**Proceedings of the Royal Society B – Supplementary Material**

Glenn T. Crossin and Tony D. Williams - “Migratory life-histories explain the extreme egg-size dimorphism of *Eudyptes* penguins”.

Table S1 | Estimates, derived from the literature, for the average time interval between colony arrival and the initiation of egg laying for all penguin species that produce a two egg clutch. This pre-laying time interval provides an estimate of the temporal overlap between migratory activity and follicle development (see Material and Methods section). References for estimates are provided, as are comments about estimation methods were made (e.g. quantitative, versus non-quantitative or anecdotal). See Table 1 for final estimates used for analysis.

|  |  |  |  |
| --- | --- | --- | --- |
| **Species** | **Interval or “overlap”****(days)** | **References** | **Data type and Comment** |
| Adélie*(Pygoscelis adeliae)* | 17.4 |  | Mean of quantitative studies below. |
|  | 42 | Speé et al. 2010 | * **Quantitative.** Estimate derived from population-level monitoring of individually marked females at Dumont D’Urville. N=92. Figure 1 shows that females are fasting on land for ~ 42 days before laying.
 |
|  | 28 | Groscolas et al. 1986 | * **Quantitative.** Estimate derived from population-level monitoring of marked individuals at Dumont D’Urville. Females arrived ~ 4 weeks before laying.
 |
|  | 21 | Trathan and Ballard 2013  | * **Quantitative.** Estimate derived from review of several population-level monitoring studies. The authors state that 21 days is the mean interval across all colonies, based on their own review of the literature. Although they acknowledge that there is likely variation around this estimate, they do not report this variation.
 |
|  | 20 | Jablonski 1987 | * **Quantitative.** Estimate derived from population-level monitoring of individually marked females at King George Island, South Shetlands. N~120 .
 |
|   | 18 | Trivelpiece and Fraser 1996 | * **Anecdotal.** The authors report information gleaned from studies at colonies along the Ross Sea and Prydz Bay region. They state that after walking across sea-ice to reach colonies, penguins fast for 3-5 weeks to the end of laying. If the 3-day lag between A and B eggs is removed, this leaves an estimate of 18 days, which is the most conservative estimate from this 3-5 week range. No samples sizes or other details provided, and so this estimate was not used in our mean calculation.
 |
|   | 17 | Trivelpiece and Trivelpiece1990 | * **Quantitative.** Estimate derived from population-level monitoring of individual banded females at King George Island, South Shetlands. N>100 females. Arrival to B-egg laying was 20 days, less a 3 day lag.
 |
|   | 14.6 | Lishman 1985 | * **Quantitative.** Estimate derived from population-level monitoring. N=19 females. Pre-laying interval is estimated at 17.6 days to B-egg (range 11-27 days) at Signy Island, South Shetlands, less 3 day lag = 14.6 days. These penguins must walk many kms across ice to reach the colony.
 |
|  | 14 | Penney 1960 | * **Quantitative.** Estimate derived from population-level monitoring. N~28 females. Arrival to laying varied from “2-4 weeks”. We used 14 days value in our mean calculation.
 |
|   | 14-24 | Taylor 1962 | * **Anecdotal.** Source unclear, but population estimates of colony arrival and first egg dates suggest a ~14 day prelaying for the Adélie population at Cape Royds (1959-60), and a 24 day pre-laying period at Signy Island (1950-51). These estimates are not used in our mean calculation.
 |
|   | 14-21 | Ainley and LeResche 1973 | * **Anecdotal.** Females have "2-3 week fast" before incubation, and so they presumably have a 14-21 pre-laying interval. No data or references are provided. These estimates are not used in our mean calculation.
 |
|  | 11 | Davis 1982 | * **Quantitative.** Estimate derived from monitoring of individual marked penguins at Cape Bird. Range 8-16 days. N=31 females.
 |
|   | 10 | McQueen et al. 1999 | * **Anecdotal.** Egg laying occurs about 10 days after arrival at the breeding colony, but no data or references are provided. This estimate is not used in our mean calculation.
 |
