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Title: Going Deep: Common Murres Dive into Frigid Water for Aggregated, Persistent and Slow-moving Capelin

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Abstract: Abstract

Owing to the necessity of delivering food to offspring at colonies, breeding seabirds are highly constrained in their foraging options. To overcome constraints imposed by central-place foraging and to adjust to fluctuating prey availability during the breeding season, many species exhibit flexible foraging tactics. Pursuit-diving common murres *Uria aalge* frequently experience widely varying prey availability during chick-rearing and make major adjustments in foraging behaviour and effort. Here we document deep (≥ 50 m) diving by parental murres foraging on female capelin *Mallotus villosus* in the northwest Atlantic. Twenty one percent of recorded dives ($n = 272$ of 1,307 dives) were deep (maximum depth 152 m), and lasted 84-212 s. Deep dives took murres into sub-0°C water in the Cold Intermediate Layer (CIL; 40-180 m) of the Labrador Current, where temperatures shaped trophic interactions, and involved trade-offs for both the predators and prey. Murres encountered spatially predictable aggregations of capelin deep (100-150 m) in the water column during the day. Frigid temperatures in the CIL would limit the fish's ability to escape from

endothermic predators by reducing burst/escape speeds and lengthening recovery times from burst-type activities. We hypothesize that common murrens engaged in costly deep diving as it increased the certainty of prey capture. From the capelin's perspective, remaining in sub-0 °C water near the bottom during the day allows them to avoid their major predator, northern cod *Gadus morhua*, though they remain vulnerable to the deepest diving avian predators.

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2 **Going Deep: Common Murres Dive into Frigid Water for**

3 **Aggregated, Persistent and Slow-moving Capelin**

4

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7 rearing and make major adjustments in foraging behaviour and effort. Here we document
8 deep (≥ 50 m) diving by parental murre foraging on female capelin *Mallotus villosus* in
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23 capelin, murre

1 **Introduction**

2 Biophysical variability in dynamic marine environments affects the performance,
3 behavioural ecology and distribution of both predators and prey (Domenici et al. 2007).
4 To cope with environmental uncertainty, foraging seabirds rely on a considerable
5 interplay of behavioural and physiological capabilities (Wendeln and Becker 1999;
6 Grémillet et al. 2001). During breeding, the demands of central-place foraging greatly
7 restrict the foraging options and provisioning opportunities of breeding seabirds (Orians
8 and Pearson 1979), often challenging their behavioural and physiological capabilities
9 (Weimerskirch et al. 2003; Jodice et al. 2006; Elliot et al. 2008a). Consequently,
10 seabirds often use flexible foraging tactics to overcome these constraints in order to
11 effectively engage environmental uncertainty.

12 Seabird species that fly and dive are compromised in both forms of locomotion
13 (Burger 1991). Pursuit-diving alcids have taken these adaptations to extremes and exhibit
14 considerable performance capability and agility “flying” underwater to capture prey
15 (Tremblay et al. 2003). Pursuit-diving common murre *Uria aalge*, the deepest diving
16 species among birds that fly (Piatt and Nettleship 1985; Burger 1991), frequently
17 experience widely fluctuating prey conditions during chick-rearing and make major
18 adjustments in foraging behaviour and effort (Burger and Piatt 1990; Davoren et al.
19 2003a; Harding et al. 2007).

20 Off Newfoundland, in the northwest Atlantic, breeding common murre
21 preferentially feed themselves and their chicks mature, female capelin *Mallotus villosus*
22 (Piatt 1990; Davoren and Montevecchi 2003a; Burke and Montevecchi 2008). During
23 spring and early summer, capelin migrate from over-wintering areas near the edge of the

1 continental shelf to the coastal waters of Newfoundland to spawn (Nakashima 1992).
2 Suitable habitat for demersal spawning and staging along the northeast coast of
3 Newfoundland creates persistent aggregations of capelin (Davoren et al. 2006) which, in
4 turn, provide important foraging areas for the massive concentrations of murre breeding
5 at the nearby Funk Island Seabird Ecological Reserve (Davoren et al. 2003 a,b).

6 Prior to spawning, persistent mixed-sex shoals of maturing capelin stage deep
7 (100-150 m) in the water column, remaining within the Cold Intermediate Layer (CIL; <
8 0°C) of the Labrador Current during the day and migrating to warmer (~ 9-13°C) surface
9 waters at night (Davoren et al. 2006). The CIL is a band of sub-0° C water that lies from
10 approximately 50-240 m (Petrie et al. 1988, Davoren et al. 2006), and is a prominent
11 oceanographic feature of the Newfoundland Shelf area through much of the year. Capelin
12 that survive spawning may return to these same staging areas to forage and replenish fat
13 reserves before winter (see also Winters 1970). It has been hypothesized that capelin
14 shoal in deep, sub-0 °C water during the day to reduce risk of predation from northern
15 cod *Gadus morhua* and visual air-breathing predators, as well as to overlap with their
16 zooplankton prey, whose biomass is higher below 50 m (Rose and Leggett 1990;
17 Mowbray 2002; Davoren et al. 2006). Capelin may migrate to warm surface waters at
18 night to increase metabolic rates, thereby accelerating digestion and gonadal development
19 (Winter 1970; Davoren et al. 2006). Two capelin staging areas that were spatially
20 persistent across years have been documented between Funk Island and the northeast
21 Newfoundland coast (Davoren et al. 2006).

22 In this paper, we analyze deep (> 50 m) diving by chick-provisioning common
23 murre foraging on shoals of capelin located within the CIL. We examine the incidence,

1 diurnal patterning and physiological efficiency of deep diving by parental murrelets relative
2 to the diel vertical movement patterns of capelin. Because the probability of an
3 endothermic avian predator capturing ectothermic prey is at least partially mediated by
4 temperature effects on the fish's ability to perform and recover from burst-type exercise
5 (Kieffer 2000; Cairns et al. 2008), we hypothesize that capelin located within the CIL
6 will be slow moving and relatively easy for murrelets to catch. On this basis, we predict:
7 (1) assuming murrelets are successful at capturing prey at the level of the diving bout
8 (Camphuysen 2005), they will perform fewer dives per bout as the average depth of dives
9 within the bout become deeper; and (2) assuming that dive bottom time (a proxy for
10 foraging time) relates to prey pursuit time, that bottom times will be shorter in colder
11 water. We consider how the physical environment has shaped interactions between
12 murrelets and capelin within the Newfoundland Shelf ecosystem.

13

14 **Materials and methods**

15 Study Sites

16 Research was conducted when most pairs were raising chicks during 14 July – 6
17 August 2007 at Gull Island (47°16'N, 52°46'W; ~ 1,632 breeding pairs of common
18 murrelets; Robertson et al. 2004) in the Witless Bay Ecological Reserve, and during 25 July
19 – 4 August 2007 at the species' largest breeding colony on Funk Island (49°45'N,
20 53°11'W, ~ 400,000 pairs, Chardine et al. 2003), Newfoundland, Canada.

