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SHORT NOTE

Earlier laying by little penguins (*Eudyptula minor*): a possible effect of global warming

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There is growing evidence that changes in the marine environment caused by global warming are affecting the timing and success of breeding, and juvenile survival of a range of seabird species (Chambers *et al.* 2011). While most little penguin (*Eudyptula minor*) populations are likely to be affected in time there are few detailed, long-term biological data sets available at present to show this. An increase in sea surface temperature (SST) is expected to have a positive effect on the little penguins on Phillip Island, SE Australia, with earlier and more productive breeding and greater survival of first year birds (Cullen *et al.* 2009; Dann & Chambers 2013). That trend is already noticeable in the little penguin (variant '*albosignata*', hereafter referred to as white-flippered penguin) population on Banks Peninsula, Canterbury, New Zealand (CNC *pers. obs.*). This note describes the extent and timing of these changes in their breeding season based on an analysis of laying dates recorded during a long-term study.

The breeding biology of the white-flippered penguin has been studied since 1976 in a nest-boxed colony in Harris Bay on the north side of Godley Head (43.58°S, 172.79°E), east of Christchurch City. Initially the colony comprised 30–40 pairs but predators reduced it to a low of 10 pairs in 1988 (Challies 2015) after which it increased again to around 30 pairs. During the study all nests were checked every 4–7 days and the presence of adults, eggs, and/or chicks recorded. This note is based on the dates the first egg in each clutch was laid. These were estimated from the number of eggs and the sex of the parent present when eggs were first seen in the nest. It is usual for the female to be absent from the nest for 2 days between laying the first and second eggs, while the male remains in the nest and takes the first incubation shift. Supplementary estimates were obtained by back-dating 37 days (the incubation period) from the day the first chick was estimated to have hatched.

The breeding season of white-flippered penguins extends from late-August to early-November with over 90% of clutches being laid in September and October. During the 42 seasons monitored (1976–2017) the laying periods ranged in length from 23 to 71 (mean 50.6) days with median dates between 2 September and 31 October (mean 3 October). Despite the wide seasonal variation, it was apparent from the scatter of median dates that the breeding seasons became progressively earlier over this period. A linear fit to these data supported this observation (days/seasons, $b = -0.475$; $r = -0.456$).

To quantify this shift in the timing of breeding the laying dates for groups of seasons were combined and treated as frequency distributions. Those for the first and last 12 seasons (1976–1987 & 2006–2017) were pooled separately to describe the

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extent of the trend. A comparison of the monthly frequencies (Table 1) shows an obvious shift in the main laying period from October to September with an extension of the season into August and a contraction in November. The mean date of laying became earlier by about 13 days during the 30 seasons between the mid-points of the subsets with laying starting up to 16 days earlier (Table 2).

Table 1. Monthly frequencies of the laying dates of white-flippered penguins for the 1976–1987 and 2006–2017 breeding seasons.

	1976–1987		2006–2017	
Month	N	%	N	%
August	1	0.3	19	5.5
September	106	30.2	196	56.6
October	211	60.1	123	35.6
November	33	9.4	8	2.3
Totals	**351**	**100**	**346**	**100**

Table 2. Means and ranges of the laying dates of white-flippered penguins for the 1976–1987 and 2006–2017 breeding seasons. *rounded to nearest day. **mean ± standard deviation x 1.96.

		Laying dates*	
Seasons	N	Mean	95% range**
1976–1987	351	9 Oct	9 Sep – 8 Nov (60 days)
2006–2017	346	26 Sep	24 Aug – 29 Oct (66 days

These data were further divided into 7 consecutive 6-season subsets to describe the general pattern of this change. A plot of the means (Fig. 1) shows laying became progressively earlier in a near linear fashion from around the early 1990s (b = -0.613; r = -0.936). The mean laying date for seasons 1976–1987, i.e. 9 October (Table 2), was assumed to be the level before the trend started. A later season would not give some adults enough time to rear chicks before moulting in February. Clutches were laid in early- to mid-November during 9 of the 12 seasons 1976–1987; they comprised 9.4% of the total (Table 1). This is effectively the end of the laying season for white-flippered penguins. The regression lines shown in Fig. 1 intersect at 1990, which suggests the shift to earlier laying started about then. Overall, laying became earlier by about 16.5 days between 1990 and 2017 at a linear rate equivalent to 0.6 days / season.

