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Climate change and the arrival of self-introduced bird species in New Zealand

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Abstract New Zealand average atmospheric temperatures showed little increase from the 1850s onwards for almost 100 years, but increased rapidly after *c.* 1940. The increase in temperatures was accompanied, at least in parts of New Zealand, by an increase in precipitation. We investigated the relationship between the arrival years (1st breeding) of the bird species that self-introduced to New Zealand during the 20th century and the period of temperature increase. Because these birds come from Australia the warming might be a prerequisite to colonize New Zealand. When considering the 1st breeding years as events in a univariate point process the process is non-stationary and the rate function has its estimated maximum in 1953. This estimate may indicate that the sequence of invasions of New Zealand by additional bird species could be a response to climate changes although the coincidence is on its own not sufficient to prove that climate changes have affected the self-introduction of birds from Australia into New Zealand. Alternative and additional explanations are discussed.

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INTRODUCTION

Global climate warming has already affected species' distributions and the Earth's biodiversity (Crick 2004; Simmons *et al*. 2004). The warming in the New Zealand region has special characteristics (Salinger *et al*. 1993). Firstly, in contrast to Northern Hemisphere land masses, New Zealand experienced an increase in both mean maximum and mean minimum temperatures. Again, the magnitude of warming between 1861–1880 and the 1980s was larger for New Zealand (0.92°C) than either the global change (0.48°C) or that for the Southern Hemisphere alone (0.56°C). (3) New Zealand temperatures showed little increase between 1853 and the middle of the 20th century, but increased rapidly in the 2nd half of the 20th century. From 1941 to 1990 the mean temperature increased in the New Zealand region by 0.77°C (Salinger 1995), in particular, as Salinger *et al*. (1993) and Salinger (1995) show there was a substantial warming between 1940 and 1960.

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Evans *et al*. (2003) noted that the most rapid warming coincides with the period of colonization of New Zealand by the Australian welcome swallow (*Hirundo neoxena*). Individuals of this species were recorded as stragglers in 1920, 1940, 1944, and 1953 (Turbott *et al*. 1990). The 1st breeding was recorded in 1958 (Michie 1959; Turbott *et al*. 1990). According to Moon (2001) this species arrived in large numbers. Other Australian birds, including wading birds, coraciiforms, and songbirds also regularly cross the Tasman Sea, aided by westerly winds, and some have become established as self-introduced species in New Zealand to New Zealand. There were self-colonizations from Australia in the 19th century, when some species, such as the silvereye (*Zosterops lateralis*) established permanent populations in New Zealand, and others, including the Australian avocet (*Recurvirostra novaehollandiae*), bred briefly but did not persist (Oliver 1955). That process was apparently a continuation of the occupation of niches made vacant by local extinctions and the creation of novel habitats by human activities (Worthy & Holdaway 2002). However, as the climate in most parts of Australia is warmer than that of New

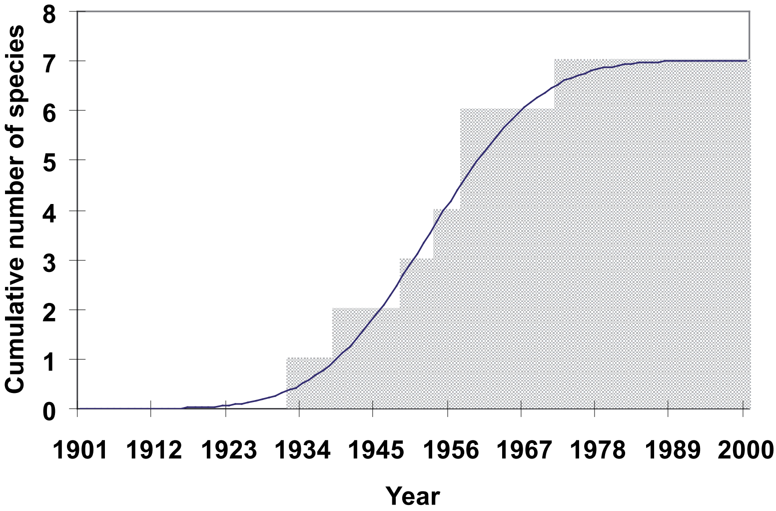

Fig. 1 Expected and observed numbers of bird species self-introduced to New Zealand in the 20th century. Years refer to date of 1st report of breeding; line, predicted; shaded, observed.

Zealand, the warming might be a prerequisite for some Australian birds being able to establish new populations in New Zealand.

To investigate the potential relationship between climate change and time of establishment of self-introduced bird species to New Zealand, we collated the 1st recorded breeding years of the species that colonized during the 20th century and related them to the temperature changes recorded over that time. We did not include the establishments in the 19th century because during that time the arrival of European settlers had a devastating effect on the New Zealand environment, and large areas of the landscape were changed (Wardle 1991). In addition, during the 19th century many, mainly European, bird species were introduced to New Zealand by human colonists. Veltman *et al*. (1996) studied the success or otherwise of these species introduced before 1907 and found that the success of deliberate introductions in New Zealand was related primarily to the management of the introduction. Our focus, however, was on self-introduced birds.