21

22 Oceanographic setting

1 To describe the thermal habitat available to murre and capelin, we delineated the
2 position of the CIL during July 2007 using temperatures (0–165 m) from hydrographic
3 Station 27 (47°31'50" N, 52°35'10" W; Fisheries and Oceans Canada Oceanographic
4 database, http://www.mar.dfo-mpo.gc.ca/science/ocean/database/data_query.html). This
5 station, located within the Avalon Channel branch of the Labrador Current, provides a
6 robust index of oceanographic conditions over the Newfoundland and Labrador Shelf
7 (Petrie et al. 1988; Drinkwater 1996).

8

9 Field protocol: Devices and Procedures

10 Adults attending chicks were caught with a 6 m telescoping noose pole and
11 equipped with a Lotek LTD 1110 logger (5 g, 32 mm length x 11 mm diameter; 128 Kb).
12 Devices that were previously attached to plastic Protouch bands with cable ties were
13 attached to the left leg ($n = 15$ at Funk Island; $n = 6$ Gull Island) and a Canadian Wildlife
14 Service metal band was attached to the right leg. These devices recorded pressure (depth
15 resolution ± 0.49 m when maximum depth < 125 m, and ± 0.98 m when 125 m $<$
16 maximum depth < 250 m) and temperature (± 0.3 °C) every 2 s for successive foraging
17 trips until the memory filled (36 hr). Upon recapture, devices were removed and murre
18 were weighed with a Pesola[®] 1 or 1.5 kg spring balance, and 0.5 ml of blood was
19 collected from the brachial vein to determine sex using W-chromosome analysis
20 (Fridolfsson and Ellegren 1999). To reduce stress, birds were held with eyes covered for
21 ~ 4 min and ~ 6 min during deployment and recapture, respectively. Nine of the 15
22 loggers were recovered from murre on Funk Island as were four of the six deployed on
23 Gull Island (60% overall recovery rate). Of the loggers recovered, data were lost from

1 one (Funk Island) and data from two others (Gull Island) were distorted and
2 unrecoverable.

3 Throughout the period of logger deployment, dawn to dusk observations (05:00 –
4 21:00 h Newfoundland Daylight Savings time) were conducted at Gull Island, and
5 equipped birds were observed at Funk Island when work time allowed. Arrival and
6 departure times and prey items delivered to chicks were noted for equipped birds. When
7 observational data were not available, arrival and departure times from the colony were
8 estimated using continuous temperature and depth records obtained from the data loggers
9 (Tremblay et al. 2003; Elliott et al. 2008a). Observations and estimates of colony arrival
10 times were used to identify the “terminal” dive (i.e. chick provisioning dive) for each
11 foraging trip.

12 At Funk Island, food samples were collected throughout the period of logger
13 deployment using dip-nets to catch prey-carrying murrelets as they returned to the colony.
14 Fish were weighed (using an 100 g Pesola[®] scale), measured (total length \pm 1 mm using a
15 ruler), identified, sexed and classed as gravid or spent (which may have included a few
16 immature fish).

17

18 Data analysis

19 As drift in the LTD 0-level exceeded \pm 1m in some cases, we defined dives as
20 submersions \geq 2m. Start and end times for each dive were determined, along with the
21 following parameters: dive duration, maximum depth, minimum temperature, bottom
22 time, surface interval duration, and dive and bottom efficiencies. Bottom time was
23 defined as the time elapsing from the first and last instant when vertical velocity

1 (calculated between successive records) fell below 0.5 ms^{-1} (Halsey et al. 2007). Dive
2 efficiency was calculated as the ratio of the duration of the dive to the duration of the dive
3 + the subsequent surface time, and bottom efficiency was the ratio of bottom time to the
4 dive + the subsequent surface time (Camphuysen 2005). V-shaped dives ($n = 165$,
5 12.6%) had no bottom time, and hence had a bottom efficiency of zero. Bouts of diving
6 were identified using a surface interval criterion (e.g., Huin and Prince 1997). A
7 frequency distribution of post-dive surface intervals showed a rapid decline to 220 s and
8 remained relatively constant after that. A bout of diving was therefore defined as either a
9 single dive or as a series of dives in which each diving event started no more than 220 s
10 after the previous dive had ended.

11 Dives were classified as either “shallow” ($< 50 \text{ m}$) or “deep” ($\geq 50 \text{ m}$). We chose
12 50 m as the criterion to define a deep dive, as this depth ensured that birds had reached,
13 and were presumably foraging within, the CIL (see Results). We examined the
14 distribution of shallow and deep dives by time of day; daytime commenced with nautical
15 twilight in the morning (the instant when the rising sun is 12° below the horizon) and
16 continued until nautical twilight in the evening (the instant when the setting sun is 12°
17 below the horizon); nighttime was the intervening period (RASC 2007).

18 We assessed whether dive depth varied as a function of time of day, and whether
19 the depth of terminal (“chick-provisioning”) dives differed from other dives, by fitting
20 generalized linear models with gamma error distributions and inverse links using SAS 9.1
21 PROC GENMOD (SAS Institute 2005). In the case of dive depth by time of day, we
22 used contrasts to test the hypothesis that murrens dive deeper in the hours following
23 sunrise (05:00 and 06:00) than during the rest of the day. Data are presented as means \pm

1 SE, and an alpha level (α) of 0.05 was used for all tests. Other data were examined, and
2 are presented, graphically.

3

4 **Results**

5 Oceanographic setting and Parental prey deliveries

6 During July 2007, the CIL or band of sub-0 °C water across the Newfoundland
7 and Labrador Shelf extended from 40 m to below 165 m (Fig. 1). Hence murre and
8 capelin below 40 m in the water column were in frigid water < 0 °C. Temperature
9 profiles obtained from the dive loggers confirmed that murre reached the CIL on all
10 deep dives.

11 Coincident with the diving records, parental prey deliveries ($n = 150$) by
12 unequipped murre at Funk Island consisted of 100% capelin. 149 of these (99%) were
13 females, of which 33% were gravid and 58% were spent. Concurrent hydro-acoustic
14 surveys detected no capelin at known demersal spawning sites (18 – 38 m water) within
15 the murre's foraging range from Funk Island, indicating that spawning within these areas
16 had finished by late July 2007 (G. K. Davoren & P. Penton, unpubl. data) when we
17 sampled murre diets at the colony.

18

19 Diving performance

20 Diving profiles were obtained for nine individuals ($n = 7$ from Funk Island, $n = 2$
21 from Gull Island) during 20 (plus 5 partial) foraging trips, involving a total of 1,307 dives
22 (Table 1). The maximum dive depth was 152 m (mean \pm SE = 30 ± 0.8 m; Fig. 2a), and
23 maximum dive duration was 212 s (mean \pm SE = 64 ± 1.3 s; Fig. 2b). Dive depth and

1 duration were strongly related (Fig. 3). By our definition, 21% ($n = 272$) of all dives
2 were deep (> 50 m) and brought murrelets into the CIL. All murrelets performed deep dives;
3 these comprised 9 - 68% of the dives performed by each individual (Table 1).

