Short Communication

CAMBRIDGE
UNIVERSITY PRESS

The cestode *Stringopotaenia psittacea* (Fuhrmann, 1904) (Cestoda: Anoplocephalidae) from a critically endangered New Zealand bird: New evidence from ancient coprolites

M. Horrocks[1,2] and B. Presswell[3]

[1]Microfossil Research Ltd, Auckland, New Zealand; [2]School of Environment, University of Auckland, Auckland, New Zealand and [3]Evolutionary and Ecological Parasitology, University of Otago, Dunedin, New Zealand

Abstract

New Zealand's kākāpō parrot, once widespread, is now critically endangered due to habitat loss and introduced mammalian predators. Prior to major population decline, a unique kākāpō cestode, *Stringopotaenia psittacea,* was found in the 1880s and first described in 1904. Here we report the discovery of eggs of this cestode in kākāpō coprolites of pre-human settlement age from the Honeycomb Hill cave system, north-west Nelson. Analysis of 52 samples, including coprolites of post-human settlement age, from nine sites within six South Island locations across a wide geographic range, yielded only eight infected samples in this single cave system. Results suggest that prior to human settlement, *S. psittacea* was not widespread within and between kākāpō populations, in marked contrast to other parasite types of the extinct moa spp. Intense management of the last remaining kākāpō has endangered or possibly caused the extinction of this cestode. This is the first confirmed record of *S. psittacea* since its discovery in 1884.

Introduction

New Zealand's long isolation from other land masses has resulted in the evolution of a unique biota. Many bird species show gigantism and loss of flight as adaptations to the absence of mammalian predators. These large flightless birds are thus extremely vulnerable to habitat destruction by deforestation and predation by people and introduced mammals since human settlement c. 600 years ago (Walter *et al.* 2017). More than 40 bird species have become extinct since human arrival (Gill & Martinson 1991). One survivor, albeit marginally, is the kākāpō (*Strigops habroptilus*), a parrot endemic to New Zealand. The kākāpō is unique in that it is the only flightless and lek-breeding parrot (Powlesland *et al.* 2006). It is also nocturnal and at up to 4 kg is the world's heaviest parrot. It's longevity, estimated up to 90 years, makes it possibly the longest-lived parrot.

Fossil remains show that the kākāpō was once widespread throughout New Zealand (Worthy & Holdaway 2002). Habitat loss and predation reduced the population to approximately 50 known individuals remaining in the 1950s, although conservation efforts have resulted in an increase to around 250 at the time of this writing (https://www.doc.govt.nz/our-work/kakapo-recovery/). As the only representative of a unique sub-family of parrots, it has no close relatives and has a global conservation status of Critically Endangered, i.e., most severely threatened, facing an immediate high risk of extinction (IUCN 2022). Their current distribution is restricted to three relatively small-sized, predator-free conservation sanctuaries, two of which are offshore islands. Despite the intense conservation activity surrounding these birds, very little is known of their parasite fauna.

In the late 1800s, when kākāpō were still common, the Austrian naturalist Andreas Reischek observed that the birds were often infected with tapeworms (Reischek 1884). The unique cestode species, *Cittotaenia psittacea* (Fuhrmann, 1904), was briefly described from a single specimen with additional details provided later (Furhmann 1922). The same specimen was redescribed in further detail in 1978 (Beveridge 1978), when the genus *Stringopotaenia* was erected to accommodate its unique features. Subsequent conservation workers have since noticed worms passed by kākāpō that presumably represent the same species, which, given the unique lifestyle and ancient origins of the kākāpō, make it almost certain that the cestode is host-specific. However, no positive identification was made, and the birds were routinely de-wormed (Boast 2014).

