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### Measurements of Diving Depth in Dovekies (*Alle alle*)

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Diving seabirds have a three-dimensional foraging habitat, and maximum diving depth is important in defining habitat availability for each species. Therefore, measurements of dive depths and profiles are significant components in many studies of seabird foraging ecology (Burger 1991, Burger et al. 1993, Wilson 1995, Gaston and Jones 1998). The Dovekie (*Alle alle*) is the most abundant seabird that breeds in the high-arctic region of the Atlantic, where it feeds chiefly on small zooplankton (Roby et al. 1981, Bradstreet 1982) that are caught by wing-propelled diving. The actual diving depths reached by foraging Dovekies have not been measured, and apart from indirect evidence, such as dive duration or projec-

tions based on dive capabilities of other species, little is known of the diving behavior of Dovekies (Bradstreet and Brown 1985).

Here, we report on field measurements of maximum dive depths attained by adult Dovekies breeding in northwestern Greenland, where most of the world population relies on the rich production of zooplankton in the North Water Polynya between Ellesmere Island and Greenland.

*Methods.*—The study was performed in a large colony of Dovekies on Hakluyt Island (77°25'N, 72°42'W) in the northern part of the species' range within northwestern Greenland (Boertmann and Mosbech 1998). Adult Dovekies with well-developed incubation patches were captured in mist nets in the colony on 30 July 1997 and between 16 and 21 July 1998 (early nestling period). A total of 56 Dovekies

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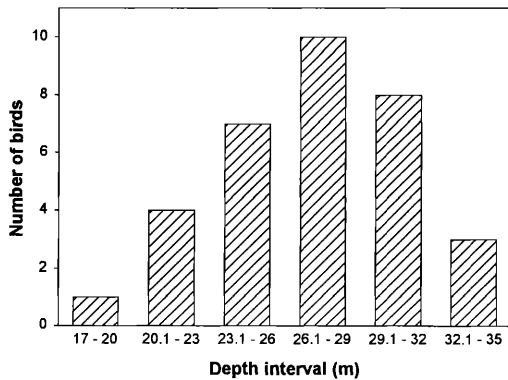


FIG. 1. Distribution of maximum dive depths attained by Dovekies ( $n = 33$ ) in the North Water Polynya, northwestern Greenland.

was equipped with maximum depth gauges (MDG) made of 120-mm capillary tubes (Tygon R-3603, 1.6 mm internal diameter) that were coated on the inside with a water-soluble powder (icing sugar) and sealed at one end, as described by Burger and Wilson (1988). Gauges recorded the single deepest depth reached by each of the tagged birds, and the depth ( $d$ ) in meters was calculated from Boyle's law:

$$d = 10.08 (L_s/L_d - 1), \quad (1)$$

where  $L_s$  is the total length of the tube (mm) and  $L_d$  is the length of tube (mm) that remains coated with icing sugar following deployment (Burger and Wilson 1988). The MDGs were attached to the central back feathers with 5-mm wide strips of waterproof adhesive tape (Tesa marine tape) wrapped around a few dorsal feathers (Burger and Wilson 1988), but with an additional attachment point at the middle of the MDG so that the unit was fixed along the center of the bird's back and extended slightly beyond the tail. The device with tape weighed 1.3 g, equivalent to less than 0.9% of the mean body mass of Dovekies ( $152.1 \pm \text{SD of } 1.13 \text{ g}$ ,  $n = 24$ ).

Individual birds in the crowded colony were virtually impossible to recapture, so we read the MDGs one to three days after attachment by the use of a  $32 \times 77$  Leica telescope from a distance of 7 to 15 m. Having marked each centimeter on the MDGs with a permanent ink marker, we read them to the nearest millimeter (by interpolation). A test of our ability to read the MDGs against a black background at a distance of 10 m disclosed that both observers read correctly in 9 of 11 cases and differed from correct values by only 1 mm in the remaining two cases. No significant differences existed between observers in their ability to read the MDGs (paired  $t = 1.49$ ,  $n = 11$ ,  $P = 0.17$ ) or between MDG values measured with a ruler versus read through a scope (paired  $t = 1.49$ ,  $n = 11$ ,  $P = 0.17$  for observer 1;  $t = 1.2$ ,  $n = 11$ ,  $P =$

TABLE 1. Maximum diving depths (m) by Dovekies fitted with maximum depth recorders (MDG) that provided data for more than one day.

