

A COMPARISON OF YELLOW-EYED PENGUIN GROWTH RATES ACROSS FIFTY YEARS: RICHDALÉ REVISITED

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ABSTRACT

Growth curves were fitted to data collected by L.E. Richdale on Yellow-eyed Penguin (*Megadyptes antipodes*) chicks during three seasons in the 1930s, and compared statistically with curves fitted to data collected at the same locality over two seasons in the 1980s. Interseasonal variation also was compared across the five decades. Although the variation was similar, chicks from Richdale's poorest season had higher fledging weights than chicks from two out of the three seasons monitored during the 1980s.

Growth rates were significantly different for all comparisons except between the 1939-40 and 1983-84 seasons, with contemporary chicks tending to grow faster at 30 - 50 days of age, i.e. during the period of maximum growth. The slower growth of Richdale's chicks during this period was not reflected in lower fledging weights. As growth rates are more likely to be affected by diet than by other factors, this difference may be due to a change in the availability or quality of prey items during the chick-rearing period, perhaps in response to long-term commercial fishing pressure in the area.

INTRODUCTION

The opportunity to compare data collected from a bird species almost half a century ago with similar contemporary data from the same locality seldom arises. Raw data collected by L.E. Richdale in the 1930s on the Yellow-eyed Penguin (*Megadyptes antipodes*) has been kept in the Hocken Library, Dunedin. During his 18 year study of the Yellow-eyed Penguin, Richdale measured chick growth during three seasons: 1936-37, 1937-38 and 1939-40. He combined the data and presented it as growth curves fitted by eye (Richdale 1957).

Population numbers of Yellow-eyed Penguins have decreased markedly since then, a trend attributed primarily to habitat destruction and increasing predation (Darby & Seddon 1990), but possibly caused also by changes in diet (van Heezik 1990a).

Population numbers of seabirds have been shown to fluctuate with changes in the marine environment (Crawford & Shelton 1978, Duffy 1983, Burger & Cooper 1984, Abrams 1985, Hays 1986). Variations in diet quality, in quantity of food and in patterns of food availability over time may result in variable breeding success and growth rates (Ricklefs 1983, Pettit *et al.* 1984, Cruz & Cruz 1990, Harris & Wanless 1990). Interseasonal and interlocality variations in growth rates of Yellow-eyed Penguin chicks between 1983 and 1986 have been attributed primarily to variations in food supply (van Heezik 1990b). Richdale did not examine Yellow-eyed Penguin diet, and so I could not compare diet and growth between decades. However, because chick growth rates can vary in response to changes in food supply, chick growth

can be used as an indirect indicator of feeding conditions (Boersma *et al.* 1980, Gaston & Nettleship 1982, Pettit *et al.* 1984, Ricklefs *et al.* 1984), and a comparison of Yellow-eyed Penguin growth rates over the last 50 years may provide a clue as to whether food availability to the penguins, and hence regional productivity, has changed. To determine whether there had been a change in growth rates since half a century ago, I statistically compared the growth data that Richdale collected from chicks on the Otago Peninsula with data collected during the 1983-84 and 1985-86 seasons. I also compared interseasonal variation 50 years ago with contemporary interseasonal variation.

Yellow-eyed Penguins are endemic to the south-eastern coast of the South Island, Stewart Island, Codfish Island, the Auckland Islands and Campbell Island (Falla *et al.* 1981). They breed in low numbers in areas of coastal scrub or forest. Two eggs are laid in late September and early October and hatch in the first three weeks of November (Richdale 1957). The fledging period extends to the end of February or early March, about 106 days after hatching (Richdale 1957).

METHODS

Data collection

At unnamed localities on the Otago Peninsula Richdale determined hatching dates and weighed chicks at weekly intervals, from hatching until fledging, for 10 chicks in the 1936-37 season, seven chicks in the 1937-38 season and eight chicks in the 1939-40 season.