Stringopotaenia psittacea is placed in the Anoplocephalinae, a subfamily of the Anoplocephalidae, found in herbivorous mammals, and unusually, parrots (Beveridge 1994). The only other New Zealand anoplocephalid cestode (*Pulluterina nestoris* Smithers, 1954) is known from the kea (*Nestor notabilis* Gould), another parrot. New Zealand's large parrots, the kākāpō, kea,
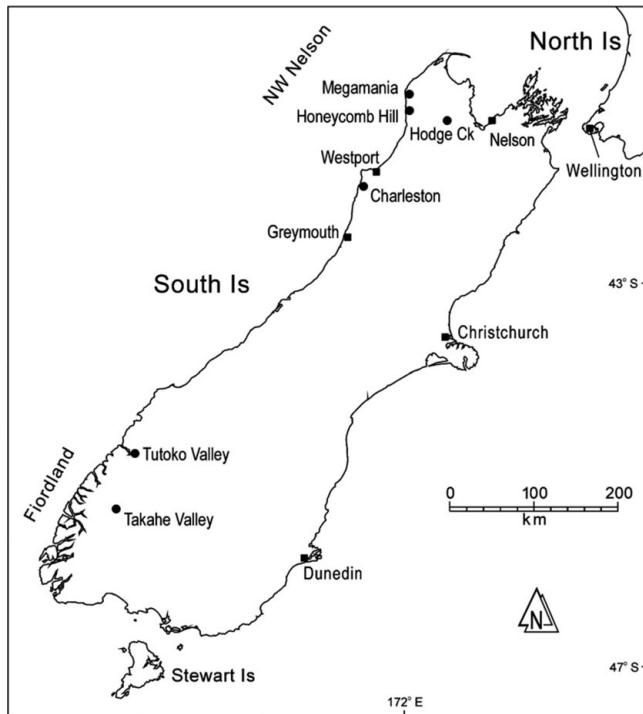
Figure 1. Map showing sampling site locations.

and kākā (*Nestor meridionalis* (Gmelin)), comprise the most ancient lineage of all living parrots (Schirtzinger *et al.* 2012).

There have been several New Zealand native bird coprolite studies to date, mostly from limestone rock shelters and overhangs in the South Island, providing evidence of diet and helminth infections. The birds studied, several moa (Dinornithiformes, now extinct) species and kākāpō, are herbivores. Most are diet studies, examining the plant remains in coprolites (Kondo *et al.* 1994; Horrocks *et al.* 2004; Wood *et al.* 2020), but ancient DNA techniques have allowed detection of a number of parasites in moa coprolites (Wood *et al.* 2013; Boast *et al.* 2018, 2023).

In 2008, Horrocks *et al.* (2008) examined 52 kākāpō coprolites preserved in caves and overhangs along a wide (620 km) northeast to southwest latitudinal section of the western South Island, from north-west Nelson to Fiordland (Horrocks *et al.* 2008) (Figure 1). The sites included lowland, montane, and sub-alpine settings. As kākāpō are nocturnal, during daylight hours they had roosted in the overhangs and short distances into the caves. The study analysed plant microfossils (pollen, phytoliths, and starch and other plant remains) within the coprolites, but no parasites were reported at the time.

The present study examined the same 52 kākāpō coprolite samples from the work of Horrocks *et al.* (2008), this time for helminth eggs. Given the lack of knowledge about the cestode *Stringopotaenia psittacea*, which by default is either critically endangered or possibly extinct, the aim was to look for its eggs in the coprolites, shedding light on the former distribution of this parasite in New Zealand.

Study areas

The sampled sites were limestone caves and overhangs at six locations in the western South Island. Three of the sites (Hodge Creek, Megamania, and Honeycomb Hill) are in northwest Nelson,

one is at Charleston, and the remainder, which are the only two overhangs, are in Fiordland (Tutoko Valley and Takahe Valley) (Figure 1). Further details of the sites are given in the initial, plant microfossil article (Horrocks *et al.* 2008).

Materials and methods

All 52 of the starch slide preparations from the initial, plant microfossil study were examined for helminth eggs, and presence/absence noted (Horrocks *et al.* 2008). Samples had been prepared for analysis of starch and other remains by density separation with sodium polytungstate (Horrocks 2020). Having a lower specific gravity (ca. 1.130–1.238) than the heavy density solution used for the starch separation (1.7–1.8 specific gravity), helminth eggs were also recovered (David & Lindquist 1982). The starch separations were mounted in glycerol jelly. The pollen and phytolith preparations were not included because these methods use corrosive chemicals harmful to helminth eggs, often destroying them completely. Photomicrographs for the present study were taken with a Canon EOS 600D camera (Auckland Camera Centre, Auckland, New Zealand) mounted on a Nikon 400E microscope (Olympus New Zealand Ltd, Auckland, New Zealand), with a blue light filter.