Bird <sup>a,b</sup>	No. of days after MDG deployment			
	1	2	3	4
A	26	26	—	—
B	35	35	—	—
C	—	—	21	33
D	35	35	35	—
E	32	—	32	33
F	27	27	27	—
G	27	27	28	—
H	29	30	32	—
I	—	29	—	30
J	24	28	29	—

<sup>a</sup> Birds A and B were marked on 17 July 1998, and all others were marked on 19 July 1998.

<sup>b</sup> Birds D, H, and I were seen carrying food to chicks.

0.26 for observer 2). In addition, repeated readings at short intervals of the same MDG, or readings subsequently compared with the few recovered tubes, never differed by more than 1 mm. However, to err on the conservative side, we consider the readings to be precise to the nearest two millimeters, so the inaccuracy of the dive measurements with this method would not exceed 10%. Individual birds could be identified by a number written on the MDG, color bands, or by permanent ink marks on the white breast plumage. All means are reported  $\pm 1 \text{ SD}$ .

**Results.**—Of the 56 equipped Dovekies, we retrieved the MDG from four birds and read the values from the MDG for an additional 30 birds; the first capture or reading took place 1, 2, or 3 days after attachment in 15, 12, and 6 cases, respectively. Most of the birds were seen carrying food (i.e. full gular pouches) in the colony, indicating that they were bringing meals to their chicks. Maximum dive depths ranged from 18.7 to 34.7 m (Fig. 1) and averaged  $27.3 \pm 4.1 \text{ m}$  ( $n = 33$ ). The MDG of the remaining bird was read 1.5 h after deployment; the recorded depth was only 3.1 m, which may represent a bathing dive, not a foraging trip, and so was excluded from further analysis. Most birds dived within the range of 20 to 32 m, with only three exceeding 32 m (Fig. 1).

The values reported in Figure 1 are based on the first reading from each bird. We read the MDGs of 10 birds on more than one day (Table 1), and subsequent dive depths by six of these birds exceeded their first records by an average of  $4.0 \pm 4.3 \text{ m}$ . When using the maximum values attained by each bird, the overall average maximum depth increased to  $28.2 \pm 3.9 \text{ m}$ . The deepest dives (two birds), however, were still 34.7 m. Maximum dive depth was not correlated with body mass ( $r = 0.03$ ,  $\text{df} = 15$ ,  $P = 0.9$ ) or wing length ( $r = 0.2$ ,  $\text{df} = 17$ ,  $P = 0.4$ ).

*Discussion.*—This study provides the first field measurements of dive depth in the Dovekie. Between one and three days after MDG attachment, all birds had been to a depth of at least 18 m, and 33% of them to 30 m or deeper, suggesting that such depths are attained regularly during the chick-feeding period in the North Water Polynya.

Our results confirm the initial estimates of the vertical limits to the pelagic foraging range in the Dovekie. In a discussion of diving performance of Dovekies, Bradstreet and Brown (1985) estimated maximum dive depths to be 15 to 30 m based on dive duration of individual birds. Burger (1991) analyzed the allometric relationship between maximum dive depth and body mass in 10 species of penguins and 9 species of alcids; a reanalysis of his data (to obtain a calculated value instead of a value read from Burger's graph) predicts a maximum dive depth of 32.2 m for Dovekies. Diving-petrels (*Pelecanoides*) in the Southern Hemisphere are similar-sized ecological equivalents of the Dovekie (and small planktivorous Pacific alcids). In general, diving-petrels do not fit the allometric relationship between maximum dive depth and body mass for diving seabirds (Chastel 1994, Schreer and Kovacs 1997). Measurements of diving ability have shown that the 100-g South Georgia Diving-Petrel (*P. georgicus*) regularly dives to 25 m, with a maximum of 48.6 m (Prince and Jones 1992). The Common Diving-Petrel (*P. urinatrix*), being about the same size (145 g) as the Dovekie, dived to 39 m with a record dive of 63.6 m (Chastel 1994).