I measured chicks at Boulder Beach (45°50' S, 170°30' E) on the Otago Peninsula in the 1983-84, 1984-85 and 1985-86 seasons, as part of a larger study. Dates of hatching (accurate to ± 1 day) were recorded, following the characteristics of chicks outlined by Richdale (1957). I weighed 15 chicks twice weekly in 1983-84 and 13 and eight chicks once weekly in 1984-85 and 1985-86 respectively, with a range of Pesola balances (300 g \pm 2 g, 600 g \pm 10 g, 1 kg \pm 20 g, 2 kg \pm 50 g, 5 kg \pm 100 g, 10 kg \pm 100 g). Detailed interpretation of this growth data is presented in van Heezik (1990b). Chicks from both studies came from a mixture of one- and two-chick nests. Any small differences in the ratio of one- and two-chick broods should not influence the seasonal comparison because the weight growth of single and two-chick broods was not significantly different during both the 1985-86 season (van Heezik & Davis 1990) and the 1983-84 season ($F = 2.748$, d.f. = 2/377, $p > 0.05$).

Curve fitting

I fitted all growth data to logistic curves and compared curves using a weighted least squares technique from the Maximum Likelihood Program (MPL) (Ross *et al.* 1980, see also Ricketts & Prince 1981, Gales 1987). This technique fits curves for each data set and then pools the data to fit a single curve. The change in the residual sum of squares is then treated for significance by an analysis of variance. If this test shows non-significant differences between curves (parallelism), the model with common parameters should be preferred. If a significant difference is indicated, individual curves should be used.

TABLE 1 — Comparison of fitted growth curves of Yellow-eyed Penguin chicks from breeding areas on the Otago Peninsula

	1936-7			1937-8			1939-40		
	F	df	p	F	df	p	F	df	p
1983-4	5.9	2/525	**	38.5	2/478	***	2.8	2/489	ns
1985-6	20.1	2/476	***	53.9	2/429	***	14.7	2/440	***

To reduce the total number of multiple comparisons made, and hence the chance of making a Type I error (Zar 1984), I have used the two extreme seasons from the 1980s, in terms of fledging weights and growth rates (van Heezik 1990b), to compare with Richdale's seasons. These were 1985-86 (the poorest) and 1983-84 (the best). Significance levels were set at 1%, following Zar (1984), to allow for the small number of multiple comparisons made.

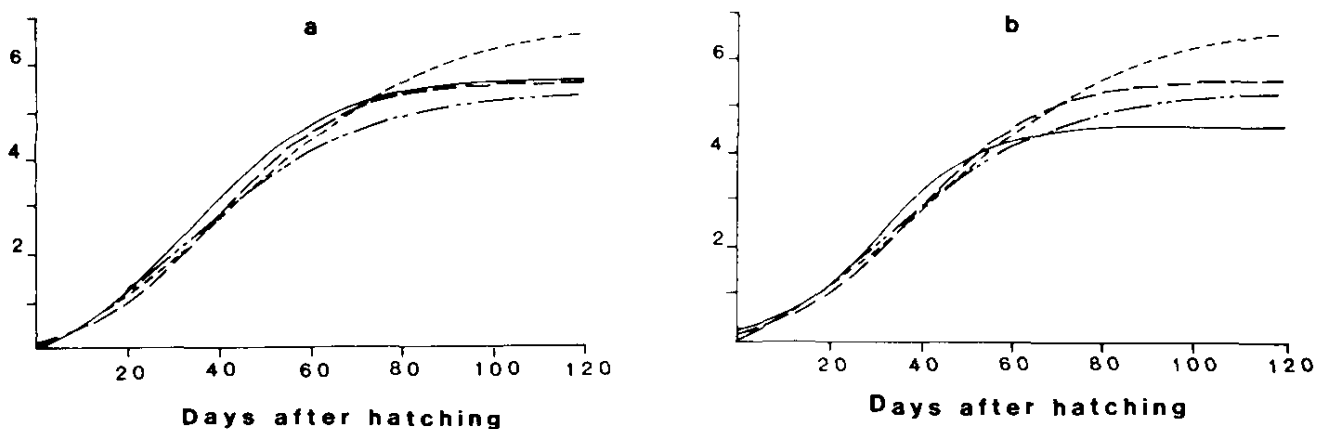


FIGURE 1 — Logistic curves fitted to Yellow-eyed Penguin chicks from different seasons: (a) solid line — 1983-84, dashed long — 1936-37, dashed short — 1937-38, punctuated — 1939-40, (b) solid line — 1985-86, dashed long — 1936-37, dashed short 1937-38, punctuated — 1939-40.