|   | 10 | Astheimer and Grau 1985 | * **Quantitative.** Estimate derived from population-level monitoring of individual marked females at Cape Crozier. N=26 females. It is noted that females must walk across "many kilometers of ice" before reaching colony. They don't give an estimate for how long this could be but say that this can be as long as 3 days. They speculate that the interval between arrival on land (ice) to clutch completion is “2-3 weeks”.
 |
|   | 7.1 | Ainley et al. 1983 | * **Quantitative.** Estimate derived from population-level monitoring of individual marked females at Cape Crozier. N>900 through 7 years. Data show mean arrival to first post-laying departure time = 10.1 days, less a 3 day lag. Penguins must cross many hundreds of kilometers of ice to reach colony.
 |
|   | 7.1 | Stonehouse (1963) | * **Quantitative.** Estimate derived from population-level monitoring. N=?? females. It is noted that penguins arrive in colony after many days walking across sea ice. Derksen (1977) presents the same estimate, attributed to Stonehouse.
 |
| Chinstrap*(P. antarcticus)* | 17.4 | Trivelpiece and Trivelpiece1990 | **Quantitative.** Estimate derived from population-level monitoring of individual banded females at King George Island, South Shetlands. N>100 females. Croxall and Davis (1999) present this same estimate. |
|  |  |  |  |
| Gentoo*(P. papua)* | 25 | Croxall and Davis 1999 | **Anecdotal.** Gentoo are non-migratory, inshore foragers who remain close to their breeding colonies during the non-breeding period. They make short, local foraging trips during day but haul out at night and are thus effectively land based during RDY, although potentially not at the nest. |
|  |  |  |  |
| Black-footed*(Spheniscus demersus)* | n/a |  | No estimates available. Penguins are generally present in or near the colony all year. |
|  |  |  |  |
| Magellanic*(S. megallanicus)* | 17 | Yorio and Boersma 1994Boersma et al. 2013 | **Quantitative.** Estimate derived from population-level monitoring. N=?? females. Yorio & Boersma (1994) state that the duration between arrival and first incubation relief is 31 days. Subtracting the first incubation shift which runs ~ 11 days, as well as the 3 day interval between eggs, the pre-laying interval could be estimated at 17 days. Similarly, Boersma et al. (2013) state anecdotally that “males may be on shore three to four weeks before females lay their eggs”, and that “males arrive a week or so before females”. This suggests a pre-laying interval on land for females of at least two weeks. Croxall and Davis (1999) list the pre-laying period at 8 days for female Magellanic penguins, but there is no reference for this. |
|  |  |  |  |
| Peruvian*(S. humboldti)* | 30 | Croxall and Davis 1999 | **Anecdotal.** No direct reference is provided for this estimate, but it is probably related to the fact that breeding in this species begins immediately after moult, which requires a long interval on land. Zavalaga and Parades (1997) note that after one or two months of territory establishment, courtship, nest building and mating, penguins begin to lay eggs. This suggest a very long pre-laying interval that exceeds RYD times, and so 30 days may be an underestimate. |
|  |  |  |  |
| Galapagos*(S. mendiculus)* | n/a |  | No reliable estimate available. Non-migratory, highly site faithful, even during the non-breeding period. As noted by Williams (1995) the pre-laying interval on land can be variable, exceeding 14 days or as little as 1 day. Species is considered a resident, inshore forager in winter, and so non-migratory. Due to the lack of estimate, Galapagos were excluded from analysis. |
|  |  |  |  |
| Little*(Eudyptula minor)* | 21 | Chiaradia and Kerry 1999 | **Quantitative.** Estimate derived from population-level monitoring of individually marked penguins. N=53 females. Authors note that the pre-laying period on the nest is 11.2 days, upon their return from a 10 day pre-breeding exodus. As inshore, non-migratory foragers, that spend time on land both during the day and night, the pre-laying period is estimated at 21 days. This is not as long as the 30 day estimate provided by by Croxall and Davis (1999). There are no data regarding arrival and laying times exist for the closely related white-flippered penguin (*E. minor ablosignata*). |
|  |  |  |  |
| White-flippered*(E. m. ablosignata)* | n/a |  | No estimate available. |
|  |  |  |  |