Results

All slides showed a high concentration of very well-preserved macro- and microscopic plant material and fungal spores, among which was found a type of helminth egg. These were observed in only one of the six main locations, namely the Honeycomb Hill cave system, in two of the three caves sampled (referred to as Honey B and C in Table 1 and the graphical diagrams in Horrocks *et al.* 2008). The eggs were observed in all six samples (1–6) from Honey B (1550 ± 48 ^{14}C BP) and samples 4 and 5 from Honey C (2514 ± 43 ^{14}C BP).

The eggs are morphologically attributable to the family Anoplocephalidae. They are subspherical, 50–70 μm in diameter, and with a delicate reticulation that often gives a dimpled or scalloped appearance (Figure 2b). Degraded eggs can appear grainy. When the pyriform apparatus is visible, it appears forked, with twin points (Figure 2c). The oncosphere is c.25 μm in diameter, and some hooklets can be seen as straight lines (Figure 2d). These characteristics are consistent with Beveridge's (1978) redescription of the type specimen of *Stringopotaenia psittacea*. He described the egg as "approximately spherical, thick shelled. Inner membrane present. Oncosphere surrounded by pyriform apparatus terminating in two elongate horns" (Beveridge 1978, p. 43). The size was given as 60 μm in diameter.

Discussion

Stringopotaenia psittacea eggs were observed in the six Honey B samples in up to reasonably large numbers: between approximately 15 to 50 individuals per slide, with a 10 x 40 mm coverslip. Only one egg was observed in each of the two Honey C samples. Sometimes several were seen in one field of view at 100x magnification (Figure 2a). The Honeycomb system is 250–300 m above sea level in the Oparara River Valley, on the western side of the river, and covers an 800 x 1000 m area. Coprolites at this site have been ^{14}C
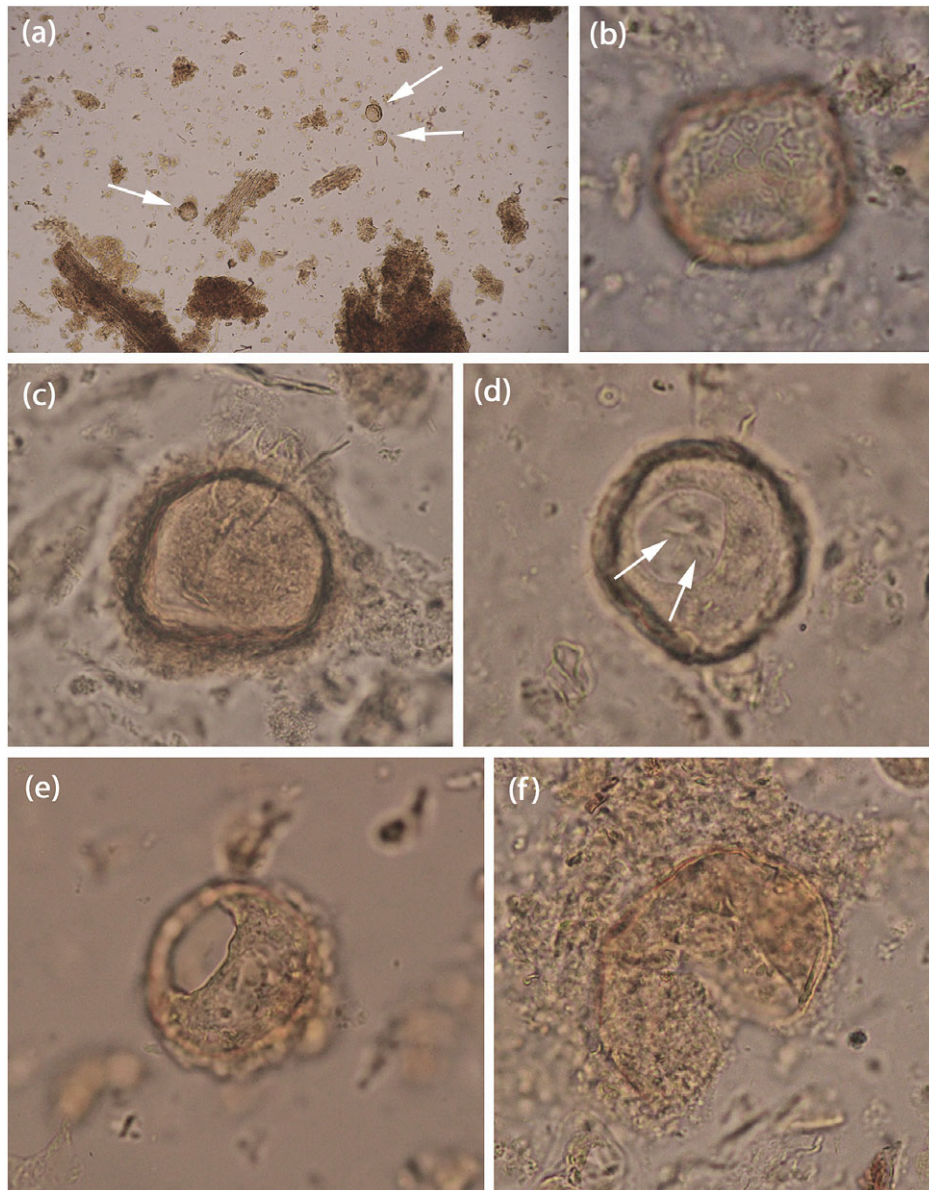
Figure 2. Microfossil eggs of cf. *Stringopotaenia psittacea*, showing characteristic features. Mounted in glycerol jelly; (a) 100x, remainder 600x; these examples are 60 μm in diameter, +/- a few μm; (a) three eggs (arrows) among plant material, shown in one field of view; (b) egg showing delicate reticulation, giving a dimpled or scalloped appearance; (c) egg with abraded surface layer, showing twin-pronged, pointed pryriform apparatus, in this case protruding above upper edge; (d) egg showing hexacanth and hooklets, seen here as faint, dark- or light-coloured straight long or shorts lines (arrows); (e) egg with a neat, round hole, suggested as possible oribatid mite damage; (f) damaged egg.