4 Murrelets dived throughout the day and night, with a peak in diving activity near
5 dusk ($\sim 21:00 - 22:00$ h; Fig. 4a). Most (97%) of the deep diving, however, occurred
6 during the day (Fig. 4b), largely from mid-afternoon to dusk, with a smaller peak in early
7 morning (Fig. 4b). Nine deep dives were recorded at night from a single individual
8 around full moon (Table 1). Though our sampling was limited ($n = 2$ birds at Gull
9 Island), there was no deep diving at night around new moon. Murrelets dived frequently at
10 night near full moon, but largely to shallow depths < 50 m (Figs. 4a & 5; Table 1).
11 Overall, the depth of dives varied with time of day ($\chi^2_{23} = 122.04$, $P < .0001$); dives 2 h
12 after sunrise (05:00-06:59 h) being significantly deeper than those during the remainder of
13 the day (contrast test: $\chi^2_1 = 29.15$, $P < .0001$, Fig. 5).

14 Dive efficiency was low for the shallowest dives (< 10 m), and it peaked for dives
15 between 10-30 m (Fig. 6a). Efficiency declined between 30 and 50 m and remained
16 relatively constant at deeper depths. Bottom efficiency was also highest for shallow
17 dives (10-20 m) and it progressively declined from 20-80 m (Fig. 6b). Bottom efficiency
18 was extremely low and relatively constant for dives deeper than 80 m.

19 Individual murrelets performed, on average, 5.0 ± 1.3 dives per bout (range of
20 individual means = 2.5 - 12.2). As anticipated, murrelets undertook fewer dives per bout as
21 the average depth of dives within the bout increased (Fig. 7). Bouts consisting of just 1
22 or 2 dives had average maximum depths > 50 m (Fig. 7). There was no obvious
23 relationship between dive depth and time spent at the bottom of the dive, though the

1 longest bottom times corresponded with the deepest dives. Contrary to our expectations,
2 dive bottom time increased with decreasing temperature (Fig. 8), but the proportion of
3 variance accounted for was small.

4 Depths of terminal (or “chick-provisioning”) dives ranged from 5 to 152 m.
5 Known successful terminal dives (verified by visual observations of parents returning
6 with a fish for the chick) were significantly deeper (75.0 ± 19.2 m, $n = 9$) than all other
7 dives combined, including terminal dives with unknown outcomes (29.6 ± 0.8 m, $n =$
8 $1,298$; $\chi^2_1 = 12.16$, $df = 1$, $P < 0.001$). There was no obvious relationship between dive
9 depth and the type of capelin delivered to the chick.

10

11 **Discussion**

12 This study documents the remarkable behavioural flexibility of common murre
13 when foraging for capelin off Newfoundland; birds dive to depths below 150 m and
14 remain submerged for more than 200 s. The most intriguing feature of this dataset,
15 however, is the incidence of long, deep dives. More than 20% of dives exceeded 50 m,
16 and 8% exceeded 75 m, which is the maximum diving depth recorded for this species off
17 Scotland and Norway in the eastern Atlantic (Tremblay et al 2003; Camphuysen 2005;
18 Table 2). Deep diving, then, is clearly an important aspect of parental foraging in the
19 western Atlantic where birds specialize on capelin. Presumably these deep dives would
20 incur high energetic costs as birds are hunting in frigid (sub-0° C) waters. The questions
21 are how do they do this and why?

22 Light intensity decreases exponentially with ocean depth (Lalli and Parsons
23 1993), so can murre hunt visually during deep dives? Using time-depth-light recorders

1 attached to marine mammals, McCafferty et al. (2004) showed that light attenuation was
2 strong in the top 50 m of the water column and that at night (sun > 6° below horizon)
3 light intensities fell below 1 lux at depths of 10 m. These findings seem paradoxical with
4 the notion of visual hunting by murres, especially at night, and sometimes to depths > 50
5 m. Yet light intensity attenuation depends on wavelength; in the open ocean green light
6 (~510 nm) penetrates the water column to around 100 m while blue light (~475 nm)
7 penetrates beyond 200 m (UN 2007). Moreover in Newfoundland waters, light
8 penetration is maximal during June when dissolved and suspended matter is low (D.
9 Deibel, pers. comm.) and consequently was likely deepest during our July study. So, it is
10 likely that murres can hunt visually for capelin below 50 m by using light in the blue-
11 green spectrum (Goldsmith 2006). The effect of decreasing light intensity is reflected in
12 the sharp reduction of deep dives at night and by the fact that night diving occurred
13 primarily during a full moon.

14 So why do murres perform deep dives? This is likely because they have to, but
15 also because when they do, they are successful at capturing prey. Common murres in
16 Newfoundland specialize on capelin and some of the deep capelin shoals targeted by
17 murres from Funk Island (Davoren et al. 2003a ,b) are both spatially (at the scale of
18 hundreds of meters) and temporally persistent (across years; Davoren et al. 2006). In
19 addition, temperature limits a fishes swimming performance (swimming speed halves
20 with every 10 °C decrease in water temperature; $Q_{10^{\circ}\text{C}} = 2$; Videler and Wardle 1991),
21 and perhaps more importantly in the context of predator-prey interactions, it increases the
22 duration of recovery from burst-type exercise (Kieffer 2000). Sub-0 °C water in the CIL
23 would result in slower escape speeds and extended recovery periods for the capelin,

1 presumably placing them at a disadvantage when facing an endothermic predator. So,
2 while deep foraging in the CIL is likely energy demanding, we hypothesize it is an
3 effective tactic as the capelin are easy to find (Davoren et al. 2006) and also easy to catch.

4 Consistent with this interpretation, murre were found to perform fewer dives per
5 bout as the average depth of dives within the bout increased. Using stomach temperature
6 loggers to identify ingestion events, Camphuysen (2005) reported murre successfully
7 captured prey on the majority of diving bouts, but that success was much more variable at
8 the level of an individual dive. If the murre in our study had similar success rates, fewer
9 deep than shallow dives were needed to capture prey. Standard (physiological)
10 assessment of diving and bout efficiency suggested that deep dives were inefficient, yet
11 physiological involvements would need to be integrated with information on catch per
12 unit effort to comprehensively assess efficiency. Resolving this will require integrating
13 information on both horizontal (ie spatial) and vertical (diving) movements with
14 information on rates of prey intake in different locations and/or on different types of prey.
15 We are addressing these issues with tracking studies and will attempt to quantify rates of
16 prey capture with stomach thermal (Weimerskirch et al. 2005) and/or beak sensors
17 (Wilson et al. 2002).

18 Off Newfoundland where Common murre provision themselves and their chicks
19 primarily with female capelin (Piatt 1990; Davoren and Montevecchi 2003a; Davoren
20 2007; Burke and Montevecchi 2008), capelin engage in diel vertical migrations. During
21 the day, capelin occur in discrete shoals in and below the CIL, then migrate through the
22 cold layer at dusk to disperse at the surface at night (Davoren et al. 2006). At dawn, they
23 re-group into shoals and move down in the CIL to deep water (Bailey et al. 1977). The

1 murre's deepest dives occurred just after sunrise, when capelin are moving toward the
2 seabed, perhaps indicating that murre's were chasing capelin to the bottom. Dawn is also
3 the period when most food loads are delivered to chicks at Funk Island (Davoren and
4 Montevecchi 2003b). Thick-billed murre's *Uria lomvia* are known to dive longer (Jones
5 et al. 2002) and deeper for chick provisions (Elliott et al. 2008b). Yet, in our study, most
6 diving occurred near sunset, when the capelin are migrating toward the surface. The
7 shoaling behaviour and upward movement of capelin at dusk, when light availability is
8 still relatively high, could provide murre's with favorable foraging conditions.

