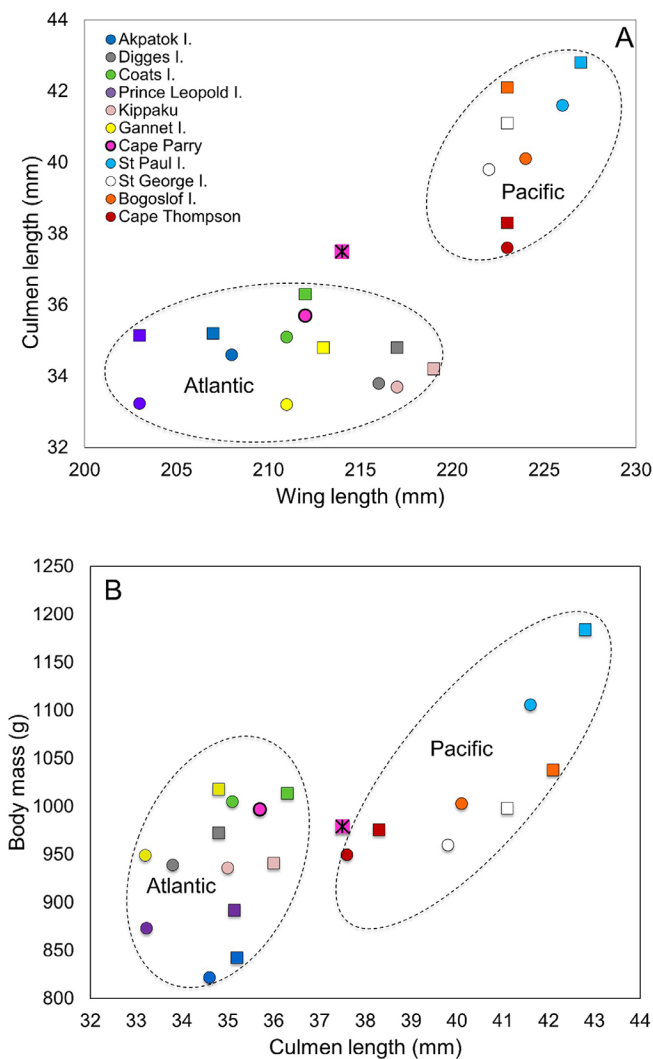
Fig. 5. Comparison of Thick-billed Murre *Uria lomvia* colonies using body size indexes. (A) Culmen length vs. wing length, and (B) body mass vs. culmen length of males (squares) and females (circles). Cape Parry murres (pink symbol), primarily males, are positioned farther from Atlantic conspecifics.

Greenland, suggesting that mechanisms other than foraging specialization may explain this behaviour (Huffeldt et al., 2021).

At Cape Parry, the consistent temporal foraging segregation (or opposite colony attendance) between the sexes aligns with the patterns observed in eight of the nine colonies for which data are available (reviewed in Huffeldt et al., 2021). In most high-Arctic colonies, males forage more often during the "night" and females during the "day" (Elliott et al., 2010; Huffeldt et al., 2021; Linnebjerg et al., 2015; this study). Opposite patterns are reported between the sexes in low-Arctic colonies (Gannet Islands & Pribilof Islands; reviewed in Huffeldt et al., 2021) and high-Arctic Prince Leopold Island (Elliot et al., 2010; but see Gaston & Nettleship, 1981). Males in the four members of the Alcini tribe spend more time at the colony brooding and/ or protecting the chick/mate/site (off-duty time) than females (Thick-billed Murres: Elliott et al., 2010; Paredes et al., 2006;

Razorbills *Alca torda*: Linnnerberg et al., 2015; Paredes et al., 2006; Common Murres: Linnnerberg et al., 2015; and Little Auks: Harding et al., 2004). Longer colony attendance by males may be required for male-chick recognition at departure (Insley et al., 2003; Lefrevre et al., 1998) and for protecting chicks, mates, and nesting sites. This is likely because males are better equipped—due to their larger head and bill size (Stewart, 1992)—to initiate agonistic interactions compared to females (Paredes & Insley, 2010). The variability in male and female attendance patterns suggests that colony-specific conditions, such as density-dependent mechanisms, light period, DVM, and aerial predator behaviour and numbers, may outweigh the male tendency to attend the colony during the day. At Prince Leopold Island (which experiences 24 h of daylight) males attended the colony between "mid-day" and "midnight" in the 1970s (Gaston & Nettleship, 1981) and primarily during the "day" in the 2000s (Elliott et al., 2010). This shift coincided with a gradual increase in colony size from 75,000 to 100,000 pairs (Gaston et al., 2012), suggesting that intraspecific competition for food or territory may be the underlying cause. At Cape Parry, murres experience fewer external factors that could influence male-female attendance patterns. These include density-dependent mechanisms related to colony size (e.g., intraspecific competition), a very small number of aerial predators, and attenuated DVM (this study).