RESULTS

Growth rates

A comparison of Richdale's seasons with the 1983-84 and 1985-86 seasons showed significant differences in growth rates for all comparisons except between the 1983-84 and 1939-40 seasons (Table 1, Figure 1a & b). Displacement of the 1939-40 and 1983-84 curves differed significantly

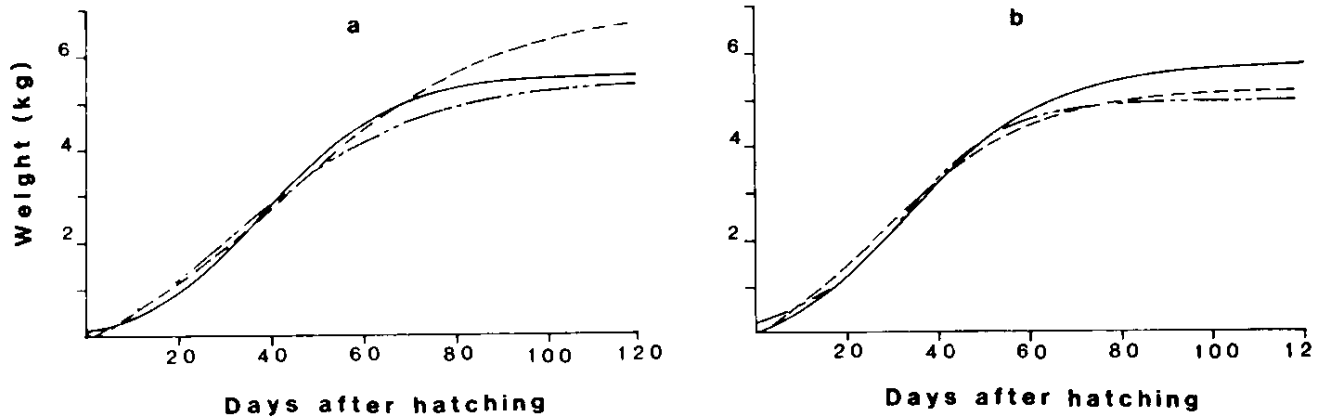


FIGURE 2 — Two seasonal comparisons of curves fitted to growth data from Yellow-eyed Penguin chicks: (a) solid line — 1936-37, dashed line — 1937-38, punctuated line 1939-40, (b) solid line — 1983-84, dashed line — 1984-85, punctuated line — 1985-86.

($F = 59.8$, $d.f = 489$, $p < 0.001$), with asymptotes from 1983-84 the higher of the two.

Growth rates of chicks during the 1936-37, 1937-38 and 1939-40 seasons were significantly different ($F = 7.4$, $d.f. = 349$, $p < 0.01$) (Figure 2a), as were growth rates of chicks during the 1983-84, 1984-85 and 1985-86 seasons at Boulder Beach ($F = 9.5$, $d.f. = 603$, $p < 0.01$) (Figure 2b).

Fledging weights

Fledging weights of chicks from Richdale's three seasons were not significantly different (ANOVA: $F = 1.30$, $d.f. = 20$, $p > 0.05$), whereas fledging weights of chicks from the 1983-84, 1984-85 and 1985-86 seasons differed (ANOVA: $F = 6.19$, $d.f. = 41$, $p < 0.01$) (Table 2).

TABLE 2 — Fledging weights of Yellow-eyed Penguins on the Otago Peninsula from six seasons

Year	Fledging Weight		
	\bar{x} (kg)	SD	n
1936-37	5.9	0.8	10
1937-38	6.2	0.3	5
1939-40	5.6	0.3	6
1983-84	5.5	0.5	15
1984-85	4.9	0.4	11
1985-86	4.8	0.7	18

DISCUSSION

Growth of chicks was significantly different in all but one of the seasonal comparisons between the 1930s and the 1980s, with an apparent trend towards faster growth during the 30 - 50 days (after hatching) period in chicks from the 1980s. This faster growth was not reflected in higher fledging weights at the end of the fledging period. The 1983-84 season was the best, in terms of fledging weights and chick mortality, of the three seasons monitored between 1983 and 1986 (van Heezik 1990b), but it showed no significant difference in growth rate from the curve fitted to chicks from the 1939-40 season, which showed the slowest overall growth and lowest asymptotic weight of Richdale's three seasons. The similarity in form appears to be due to a slightly faster initial phase of growth (up to 40 days after hatching) in the 1939-40 year than is apparent in Richdale's other seasons, followed by relatively slower growth in the latter part of the fledging period.