9 During the 1990s, capelin shifted deeper in the water column and likely
10 experienced considerable predator-prey tradeoffs (Mowbray 2002). Capelin produce
11 very little anti-freeze protein but can super-cool and have been documented in water
12 temperatures below the freezing point of their bodily fluids (-0.4 to -1.5 °C; Raymond
13 and Hassel 2000, Nakashima and Wheeler 2002). It has been hypothesized that capelin
14 occupy sub-0 °C water to reduce predation risk from their primary predator – cod that
15 generally occupy waters between -0.5° and 8.5 ° C (Rose and Leggett 1990, Mowbray
16 2002). Zooplankton biomass is also considerably higher in the lower (> 50 m) compared
17 with the upper (< 50 m) water column and capelin might occupy the CIL during daylight
18 to take advantage of enhanced feeding conditions (Mowbray 2002, Davoren et al. 2006).
19 To summarize, by aggregating at depth during the day, capelin are inaccessible to cod
20 and most species of seabirds (Regehr and Montevecchi 1997; Regehr and Rodway 1999)
21 but they remain vulnerable to deep-diving murre's. This cost would perhaps be a
22 relatively minor cost, as the consumption of capelin by murre's would pale in comparison
23 to that of cod (Montevecchi 2001).

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8

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1 **Figure legends**

2 Figure 1: Cold intermediate layer (CIL) of sub-0°C water derived from thermal data at
3 hydrographic Station 27, 13-31 July 2007.

4 Figure 2: Frequency distributions of (a) diving depth (m) and (b) diving duration (s) for
5 chick-rearing common murrelets in Newfoundland, July 2007.

6 Figure 3: Dive depth versus duration for nine chick-rearing common murrelets in
7 Newfoundland, July 2007.

8 Figure 4: Frequency distributions of the time of diving by common murrelets during chick-
9 rearing, July 2007: (a) all dives, $n = 1,307$, (b) deep (> 50 m) dives only, $n = 272$.

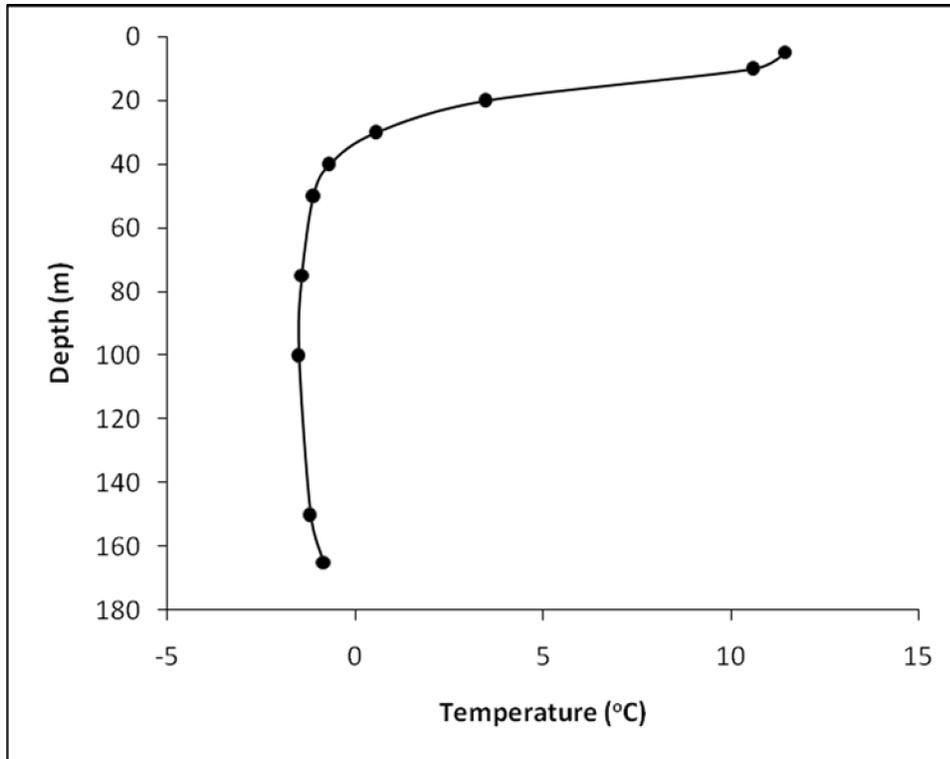
10 Figure 5: Mean (\pm SE) dive depth by time of day for nine common murrelets during the
11 chick-rearing period, July 2007.

12 Figure 6: Mean (a) dive and (b) bottom efficiency per depth class. Means are plotted
13 only when $n \geq 4$ dives per depth class.

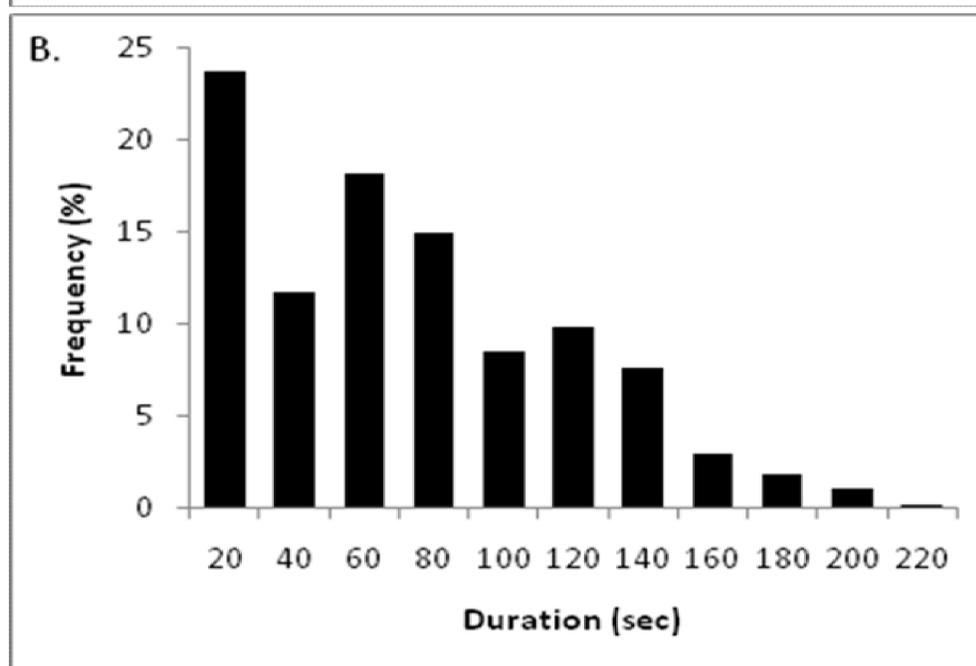
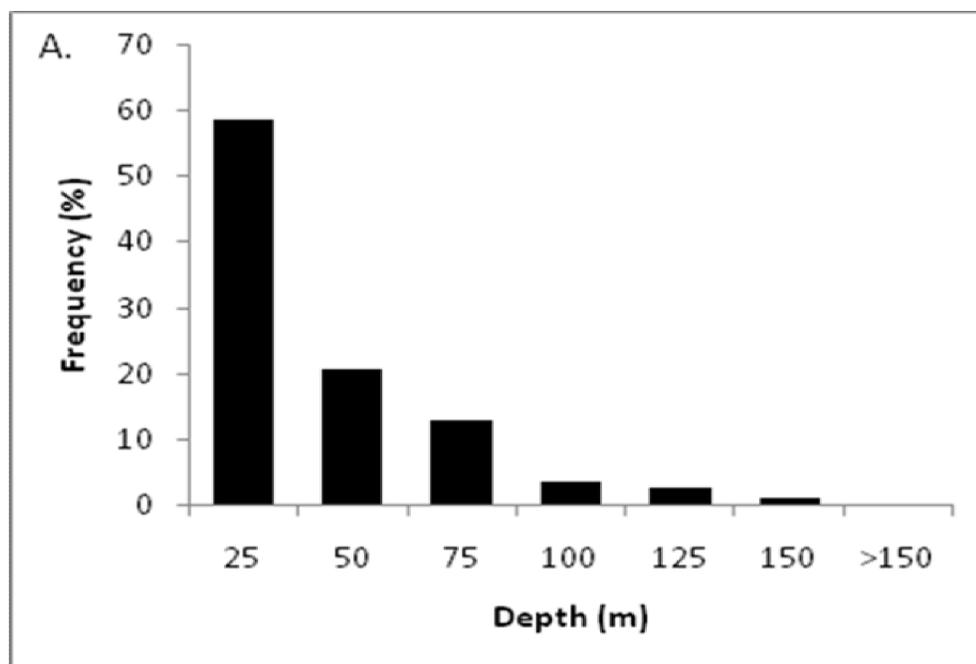
14 Figure 7: Mean dive depth ($m \pm 95\%$ confidence intervals) as a function of the number of
15 dives per bout.