| Yellow-eyed*(Megadyptes antipodes)* | 30 | Darby and Seddon 1990 | **Quantitative.** Estimate derived from population-level monitoring of individually marked penguins. N=637 adults. This chapter in Davis and Darby’s (1990) book provides a timeline of breeding phenology, indicating a very long pre-breeding interval on land. Yellow-eyed penguins are inshore foragers and are not considered migratory, and so are present at colonies year round. This estimate is also presented in Croxall and Davis (1999) and Davis and Renner (2003). |
|  |  |  |  |
| Erect-crested*(Eudyptes sclateri)* | 10.5 | Davis 2013Davis 2001 | **Anecdotal.** Croxall & Davis (1999) list the pre-laying period as 23 day in males, but provide no estimate for females. Davis (2013) states that males arrive at the colony “about 3 weeks ashore before laying occurs”. Other species accounts state that females arrive approximately 2 weeks after males (<http://marinebio.org>, <http://penguins.cl>, <http://penguin.net.nz>). These observations suggest suggest that females are on land about a week before laying. However, Davis’ (2001) “casual observations” noted that females arrived “about 2 weeks before laying begins”. We therefore estimate pre-laying interval at 10.5 days, which would be the midpoint between 1 and 2 weeks. Unfortunately, more precise estimates do not exist for this species. Note: Richdale’s (1950) estimate of a 24 day pre-laying period for females was derived from observations of a single female erect-crested penguin, nesting in isolation in a forest outside of Dunedin, NZ. Such birds were called “stragglers” by Warham (1963). We do not use this estimate as this single, non-colonial individual, living on the mainland away from the remote offshore islands where the species breeds (Antipodes Island and Bounty Islands), must surely be considered an outlier as this breeding pattern does not fit with the observations from actual breeding colonies. |
|  |  |  |  |
| Royal*(E. schlegeli)* | 10 | Warham 1971Waas 1995 | **Quantitative.** Warham’s account at Macquarie Island shows mean female arrival is ~ 3 October, and mean A-egg laying is ~14 October, which is an ~11 day pre-laying interval. Waas (1995) conducted an social-manipulation experiment where females were monitored from the time of pair formation to A-egg laying, and the interval in control (unmanipulated) females was 8 days. Williams (1995) summarizes data from Warham and studies by Carrick and Ingram and others. Generally for the species, males arrive at colonies 20 Sept-15 October, with a midpoint of 3 October, and females generally 7-10 day later between 30 Sept-23 October, with a midpoint of 11 October. As peak laying occurs 20-23 October, an population level pre-laying interval can be estimated at ~10 days, which is similar to that of closely related macaroni penguins. |
|  |  |  |  |
| Macaroni*(E. chrysolophus)* | 10.5 | Crossin et al. 2013 | **Quantitative.** Well studies species. Estimate derived from individually marked females, as in Williams (1990) and Crossin et al. (2010). Estimate also presented in Williams (1995). |
|  |  |  |  |
| Rockhopper*(E. chrysocome)* | 14.6 | Williams 1995Warham 1963Poisbleau et al. 2015Morrison 2016 | **Quantitative.** Well studies species. Estimates from population-level monitoring and individually marked penguins. See Williams 1995 account and references therein; the estimate is 10.3 days. Morrison (2016) estimated from ~ 112 females an estimate of ~15 days. Poisbleau et al. (2015) studied >35 females over two years and estimated the interval at 18 days. Warham (1963) had arrival and laying dates for 3 individual females, and interval to A-egg laying was 15 days (14, 14, and 17). Croxall and Davis (1999) place the estimate at 11.3 days, although a clear references to this is not apparent. The estimate provided here is the mean of these estimates, excluding Croxall and Davis. |
|  |  |  |  |
| Fiordland*(E. pachyrhynchus)* | 15 | Warham 1963 | **Semi-Quantitative.** Estimate derived form population-level observations. Majority of birds returned to a colony at Jackson Head, NZ between 20 July (14-26 July), and peak of A-egg laying was 5 August (mean of 4 years, 1 August in one year and 6 August in 3 others). This provides a population level interval estimate of ~15 days. |
|  |  |  |  |
| Snares*(E. robustus)* | 13.5 |  | **Quantitative.** Estimate derived form population-level observations. Croxall and Davis (1999). |