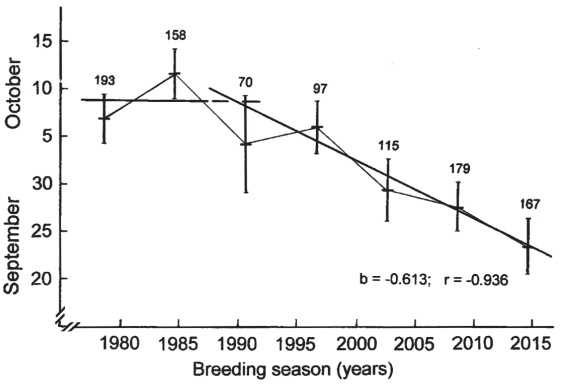

Figure 1. Trend in the timing of laying of white-flippered penguins during the 1976–2017 breeding seasons. Shown are the means with 95% confidence limits and sample sizes of consecutive 6-season subsets of laying dates. The horizontal line represents the mean laying date for the 12 seasons 1976–1987, and the diagonal line is the linear fit to the 4 means spanning the 24 seasons 1994–2017.

Breeding success improved during the shift to earlier laying with increases in both the proportion of pairs fledging 1 or 2 chicks, and in the proportion of these that fledged 2 chicks (CNC *unpubl. data*). This was reflected in the fledging rates for seasons 1976–1987 and 2006–2017 which averaged 1.12 and 1.33 chicks / 2-egg clutch respectively. It was not possible in this study to obtain comparable estimates of juvenile survival.

Without supporting data on the local marine environment and how the penguins use it, any discussion of the reasons for the earlier laying is speculative. The time of laying in non-migratory seabirds such as the white-flippered penguin is strongly influenced by the availability of their prey (Warham 1990). Little penguins feed predominately on small shoaling pelagic fish with the species taken varying seasonally and from year to year (Cullen *et al*. 1992; Fraser & Lalas 2004). It seems likely that the principal prey species of the penguins have become available to them in greater numbers progressively earlier in spring and that they have responded by breeding earlier. This is consistent with the widely reported poleward shift in the distribution of pelagic fish species commonly linked to global warming (e.g. Last *et al* 2010; McLeod *et al*. 2012).

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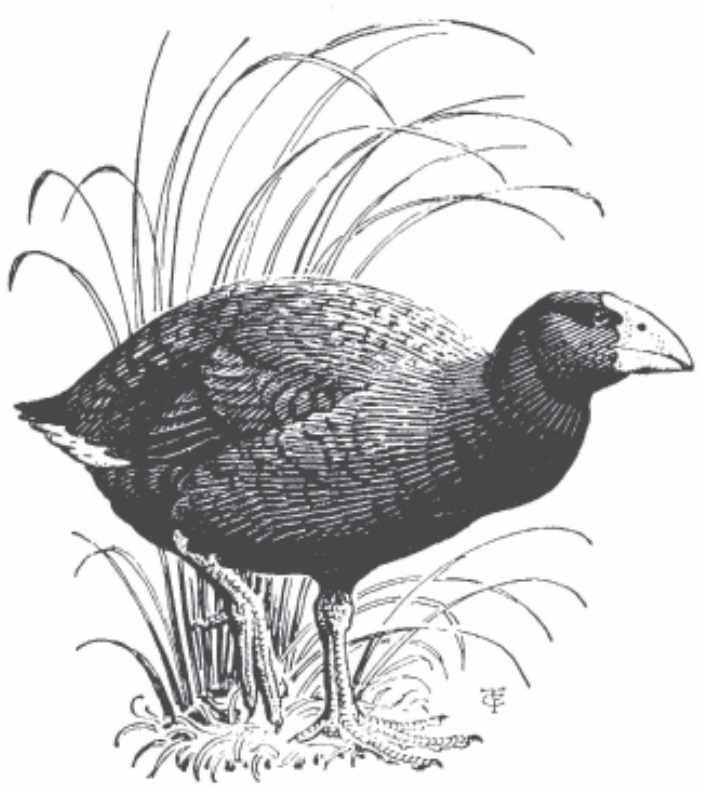

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