16 Figure 8: Bottom time as a function of the minimum temperature attained during a dive.
17 V-dives (with no bottom time) are excluded and to accommodate the lagged
18 response of the temperature sensor, only dives ≥ 30 sec were plotted.

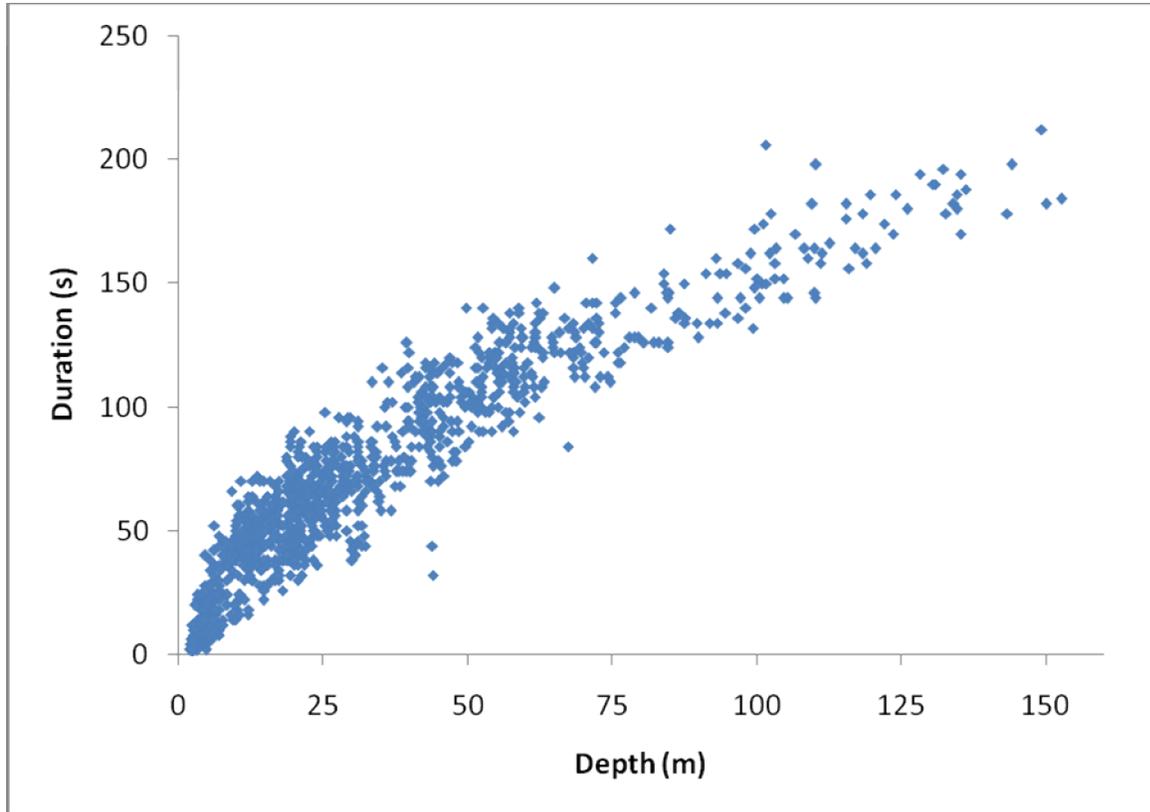
