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SHORT COMMUNICATION

Post-settlement extinction rates for the New Zealand avifauna

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Abstract: Post-settlement faunal extinction rates are widely cited statistics and help to understand the magnitude of recent biodiversity loss driven by human activity. However, extinction rate estimates can vary greatly depending on factors such as the geographic boundaries of the region being considered, how the faunal group is defined, completeness of fossil records, and taxonomic frameworks. Here, I combine recently described extinct bird species with the latest taxonomic revisions and well-defined geographic regions to provide an updated estimate of post-settlement extinction rates for the New Zealand avifauna. The results show that extinction rates varied regionally from 50% species extinction on the North Island to just 14.5% on offshore islands. As a whole, the New Zealand mainland and its offshore islands lost 30.9% of bird species, although this rate increases to 32.8% with the inclusion of the distinct Chatham Islands/Rēkohu avifauna.

Keywords: birds, Holocene, human impacts, islands, palaeoecology

Introduction

Terrestrial vertebrate faunas on insular landmasses around the world have suffered from high rates of extinction following human settlement (Wood et al. 2017). Birds in particular have experienced high rates of species extinction on islands as a result of hunting, introduced predators, and habitat loss (Blackburn et al. 2004; Duncan & Blackburn 2007). Extinction rates for faunal groups such as birds are often cited statistics, yet ones which can vary widely depending on the source. Several factors appear to contribute to this variability. First, reliable rates of bird extinction can be difficult to quantify as they require a near complete fossil and/or archaeological record of extinct bird species. As bones of new extinct species are discovered this can lead to an increase in the estimated extinction rate. Second, extinction rate estimates can vary for a particular region depending on the geographic boundaries being used. Third, there can be differences in whether the extinction rate is calculated based on the entire avifauna or a specific subset (i.e. only terrestrial birds, non-passerine birds, etc.).

Although New Zealand has one of the most complete records of recently extinct vertebrate species globally (Worthy & Holdaway 2002), variable classification of geographic boundaries and avifaunal subsets has led to reported extinction rate estimates for New Zealand birds ranging from about 24 to 50% (Table 1). Such variability has the potential to cause confusion amongst authors wishing to cite the statistic, especially when details of how the statistic was calculated are not provided. Moreover, taxonomic revision of the New Zealand avifauna and the description of several additional extinct bird species within the past decade will have also altered extinction rate estimates. The recent publication of a revised New Zealand bird checklist (Checklist Committee 2022), which includes these recent changes to the New Zealand avifauna, provides the ideal basis for an updated post-settlement extinction rate estimate.

Methods

The fifth edition of the New Zealand bird checklist (Checklist Committee 2022) was used to create a table of bird species that were breeding in New Zealand at the time of initial human settlement (13th century AD) (Appendix S1 in Supplementary Materials). For the purposes of this study, New Zealand was classified as encompassing five subregions: North and South Islands, Stewart Island/Rakiura, offshore islands and Chatham Islands/Rēkohu. Using distribution records from the checklist, each bird species was recorded as being either extinct or extant in each of these five subregions, based on their former and current distribution. Extinction rates were then estimated for all birds, and for the terrestrial bird subset (excluding the Procellariiformes, Sphenisciformes, and marine species within Suliformes and Charadriiformes). Decisions about former species distributions and whether a breeding population once existed within a subregion were made following a conservative approach, so that extinction rates would also be conservative estimates. The considerations involved are detailed below.

Vagrant and non-breeding migrant bird species were excluded from the analysis. Moreover, as the aim was to calculate extinction rate estimates, translocated populations were not considered as part of a species' current distribution. This was because translocations were frequently to subregions where the species may have actually been absent or locally

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Table 1. Examples of reported post-settlement extinction rates for the New Zealand avifauna.

Year	Rate	Details	Reference
1980s	24.76%	51 of 206 bird species extinct. Includes native breeding birds on New Zealand mainland, Chatham Islands/ Rēkohu, New Zealand subantarctic islands, Norfolk Island and Macquarie Island.	Cited by Tennyson (2010)
1989	40–50%		Holdaway (1989)
2001	31.02%	76 of 245 late Holocene breeding bird species extinct. New Zealand defined as South, North and Rakiura/Stewart Islands, surrounding offshore islands, Norfolk Island, the Kermadec, Chatham/ Rēkohu, Bounty, Antipodes, Campbell, Auckland, Snares, and Macquarie Islands, but excluding the Ross Dependency and islands south of Macquarie Island. Extinction rates by geographic region were: North Island 51%; South Island 46.9%; Chatham Islands/ Rēkohu 35%; Rakiura/Stewart Island 20%; subantarctic islands 7.35%.	Holdaway et al. (2001)
2004	47.3%	62 of 131 prehuman breeding species on the North and South Islands extinct.	Duncan and Blackburn (2004)
2005	28.6%	70 of 245 breeding bird species extinct, including 37.9% of endemic species.	Didham et al. (2005) citing Holdaway et al. (2001) and authors own unpublished materials and methods
2008	c. 40%	Non-marine New Zealand birds.	Massaro et al. (2008) citing Didham et al. (2005), Diamond & Veitch (1981), Holdaway (1999)
2008	> 41%	Endemic bird species	Boessenkool et al. (2008) citing Worthy & Holdaway (2002)
2009	24.38%	59 of 242 bird species extinct. Includes native breeding birds on New Zealand mainland, Chatham Islands/ Rēkohu, New Zealand subantarctic islands, Norfolk Island and Macquarie Island.	Tennyson (2010)
2013	c. 25%	Native terrestrial bird species.	Wood (2013)
2013	26%	18 of 68 non-passerine land bird species extinct before European arrival on North Island	Duncan et al. (2013) citing Holdaway et al. (2001)
2013	28%	21 of 75 non-passerine land bird species extinct before European arrival on South Island	Duncan et al. (2013) citing Holdaway et al. (2001)
2014	~50%		Beever and Lebel (2014) citing Holdaway (1989), Duncan and Blackburn (2004)