Chastel's (1994) study revealed variation in diving depth during the breeding season, perhaps reflecting changes in vertical distribution of the main planktonic prey of diving-petrels. Our study of Dovekies covered only a short period of their presence in the breeding area, and it is possible that their diving depths varied over time. Thus, dive measurements obtained throughout the breeding season, coupled with dietary studies, are needed to reveal seasonal variation in foraging ecology. Because MDGs recorded only the maximum depth reached, details in dive profiles and daily shifts in maximum dive depths require investigations with data loggers that have been successfully deployed on larger species of diving seabirds (Croll et al. 1992, Falk et al. 2000).

Burger and Wilson (1988) identified sources of error associated with MDGs, and to meet their recommendations for reducing potential errors we tried to read the MDGs soon after they were deployed. Although the MDGs were not recovered, as inspected through the telescope none of them appeared to have accumulated major droplets inside the tube (which may reduce the air volume and lead to an overestimate of dive depth), and the border between the wet and dry sections of the MDG nearly always was sharp and easily identifiable. Thus, the potentially large error induced by droplet accumulation is not likely to have affected our results.

In other studies that have used MDGs on alcids, the greatest limitation of the technique has been the difficulty of recapturing birds, so sample sizes have been small (Burger and Simpson 1986, Burger 1991, Prince and Jones 1992, Burger et al. 1993). Reading the values of dorsally mounted MDGs from a distance partly overcomes the problem, and we obtained data from 61% of our instrumented Dovekies. Individual birds often spent extended time near the nest entrance, permitting careful reading of the MDG. The technique that we describe may be applicable in other species where individuals are hard to recapture but easy to observe.

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### Assortative Mating by Color in a Population of Hybrid Northern Flickers

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Yellow-shafted Flickers (*Colaptes auratus auratus*) with black moustache marks and red nape patches, and Red-shafted Flickers (*C. a. cafer*) with red moustaches and no nape patches, formerly were considered separate species (see Moore 1995). Because the two hybridize extensively along a zone that extends along the eastern slope of the Rocky Mountains from Alaska to Texas (Short 1965, Moore 1995), they were classified as a single species, the Northern Flicker (*C. auratus*; AOU 1983). The persistence of hybrids and the apparent stability of the hybrid zone over centuries (Rising 1983, Moore and Buchanan 1985) has been of considerable interest to evolutionary biologists because patterns of mate assortment after secondary contact bear on competing hypotheses for mechanisms of speciation. If genetic incompatibility reduces hybrid fitness, reproductive isolating mechanisms should be favored. However, flickers in the central and southern United States do not appear to mate assortatively (Short 1965, Beck 1971, Moore 1987), and hybrid individuals do not seem to have lower fitness than the parental types (Moore and Koenig 1986).

Little is known about flicker populations in the northern part of the hybrid zone (Rising 1983), where evidence suggests that the distributions of subspecies have shifted over time (McGillivray and Biermann 1987). Using the largest sample of mated

pairs yet obtained from a single location, I examined whether hybrids in a northern population mated assortatively.

*Study Area and Methods.*—The study area was near Riske Creek, central British Columbia (51°52'N, 122°21'W), and encompassed approximately 71 km<sup>2</sup> of grassland with scattered clumps of trembling aspen (*Populus tremuloides*) and mixed forest. Flickers of a variety of phenotypes occur at Riske Creek, and many (but not all) display characteristics of hybrids. I observed flickers in 1998 from the time adults arrived on territories in late April until the young left the nest in July. I censused territories about every second day using tape-recorded territorial vocalizations. When a nest with eggs was found, I cut a small "door" into the tree cavity after I determined that the clutch was complete and there was little risk of the pair abandoning.

Adult flickers were trapped at the nest during the incubation or brood-rearing periods. Trapped adults were given a unique combination of colored leg bands and were weighed and measured. Wing chord (flattened) and the lengths of the tail and the 9th primary were measured with a ruler to the nearest mm, and bill length (from the anterior edge of the nostril), bill depth, and tarsus length were measured with digital calipers to the nearest 0.05 mm. Only one parent was trapped at some nests, so sample sizes differed for analyses.

Except where noted, I ranked plumage color following the methods in Short (1965). Malar mous-

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