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Observations on the Cooling Tolerance of Embryos of the Diving Petrel *Pelecanoides georgicus*

DANIEL D. ROBY AND ROBERT E. RICKLEFS
Department of Biology, University of Pennsylvania, Philadelphia, Pennsylvania 19104 USA

The tolerance of procellariiform embryos to extended periods of cooling has been documented for storm-petrels (Hydrobatidae) (Pefaur 1974, Boersma and Wheelwright 1979, Vleck and Kenagy 1980, Simons 1981), members of the family Procellariidae (Matthews 1954, Tickell 1962, Richdale 1963, Bartle 1968), and anecdotally for the Waved Albatross (*Diomedea irrorata*, Diomediidae; Harris 1973, no details given). Cooling tolerance in these taxa is assumed to be an adaptation to long-distance foraging on unpredictable food supplies, which may cause adults to leave eggs unattended for periods of one to several days. Cooling tolerance may not be ubiquitous among the Procellariidae, however, as advanced embryos of the Southern Giant Fulmar (*Macronectes giganteus*) cannot tolerate cooling to 3°C for 48 h (Williams and Ricklefs MS), and tolerance has not been confirmed in the albatrosses (Diomediidae, cf. Richdale 1952) or in the diving petrels (Pelecanoididae).

Apropos of the diving petrels, Thoresen (1969) discovered a deserted, pipping egg of *Pelecanoides u. urinatrix*, which subsequently hatched after being unattended for 10 days at an ambient temperature of about 17°C. Unusual variability in incubation periods has been cited as indirect evidence of egg neglect in some species (Boersma 1982). Payne and Prince (1979) found little variation in the incubation period of 10 *P. georgicus* eggs (44–49 days), except for one period of 65 days, which suggested the possibility of about 20 days of neglect. Because this egg was neither marked nor checked early in the incubation period, however, the possibility of egg loss and subsequent relaying cannot be ruled out. In this paper, we report observations that demonstrate a well-developed tolerance for chilling by embryos of the South Georgian Diving Petrel (*Pelecanoides georgicus*).

During the course of a study of the reproductive biology of *P. georgicus* on Bird Island, South Georgia (54°00'S, 38°02'W) during January and February 1982, our activities at nests caused some adults to abandon eggs late in the incubation period. Nests were usually checked daily, 8 or more hours after dawn. Adult diving petrels are strictly nocturnal at the breeding colony (pers. obs.), so an egg found cold in an unattended burrow was assumed to have been unincubated for at least 8 h. If the egg was found cold on subsequent consecutive days, it was assumed that the egg had not been incubated in the interim period. With these assumptions, we estimated the total chilling period for each egg before placement in the incubator (Table 1).

Eggs from 25 nests, abandoned for between 8 and 56 h in most cases, were removed and placed in an incubator. We measured temperatures of 7.8, 8.1, and 8.9°C in three unoccupied burrows. The temperature in the incubator was 36 ± 0.5°C, but, owing to the daily shutdown of the field station generator for maintenance, all eggs cooled to room temperature (ca. 20°C) for about 8 h each night. Eggs were left in the incubator and turned daily.

Despite initial chilling in the nest and subsequent daily temperature fluctuation in the incubator, 14 eggs hatched after periods of 4–19 (average = 10.2) days in the incubator, with the exception of 1 egg, which hatched after 32 days (Table 1). We estimated the ages of embryos to be 24 days in one case and between 34 and 44 days for the remaining eggs at the time they were abandoned (see Table 1). The average

TABLE 1. Hatchability of *P. georgicus* eggs following chilling in the nest burrow.

Egg number	Age at abandonment (days)[a]	Chilled at 5–10°C (h)	Incubation before hatching (days)	Hatched?
1	38	8	12	yes[b]
2	39	8	11	yes
3	40	8	9	yes
4	—	8	—	no[b]
5	—	8	—	no
6	—	8	—	no[c]
7	—	8	—	no[b]
8	40	32	10	yes
9	42	32	7	yes
10	44	32	4	yes
11	—	32	—	no[b]
12	25	56	32	yes
13	36	56(?)	16	yes
14	39	56	11	yes[c]
15	39	56	11	yes
16	41	56	8	yes
17	43	56	5	yes
18	—	56	—	no[c]
19	—	56	—	no[b]
20	—	56	—	no
21	—	56	—	no[b]
22	34	80(?)	19	yes[c]
23	40	80(?)	10	yes
24	—	80+	—	no
25	—	104(?)	—	no[b]

[a] Age estimated to nearest day by assuming no previous egg neglect and subtracting the period in the incubator at 36°C before hatch (⅔ of column 4) from the average incubation period of 46.4 days (Payne and Prince 1979).
[b] Egg shell had large crack when removed from nest burrow.
[c] Egg shell had small crack when removed from nest burrow.

incubation period for *P. georgicus* is 46 days (Payne and Prince 1979). Of the 11 eggs that failed to hatch, the shells of 8 had cracked when nest burrows collapsed during excavation, 1 died shortly after pipping, and 2 died from unknown causes.

Of the 14 eggs that hatched, 3 had been chilled for at least 8 h, 3 for at least 32 h, and 5 for at least 56 h. Three other eggs were from nests that we did not check daily after the eggs were first found abandoned. One was unattended on the 3rd day but not checked on the 2nd, another was unattended on the 4th day but not checked on the 2nd and 3rd days, and the last was unattended on the 3rd and 4th days but not checked on the 2nd. This last egg probably was unattended at ambient temperatures of 5–10°C for about 80 consecutive hours before being placed in the incubator.

These data demonstrate that advanced embryos of *P. georgicus* can tolerate considerable cooling. There is no direct evidence concerning attentiveness during the incubation period in diving petrels, so it is not possible to interpret the adaptive significance of cooling tolerance of embryos in this group.

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