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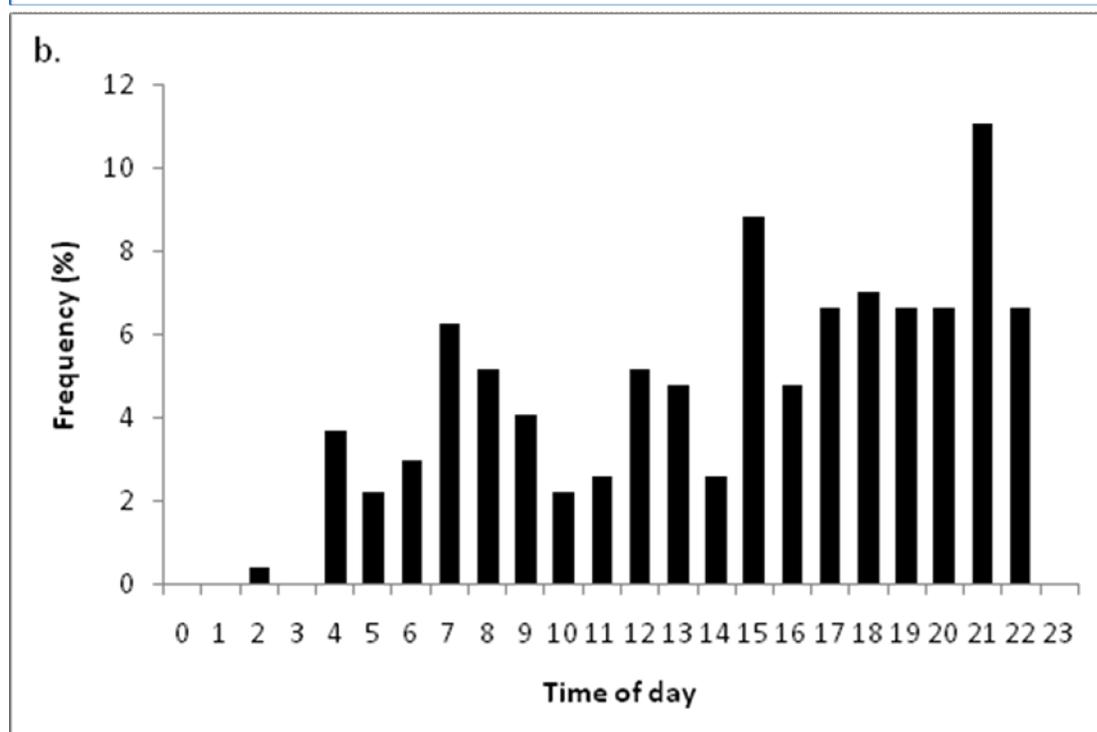
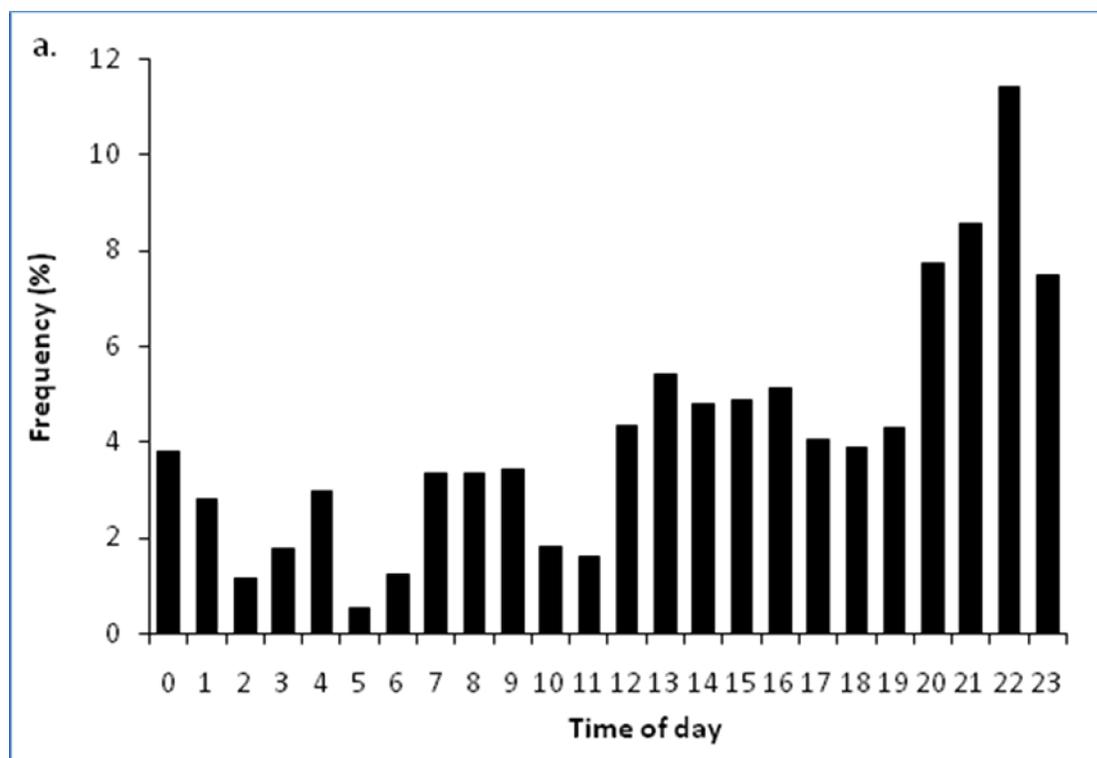
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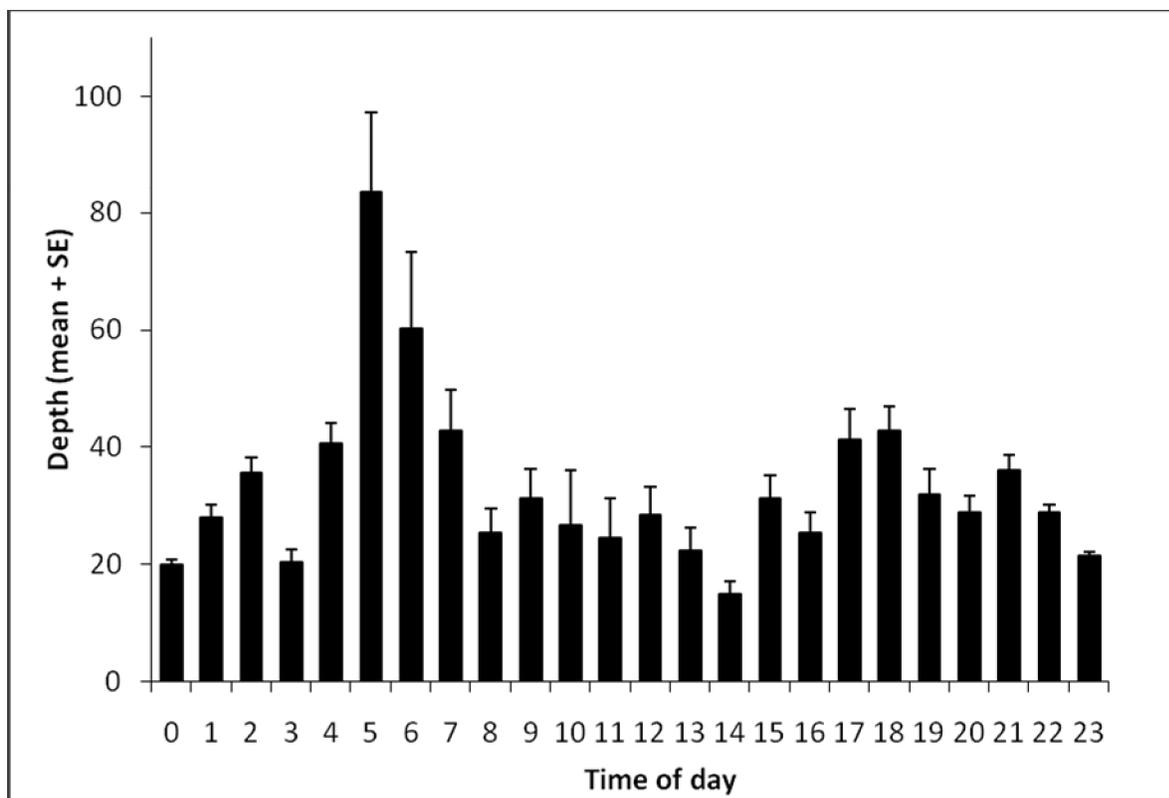
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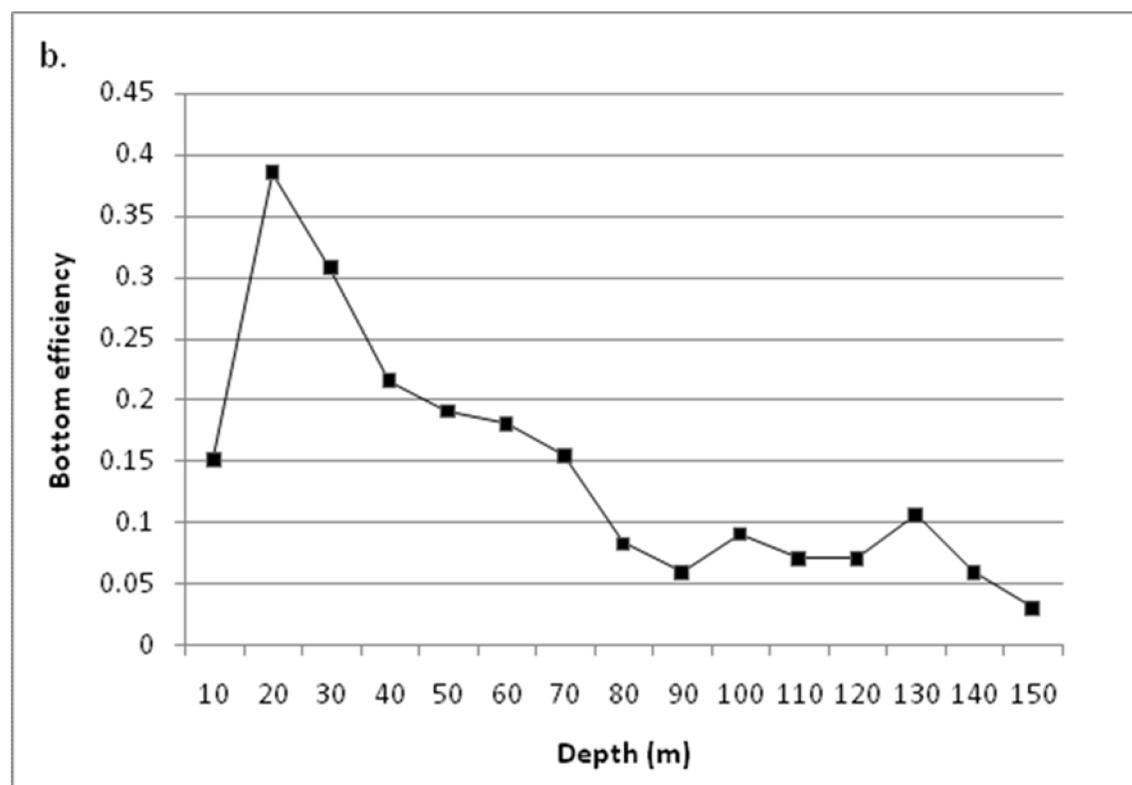
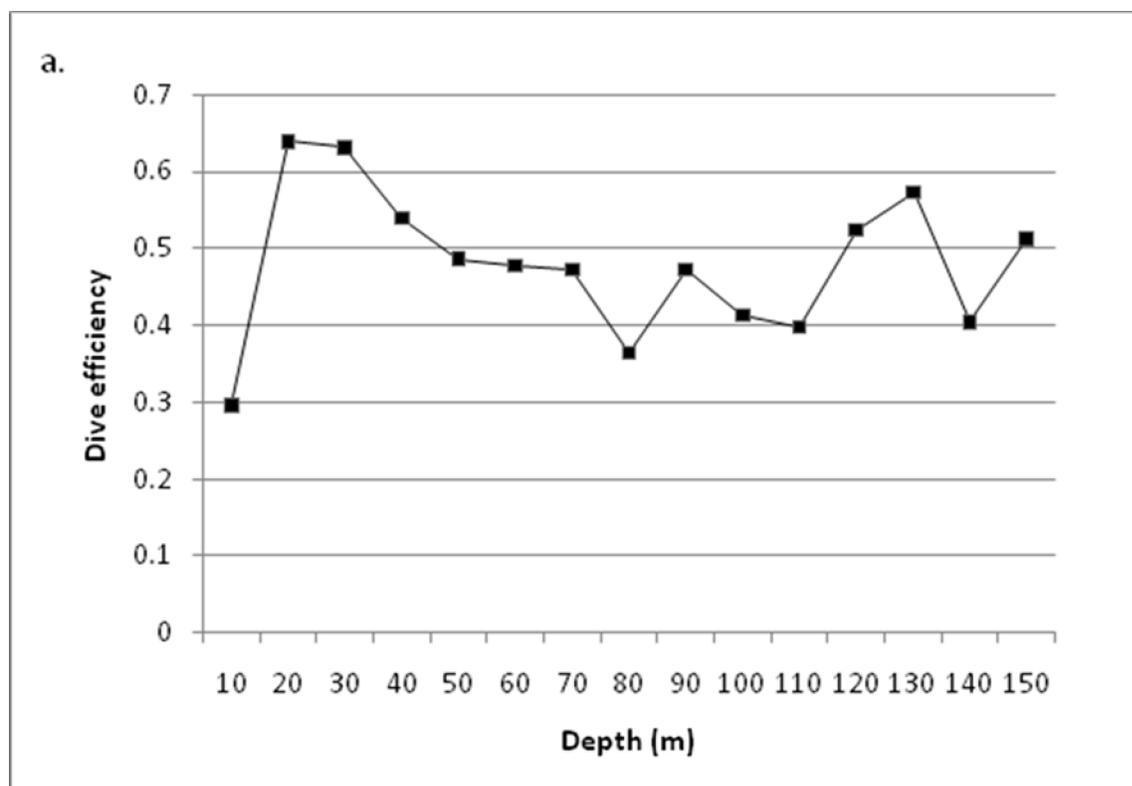