dated to 1550 ± 48 BC (Horrocks *et al.* 2008). Boast *et al.*'s (2023) coprolite study also included this cave system.

The intermediate hosts of anoplocephaline cestodes are invariably soil mites of suborder Oribatida (Beveridge 1994), which are presumably picked up with plant and fungal material during feeding. As the mites are infected via the eggs in the bird's faeces, it is understandable that infection could be localised, since the birds appear to use a roosting site habitually for long periods of time (Powlesland *et al.* 2006).

An unusual observation was made while examining the eggs in these coprolite samples. Most of the eggs exhibited a neat round hole in the surface of the shell (Figure 2e). Caley (1975) wrote that the shelled egg is too large and tough for an oribatid mite to ingest whole. He noted that mites manipulate the eggs for some time without swallowing them, possibly causing mechanical disruption of the shell, which allows them to remove the onchosphere. It was suggested that the rough or sometimes tetrahedral shape of the egg increased their ability to handle the eggs. Caley (1975) was observing the eggs of *Moniezia*, but those of this subfamily share similar features, and the intermediate host of all of them is an oribatid mite. We wonder whether the neat round holes in the shell of our specimens were made by mites feeding on eggs within the faeces.

The observations reported in this study constitute only the second time this species of cestode has been positively identified. *Stringopotaenia psittacea* has not been formally reported since 1884, and although we are aware of anecdotal evidence from wildlife veterinary sources, the species has been presumed extinct in the literature (e.g., Lafferty *et al.* 2018). There is growing concern among conservationists about parasites becoming extinct along with their hosts (Spencer & Zuk 2016). When the last remaining

individuals of a species are taken into captivity, they are often routinely de-wormed, ostensibly for the health of the individual. But an extreme change of environment and ecological conditions, along with concomitant loss of intermediate hosts and generations of captive breeding, can also result in parasite extinction (Stringer & Linklater 2014). However, parasites are now known to be fundamental drivers of ecosystem structure and evolution (Poulin 2021). In addition, it has been shown that low to moderate levels of infection boost the immune system of hosts in defending against a wide variety of infections (Spencer & Zuk 2016). Parasites are part of their host's biology and as such, should be considered in conservation plans and not expurgated without careful thought.

Conclusions

Results suggest that prior to human settlement, *S. psittacea* was not widespread within and between kākāpō populations, in marked contrast to other parasite types of the extinct moa spp. Intense management of the last remaining kākāpō has endangered or possibly caused the extinction of this cestode. This is the first confirmed record of *S. psittacea* since its discovery in 1884. Our findings of eggs of this species in coprolites of pre-human settlement age depict a time when the kākāpō was abundant and its cestode parasite prevalent.

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