extinct prior to reintroduction. Extant species that exist only in translocated populations, e.g. kākāpō (*Strigops habroptila*) and little spotted kiwi (*Apteryx owenii*), were considered extinct in all parts of their former range, but considered extant when calculating national extinction rates. Only species, rather than subspecies, were considered. However, one exception to this was where there were cryptic extinction events, despite the species still existing. For example, *Megadyptes antipodes* is considered extinct on the NZ mainland (subspecies *M. a. waitaha*), despite the same species having subsequently recolonised (*M. a. antipodes*) (Boessenkool et al. 2009). This example leads to another consideration, that it is often difficult to know exactly when a species first arrived in New Zealand. For example, the Swamp Harrier or kāhu (*Circus approximans*), south-west Pacific swamphean or pūkeko (*Porphyrio melanotus*) and New Zealand kingfisher or kōtare (*Todiramphus sanctus*) have limited late Holocene fossil records and are thought to have arrived during the post-settlement but pre-European period (Checklist Committee 2022). Species that were thought to have arrived in New Zealand after human settlement were excluded from the analysis.

Interpretation of past species distributions from the fossil or archaeological records can also have an influence on estimated extinction rates. For the purposes of this study, fossil bones of vagrant or non-breeding species from coastal dune deposits were not considered to represent extinct breeding populations except where other evidence was present, e.g. as in the case of kōtuku (*Ardea alba*) where abundant bones, including immature individuals, indicated a former breeding colony on the North Island. This is because coastal deposits commonly include storm-wrecked migratory or vagrant birds that can breed large distances away from the deposit site. The presence of bones in middens was considered greater evidence for a local breeding population, though in cases where a species frequently occurs as beach-wrecked individuals, e.g. short-tailed shearwater *Ardenna tenuirostris*), these were considered more likely to represent migrating individuals and hence were also excluded from the analysis.

Results

A total of 171 bird species were considered breeding in the New Zealand region at the time of initial human settlement. Of these 56 are now extinct, resulting in an extinction rate of 32.8%. When the Chatham Islands/Rēkohu are excluded, the extinction rate for the New Zealand mainland and offshore islands was 30.9%. Extinction rates for individual subregions varied from 50% for the North Island to just 14.5% on offshore islands (Fig. 1; Table 2). Excluding marine birds either increased (offshore islands, Chatham Islands/Rēkohu) or decreased (South, North and Rakiura/Stewart Islands) extinction rate estimates, depending on the contribution of marine birds to the total extinct avifauna of that particular region (Fig. 1; Table 2). For the New Zealand mainland and offshore islands the extinction rate for the terrestrial bird subset was 38.53% (Fig. 1; Table 2).

Discussion

This analysis provides a current estimate of avifaunal extinction rates in the New Zealand region that can be used to better understand post-settlement changes to native ecosystems and for comparison with other landmasses around the world. However, the estimates are conservative and will undoubtedly continue to change as new data comes to light. Further work on determining past distributions of bird species using the fossil record has the potential to influence estimates of local extinction rates. For example, a major current knowledge gap involves which species of seabird had breeding colonies on the New Zealand mainland in the past. If it was assumed that all seabird species now restricted to breeding on offshore islands were once also present on the mainland, then this would result in increased local extinction rates for the North, South, and Rakiura/Stewart Islands. The discovery of new fossil deposits in areas where few currently exist may also affect local extinction rate estimates. For example, fossil deposits are exceedingly rare on offshore islands, and relatively limited on Rakiura/Stewart Island, perhaps leading to underestimates of former avifaunal diversity and hence low extinction rate estimates. On a national scale, further taxonomic revisions and the discovery of new extinct species, likely to be driven mainly by increased genetic analyses of museum specimens (Cole & Wood 2018; Card et al. 2021) has the potential to alter extinction rate estimates in future.