The 1985-86 growth season has been identified as one of poor food supply after about 40 - 55 days post-hatching, resulting in depressed growth rates and low fledging weights (van Heezik & Davis 1990). Even though the asymptote of the 1985-86 chicks was the lowest of all curves, the period of growth between 30 and 50 days was still faster than that of Richdale's chicks. The consistent nature of this difference is evident in both three-season comparisons, which show little variation in form between the three curves up till 50 days. Assuming that changes in diet are most likely to result in changes in growth pattern in Yellow-eyed Penguins (van Heezik 1990b), this difference could be interpreted as evidence for a change in the pattern of food consumption during the chick-rearing period.

Faster rates of growth in the 1980s could be achieved by: (1) more frequent delivery of food, (2) delivery of larger meals, and/or (3) delivery of better quality food by adults. Frequency of feeding does not appear to have changed (about three times every two days in guard phase, twice a day during post-guard (Richdale 1957, P.J. Seddon pers. comm.)). Richdale (1957) measured chick meal size at only one nest, but it has not been studied since, and so a direct comparison cannot be made. Larger meals might be delivered to offspring if adults foraged closer to the breeding areas, thus decreasing the amount of travelling time and hence digestion time before feeding chicks (Wilson *et al.* 1989). However, diet composition in the 1980s indicates that adults either avoid species found close to the coast or do little coastal foraging (van Heezik 1990a), suggesting that foraging has not moved further inshore.

Delivery of better quality food would be possible if adults were foraging from more favourable species assemblages. The oil content of prey is an indication of its quality. Diets of oil-rich species, such as clupeids, resulted in most rapid growth and highest fledging weights in Puffins *Fratercula arctica* (Harris & Hislop 1978). Yellow-eyed Penguin chicks that ate a significant proportion of sprat (*Sprattus antipodum*), an oily species – value for *S. antipodum* assumed to be similar to that for *S. sprattus* (Harris & Hislop 1978) – grew faster than chicks on a diet in which sprat was replaced with arrow squid (*Nototodarus sloanii*) (van Heezik & Davis 1990), which has a very low oil content (Vleig 1984). Moreover, seabirds such as Yellow-eyed Penguins that feed predominantly on fish are likely to have poor assimilation

efficiencies of other food types such as squid (Jackson 1986). However, although a significant drop in food quality was detected in the 1985-86 season (van Heezik & Davis 1990), differences in growth rates in the 1980s were not as great or of the same form as that observed between Richdale's chicks and contemporary chicks. Perhaps the difference across five decades is the product of more than one change in foraging, brought about as a result of changes in prey composition, availability, and abundance, together effecting a greater change in growth form.

Such changes could be the result of long-term commercial fishing activity, which inevitably influences populations of non-target species by changing the availability, quantity or quality of their food supplies (Furness 1984). Yellow-eyed Penguin diet is composed of seven species that contribute to over 90% of the weight of the food items (van Heezik 1990a), but only two of these species are commercially fished: red cod (*Pseudophycis bachus*) and arrow squid, and commercial pressure on these species in this area has been slight up to the last two decades (McKoy 1988).^{*} However, it is likely that long-term fishing in an area will result in some changes in species assemblages; smaller species, such as sprat, might benefit from the removal of larger predatory fish from the ecosystem. If Yellow-eyed Penguin growth rates are considered as indicators of marine resources, it could be concluded that long-term changes have occurred in the marine environment off the Otago Peninsula.

Seasonal variation in growth rates 50 years ago was as great as at present, although fledging weights from the poorest of Richdale's three seasons (1939-40) were heavier than those from two out of the three years monitored during the 1980s. Therefore, although faster growth rates in the birds of the 1980s during the period of maximum growth (December) suggests prey species may have been more available or of better quality, lower fledging weights may reflect poorer diet in late February and early March, and may ultimately result in lower survival after fledging (van Heezik & Davis 1990).

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