**References**

Ainley, D. G., and R. E. LeResche. 1973 The effects of weather and ice conditions on breeding in Adélie penguins. Condor 75:235-239.

Ainley, D. G., R. E. LeResche, W. J. L. Sladen. 1983 Breeding Biology of the Adélie Penguin. University of California Press, Los Angeles.

Astheimer, L. B., and C. R. Grau. 1985 The timing and energetic consequences of egg formation in the Adélie penguin. Condor 87:256-268.

Boersma, P. D., E. Frere, O. Kane, L. M. Pozzi, K. Pütz, A. Raya Rey, G. A. Rebstock, A. Simeone, J. Smith, A. Van Buren, et al. 2013 Magellanic Penguin. In *Penguins: Natural History and Conservation*, P. G. Borboroglu and P. D. Boersma (eds). University of Washington Press, Seattle.

Chiaradia, A. F., and K. R. Kerry. 1999 Daily nest attendance and breeding performance in the little penguin *Eudyptula minor* at Phillip Island, Australia. Marine Ornithology 27:13-20.

Croxall, J. P., and L. S. Davis. 1999 Penguins: paradoxes and patterns. Marine Ornithology 27:1-12.

Darby, J. T., and P. J. Seddon. 1990 Breeding biology of yellow-eyed penguins (*Megadyptes antipodes*). In *Penguin Biology*, L. S. Davis and J. T. Darby (eds). Academic Press, San Diego.

Davis, L. S. 1982 Timing of Nest relief and its effect on breeding success in Adélie penguins (*Pygoscelis adeliae*). Condor 84:178-183.

Davis, L. S. 2001 A superlative penguin. Natural History 110:46-55.

Davis, L. S. 2013 Erect-crested penguin. In *Penguins: Natural History and Conservation*, P. G. Borboroglu and P. D. Boersma (eds). University of Washington Press, Seattle.

Davis, L. S., and J. T. Darby. 1990 Penguin Biology. Academic Press, San Diego.

Davis, L. S., and M. Renner. 2003 Penguins. Yale University Press, New Haven.

Derksen, D. V. 1977 A quantitative analysis of the incubation behavior of the Adélie penguin. Auk 94:552-566.

Groscolas, R., M. Jallageas, A. Goldsmith, and I. Assenmacher. 1986 The endocrine control of reproduction and molt in male and female emperor (*Aptenodytes forsteri*) and Adélie (*Pygoscelis adeliae*) penguins: I. Annual changes in plasma levels of gonadal steroids and LH. General and Comparative Endocrinology 62:43-53.

Lishman, G. S. 1985 The comparative breeding biology of Adélie and chinstrap penguins *Pygoscelis adeliae* and *P. Antarctica* at Signy Island, South Orkney Islands. Ibis 127:84-99.

McQueen, S. M., L. S. Davis, and G. Young. 1999 Sex steroid and corticosterone levels of Adélie penguins (*Pygoscelis adeliae*) during courtship and incubation. General and Comparative Endocrinology 114:11-18.

Richdale, L.E. 1950 Further notes on the erect-crested penguin. Emu 49:153-166.

Stonehouse, B. 1963. Observations on Adélie penguins (*Pygoscelis adeliae*) at Cape Royds, Antarctica. In *Proceedings of the 13th International Ornithological Congress*, pp. 766-779

Taylor, R. H. 1962 The Adélie penguin *Pygoscelis adeliae* at Cape Royds. Ibis 104:176-204.

Trathan, P. N., and G. Ballard. 2013 Adélie penguin. In *Penguins: Natural History and Conservation*, P. G. Borboroglu and P. D. Boersma (eds). University of Washington Press, Seattle.

Trivelpiece, W. Z., and W. R. Fraser. 1996 The breeding biology and distribution of Adélie penguins: adaptations to environmental variability. Foundations for Ecological Research West of the Antarctic Peninsula – Antarctic Research Series 70:273-285.

Trivelpiece, W. Z., and S. G. Trivelpiece. 1990 Courtship period of Adélie, gentoo and chinstrap penguins. In *Penguin Biology*, L. S. Davis, J. T. Darby (eds). Academic Press, San Diego.

Davis, L. S., and J. T. Darby. 1990 Penguin Biology. Academic Press, San Diego.

Warham, J. 1963 The Rockhopper penguin, *Eudyptes chrysocome*, at Macquarie Island. Auk 80:229-256.

Warham, J. 1971 Aspects of breeding behaviour in the royal penguin *Eudyptes schlegeli*. Notornis 18:289-301.

Warham, J. 1972 The breeding biology and behaviour of *Eudyptes* penguins. PhD thesis, University of Canterbury.

Williams, T. D. 1995 The Penguins. Oxford University Press, Oxford.

Yorio, P., and P. D. Boersma. 1994 Causes of nest desertion during incubation in the Magellanic penguin (*Spheniscus magellanicus*). Condor 96:1076-1083.

Zavalaga, C. B., and R. Parades. 1997 Humboldt penguins at Punta San Juan, Peru. Penguin Conservation 10:6-8.