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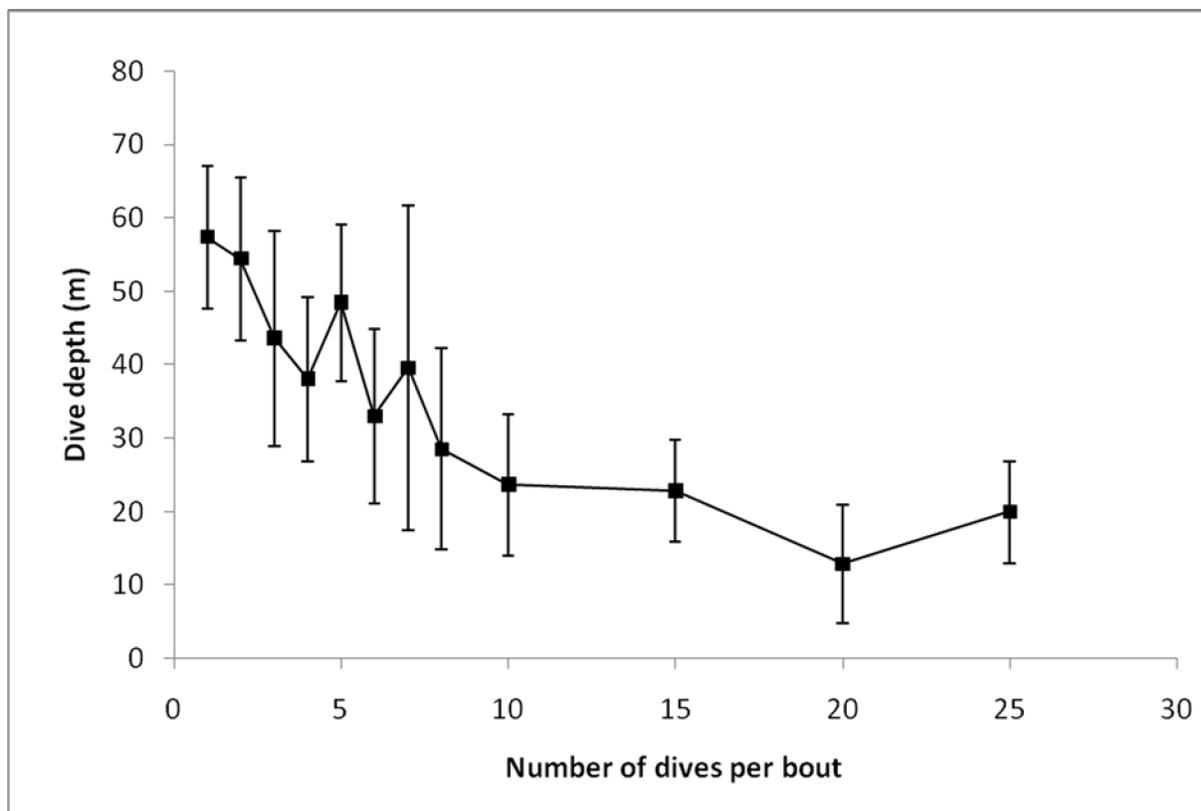