Our morphometric findings of Cape Parry Thick-billed Murres partially support our body size predictions based on morphometric and genetic studies (Gaston & Jones, 1998; Tigano et al., 2015), as Cape Parry female murres are smaller than Pacific murres. When using culmen length and body size as variables of a body size index, Cape Parry males were more distantly related than females to their genetically closer congeners in the Atlantic, but more closely related to Cape Thompson murres in the Bering Sea (i.e., Pacific). Although gene flow between the Pacific and Cape Parry colonies appears to occur (Tigano et al., 2015), it is not clear which colony is the source of this flow and whether this dispersal is sex-biased (Barbraud & Delord, 2021). The physical proximity of Cape Thompson to Cape Parry, along with their similarity in body size index (Fig. 2B), suggests Cape Thompson as a potential source of gene flow. The potential for ongoing gene flow with western populations is supported by findings of consistent westward movement of Cape Parry murres during the non-breeding season (Paredes et al., 2024). The slight but significant sexual size dimorphism of Cape Parry murres found for head and bill measurements concur with that reported in other colonies (Gaston & Jones, 1998; Huffeldt et al., 2021; Orben et al., 2015; Paredes et al., 2006). Male-male competition for breeding sites and mate guarding to avoid extra pair copulations may select for larger bills and skulls (Jehl & Murray 1986; Stewart, 1992). These traits may also be advantageous for protecting the chick during the male-only care stage. In fact, males initiate aggressive interactions more often than females (Paredes & Insley, 2010). Sex differences in diet have also been hypothesized to explain sexual dimorphism in culmen size in Thick-billed Murres (Elliott et al., 2010), although this relationship does not apply to all colonies (reviewed in Huffeldt et al., 2021). Sexual size dimorphism in culmen length is stronger in some colonies, including Cape Parry, Prince Leopold Island, and the Gannet Islands (Appendix 1). Comparative studies examining factors that may drive variation in sexual size dimorphism in murre colonies, such as colony size, unequal male-female ratios, reduced breeding habitat, and

high depredation rates, would help to explain the phenotypic placement of Cape Parry murres.

CONCLUSIONS

This study provides the first data on foraging distribution, diving behaviour, diet, and morphometric measurements for the Cape Parry population of Thick-billed Murres—critical information for the conservation and further understanding of the species both locally and globally. The small foraging ranges, lack of spatial sexual segregation, and the fact that chick diets consist exclusively of fish, suggest favourable local foraging conditions during the brooding period, with little intraspecific competition. The intermediate body size of Cape Parry murres aligns with their central geographic location relative to Atlantic and Pacific conspecific colonies, supporting the occurrence of population mixing.

The question remains: what are the principal factors limiting the population growth of Cape Parry murres? Despite seemingly adequate food availability, chicks were fed fish with relatively low energy content, such as age-0 juvenile Arctic Cod and benthic fish. Foraging conditions during incubation remain unknown and are likely more variable due to fluctuating ice and weather conditions in the early season. Conditions outside the breeding season remain largely unexplored, and determining migratory routes and overwintering areas will be an important next step in our research (Paredes et al., 2024).

Of particular importance is the need to identify nursery areas of male-chick pairs after breeding when both the chick and male parent are flightless and vulnerable to shipping, as well as to other anthropogenic impacts such as oil and gas development and aircraft disturbances. Given its small population size (1,358 individuals; Hogan & Sidler, 2023), Cape Parry murres are highly vulnerable to such anthropogenic impacts, in addition to the range of environmental changes associated with climate change, including the influx of new species and pathogens. On a positive note, much of the core-use activity during the chick-rearing period occurred within the currently designated ANMPA, and the population appears to be stable or possibly growing (Hogan & Sidler, 2023). However, to confirm these findings and better understand the potential impacts of climate change on this unique western Canadian colony, it is recommended that this single-year study be replicated, potentially including earlier breeding stages.

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AUTHOR CONTRIBUTIONS

Rosana Paredes: conceptualization, investigation, methodology, formal analysis, and manuscript writing. Stephen Insley: conceptualization, funding acquisition, investigation, manuscript review and editing. Sebastian Luque: formal analysis, software, manuscript writing, review, and editing. Piia Kortsalo: formal analysis, software, visualization.

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