MATERIAL AND METHODS

The dates of 1st reports of breeding, 1st attempted breeding, or suspected 1st breeding, respectively, were extracted from Turbott *et al*. (1990). Notwithstanding breeding by a single pair of yellow-nosed mollymawks (*Thalassarche chlororhynchos*) at the Chatham Islands (Miskelly 2006) no bird species has colonized New Zealand since 1990. The 1st breeding years of new successfully established species were considered as events in a univariate point process. We used the χ^2 test to test the null hypothesis that the process is stationary: because there are only a few self-introduced species the *P*-value of the exact permutation test was calculated in addition to the asymptotic *P*-value. As in Steinijans (1976), who also investigated a process of rare events, we modeled the process using an exponential polynomial rate function of degree 2. That is, the rate function is

$$\lambda(t) = \alpha_1 \exp(\alpha_2(t - \alpha_3)^2),$$

where t is the number of years since 1900. Then, the expected number of events between the years 1900 and 1900 + t is

$$\int_0^t \lambda(u)\, du.$$

Because in 1 year 2 species bred for the 1st time, the formulae for a Poisson process as given by Steinijans (1976) cannot be used. Instead, using the statistical software SAS®, version 8.2, the framework of a nonlinear regression was used to obtain maximum likelihood estimates of the parameters α_1, α_2, and α_3.

RESULTS

Six self-introduced species established self-sustaining populations in New Zealand during the 20th century: spur-winged plover (*Vanellus miles*), 1st-breeding 1932; white-faced heron (*Ardea novaehollandiae*) 1939; royal spoonbill (*Platalea regia*) 1949; black-fronted dotterel (*Charadrius melanops*) 1954; welcome swallow (*Hirundo neoxena*) 1958; nankeen night heron (*Nycticorax caledonicus*) 1958; Australasian little grebe (*Tachybaptus novaehollandiae*) 1972. In addition, the masked wood-swallow (*Artamus personatus*) has bred or attempted to breed.

All 7 bred 1st in the middle ½ of the century (i.e. between 1925 and 1975): no species arrived in the 1st or last quarters of the century. This pattern indicates that the process is non-stationary (χ^2 = 7, df = 2, $P_{asymptotic}$ = 0.0302, P_{exact} = 0.0378), so there is evidence that the rate was not constant during the

20th century. The estimated rate function is

$$\hat{\lambda}(t) = 0.217 \exp(- 0.003 (t - 52.822)^2).$$

This rate function has its maximum at $t = 52.8$ which corresponds to the year 1953 (95% confidence interval 42.9 to 62.8, or 1943 to 1963, respectively). The estimated maximum and the entire confidence interval are therefore in very good agreement with the timing of the observed warming between 1940 and 1960. Fig. 1 shows the expected number of species under the non-stationary process together with the step function of the numbers of observed new species.

Because of a 2nd breeding record (Marsh & Lövei 1997) the nankeen night heron was included in the analyses presented above although there is no evidence at present of a breeding population of this species. Without this species results are very similar: the maximum of the rate function is 50.1 with a 95% confidence interval 38.8 to 61.3.

DISCUSSION

This study suggests that the success in colonization by highly mobile birds reaching New Zealand from Australia may be enhanced by observed features of climate change in New Zealand. It is already known that global warming can affect the breeding biology (Crick & Sparks 1999; Dunn & Winkler 1999; Evans *et al*. 2003; Crick 2004), the timing of migration (Crick 2004), and the range of birds (Simmons *et al*. 2004). The findings presented here suggest that even the invasion of a previously uncolonized area distant from source populations could be an additional effect of climate change. However, although there was a greater rate of self-introduction during a period of relatively rapid increase in atmospheric temperature, a causal relationship has yet to be established between likelihood of invasions and climate change. As is possible for other changes in geographical range, there are potentially confounding factors that might also affect birds (Crick 2004).

First, changes in the source populations in Australia may be responsible for changes in the rate of self-introduction in New Zealand. Climate change also can result in stronger or more persistent westerly winds, which may be necessary for crossing the Tasman Sea, at least for some species, and periods of strong westerly winds can occur under El Niño conditions (Jones 2003). Again, although the most radical recent habitat alteration in New Zealand occurred during the 19th century, following the initial major habitat changes engendered by Polynesian fires in the 13th century, which resulted in new habitats for pukeko and bittern (Worthy & Holdaway 2002), habitat change has continued more recently.

Climate is also implicated in some of these changes: for example, an increase in precipitation has accompanied, at least in parts of New Zealand, the increase in temperatures (Salinger & Mullan 1999; Salinger & Griffith 2001; Salinger *et al*. 2001). The increase in precipitation may be important because 6 of the 7 self-introduced species are birds associated with wetlands. The remaining species, the welcome swallow, lives in open country, but also especially near water (Robertson & Heather 1999). The black swan (*Cygnus atratus*), also a wetland-associated species, was introduced by humans, but the population swelled suddenly in the 1960s. Therefore, it is assumed that there have been self-introductions in the 1960s (Peat & Patrick 2002). Hence, both effects of the climatic change, warming and increase in precipitation, may be important factors in the success of colonizing species.

Some of the 7 self-introduced species breed regularly in the southern half of the South Island (Robertson & Heather 1999), where mean annual temperatures are *c*.4°C lower than in the north of the North Island (New *et al*. 2002). However, although birds may arrive more often in the South Island because of the direction of the prevailing north-westerly winds. Thus, in the South Island, temperature may be more important. However, the significant increase in minimum temperatures has been associated with a decreased frequency of extreme 'cold nights' (Salinger & Griffith 2001). The reduction in such stress events might well be important during the build-up phase after colonization. The failed colonization by wood swallows in Otago in the 1970s (Child 1974, 1975) could be related to cold events that even stress resident New Zealand species (Wood 1998; Powlesland 2002) and established introduced and self-colonizing species (Bull & Dawson 1969).

In summary, although our results do not demonstrate a causal relationship between colonization of New Zealand by Australian birds and climate change, or of significant influence of climate change on the rate of colonization, the coincidence between the arrival dates and the period of temperature increases and precipitation changes merits further analysis.

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