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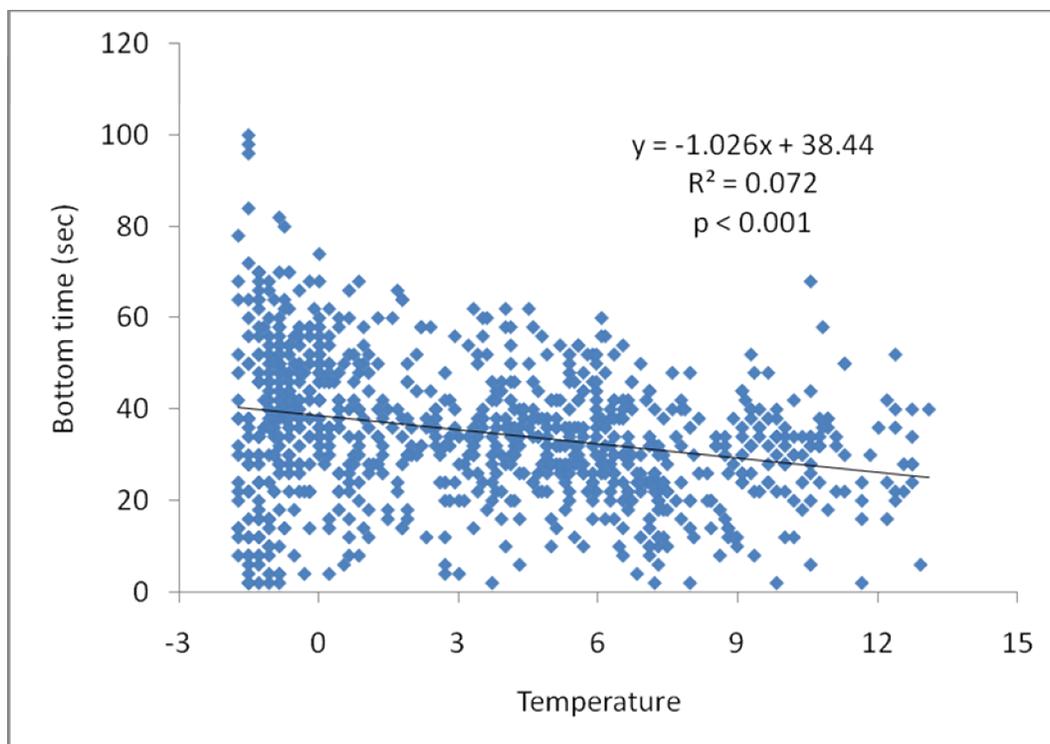


Table 1: Number of complete (partial) foraging trips, along with frequency and occurrence of deep (≥ 50 m) and shallow (< 50 m) dives by nine chick-rearing common murrelets during the day and night.

Bird	No. Trips	Total dives (n)	Deep dives		Shallow dives		Lunar phase
			Day N (%)	Night N (%)	Day N (%)	Night N (%)	
Funk Island							
84650436	4	93	32 (34%)	0 (-)	41 (44%)	20 (22%)	Full
84650437	3 (1)	310	27 (9%)	0 (-)	143 (46%)	140 (45%)	Full
84650438	2 (1)	197	60 (31%)	9 (5%)	45 (23%)	83 (41%)	Full
84650442*	1	38	26 (68%)	0 (-)	12 (32%)	0 (-)	Full
84650445*	1 (1)	66	27 (41%)	0 (-)	39 (59%)	0 (-)	Full
84650447	2 (1)	121	21 (17%)	0 (-)	61 (50%)	39 (32%)	Full
84650478*	3 (1)	409	54 (13%)	0 (-)	355 (87%)	0 (-)	Full
Gull Island							
99685172	3	68	14 (21%)	0 (-)	50 (74%)	4 (6%)	New
99685173	1	5	2 (40%)	0 (-)	3 (60%)	0 (-)	New
Total	20 (5)	1307	263 (20%)	9 (<1%)	749 (57%)	286 (22%)	

*Indicates birds were at the colony at night (i.e., there was no nighttime sampling at sea)

Table 2: Common and thick-billed murre approximated mean and maximum (in parentheses) dive characteristics as revealed by electronic data loggers. Data are organized by location and arranged west to east

Location, year(s)	Dive duration (s)	Dive Depth (m)	Method	Sources
common murre				
California 2001	37 (193)	-	VHF telemetry	Nevins 2004
Newfoundland 2007	62 (212)	30 (152)	TDR	This study
Scotland 1986-87	67 (202)	-	VHF telemetry	Wanless et al. 1988
Scotland 1997-98 ^a	107 (-)	41 (-)	VHF telemetry	Camphuysen 2005
Scotland 2001-03 ^a	92 (-)	34 (~75)	PreciTD loggers	Camphuysen 2005
Norway 1999	39 (119)	10 (37)	TDR	Tremblay et al. 2003
thick-billed murre				
Northwest Territories 1988-89	55 (224)	18 (107)	TDR	Croll et al. 1992
Northwest Territories 1998	86 (-)	-	Direction recorders	Falk et al. 2002
Northwest Territories 2005 ^b	68 (246)	79 (140)	TDR	Elliott et al. 2007
Labrador 1999	100 ^c (240)	-	T recorders	Jones et al. 2002
Greenland 1997-98	117 ^a (240)	-	Direction recorders	Falk et al. 2000 & 2002
Greenland 1998	105 ^d (-)	- (> 70)	Direction recorders	Benvenuti et al. 2002
Norway, 1998	97 (196)	45 (136)	TDR	Mehlum et al. 2001

^a averaged across years, ^b non-handicapped birds only, ^c averaged for males and females, ^d chick-rearing birds only