It is also worth considering, when citing faunal extinction rate estimates, what represents a sensible geographic area for

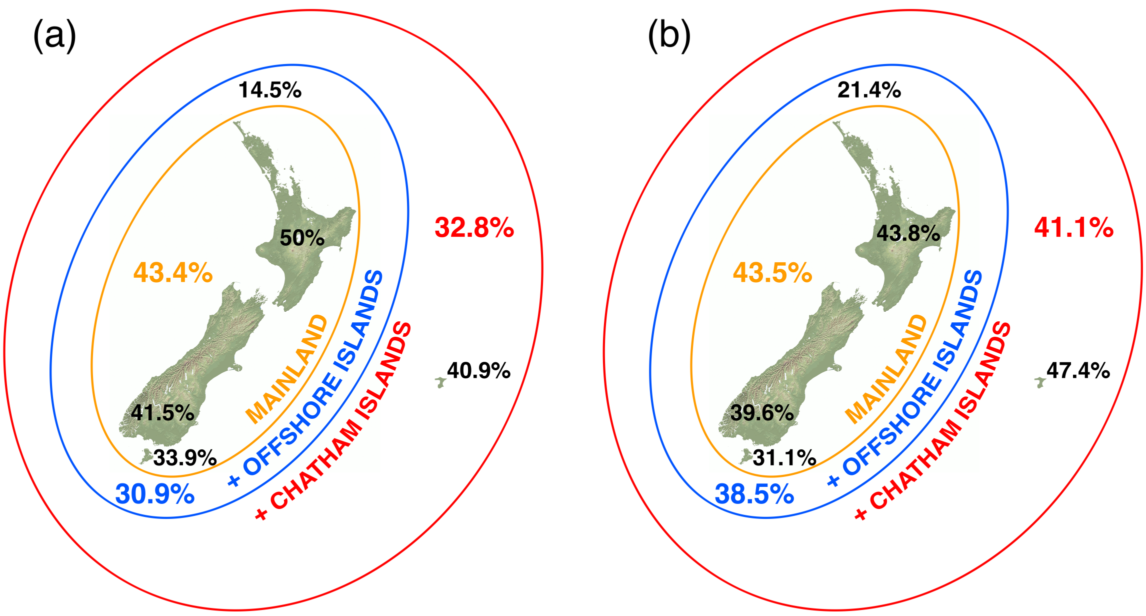

Figure 1. Post-settlement avifaunal extinction rates for individual islands and island groups (black) and different combinations thereof (colours) for (a) all breeding birds; and (b) terrestrial bird subset.

Table 2. Post-settlement avifaunal extinction rates for individual islands and island groups. Values in parentheses are for the terrestrial bird subset (marine birds excluded).

Landmass	Extinct	Extant	Percentage extinct
New Zealand (including Chatham Islands/Rēkohu)	56 (51)	115 (73)	32.75% (41.13%)
New Zealand (excluding Chatham Islands/Rēkohu)	46 (42)	103 (67)	30.87% (38.53%)
New Zealand mainland (excluding Chatham Islands/Rēkohu and offshore islands)	62 (47)	81 (61)	43.36% (43.52%)
North Island	50 (35)	50 (45)	50% (43.75%)
South Island	49 (36)	69 (55)	41.53% (39.56%)
Rakiura/Stewart Island	21 (14)	41 (31)	33.87% (31.11%)
Offshore islands	10 (9)	59 (33)	14.49% (21.43%)
Chatham Islands/Rēkohu	27 (18)	39 (20)	40.91% (47.37%)

the purpose. For example, in the past the New Zealand bird checklist and related extinction rate estimates have included grouping New Zealand mainland and offshore islands with Chatham Islands/Rēkohu, the New Zealand subantarctic islands and even Norfolk and Macquarie Islands (Holdaway et al. 2001; Gill et al. 2010; Tennyson 2010). However, this broad grouping encompasses landmasses with distinct and largely isolated avifaunas, different human settlement chronologies, and different patterns of mammal introductions. It can be argued that such a grouping offers little in the way of allowing sensible comparison of extinction rates between New Zealand and other landmasses globally. A better approach might be to consider regional boundaries that have a strong basis in biogeographic and human history patterns. For example, New Zealand and its offshore islands represent a distinct biogeographic unit where short distances between landmasses mean relatively high connectivity between bird populations, many islands were physically connected during glacial sea-level low-stands, and there is high-connectivity among human and commensal mammal populations. In contrast in may be more appropriate to consider the Chatham Islands/Rēkohu and subantarctic islands, which have high rates of local endemism, avifaunas with reduced connectivity to the mainland (at least for terrestrial bird species) and different human histories, as separate units when calculating avifaunal extinction rates.

Data availability

Data is provided as online supplementary material (see Supplementary Materials Appendix S1).

Author contributions

JRW compiled and analysed the data and wrote the manuscript.

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Supplementary material

Additional supporting information may be found in the supplementary material file for this article:

Appendix S1. Spreadsheet of data used in analysis for this study.

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