Birds of a 'hyper-disturbed' rainforest remnant: volunteer surveys at Lake Eacham on the Atherton Tablelands, Far North Queensland, 1993-1998

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Abstract

Remnant protected areas are essential for the survival of rainforest bird species within agricultural landscapes. The Lake Eacham section of Crater Lakes National Park on the Atherton Tablelands, Far North Queensland, is a 450 ha remnant of mid-altitude tropical rainforest in the Wet Tropics World Heritage Area, surrounding a 52 ha volcanic crater lake, and 3 km from intact forest. It has been 'hyper-disturbed' by edge effects and periodic tropical cyclones, and has high tourist visitation rates. From 1993-1998 a volunteer group, the Tablelands National Park Volunteers, conducted monthly bird surveys in three sites. These sites supported a significant rainforest avifauna, with 7,496 bird records of 87 species. Most birds were dependent or largely dependent on rainforest, including 28 Wet Tropics endemic species or subspecies of which four were rainforest obligates. Arboreal insectivores were most abundant, followed by disperser frugivores. Birds seen included nine threatened and four near threatened species. The suite of species at Lake Eacham was comparable with that found in nearby intact forest. We believe this important remnant should be resurveyed, as recent surveys in intact rainforest in the region have detected declines in a number of species including 17 that we recorded as common or abundant. Further, two severe tropical cyclones have impacted the Park since 1998 and Lake Eacham is central to two major revegetation linkage projects, the Peterson Creek and Lakes Corridors. As the volunteer group disbanded in 2016, we provide the complete data as a supplementary file, to give others the opportunity for resurvey.

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Introduction

The Wet Tropics World Heritage Area (WTWHA) was established in 1988. It encompasses ~900,000 ha of intact and remnant forests preserved within northern Queensland landscapes that were cleared for timber and agriculture from the 1870s (Winter *et al*. 1987; Valentine & Hill 2008). Remnant protected areas are critical habitat for rainforest birds in Wet Tropics agricultural landscapes (Barnes *et al*. 2015). Lakes Eacham and Barrine are volcanic crater lakes on the Atherton Tablelands in Far North Queensland, within the WTWHA. Rainforest in the vicinity was largely cleared from the 1880s to 1913 (Tucker 2000), but some was retained around each of the lakes. These remnants were initially protected for their beauty and recreational use and were declared as National

Parks in 1934 (Frost 2004). Laurance (1997) described the Parks – later combined as Crater Lakes National Park (NP) – as 'hyper-disturbed' by periodic tropical cyclones and clearing of the surrounding landscape. These great physical and biological changes (Bierregaard *et al*. 1992) can trigger progressive loss of bird species (Warburton 1997; Ewers & Didham 2006). Lake Eacham may also be seen as 'hyper-disturbed' because of internal fragmentation by roads and clearings (Fig. 1; Goosem 2007; Turton & Stork 2008) and high visitor numbers.

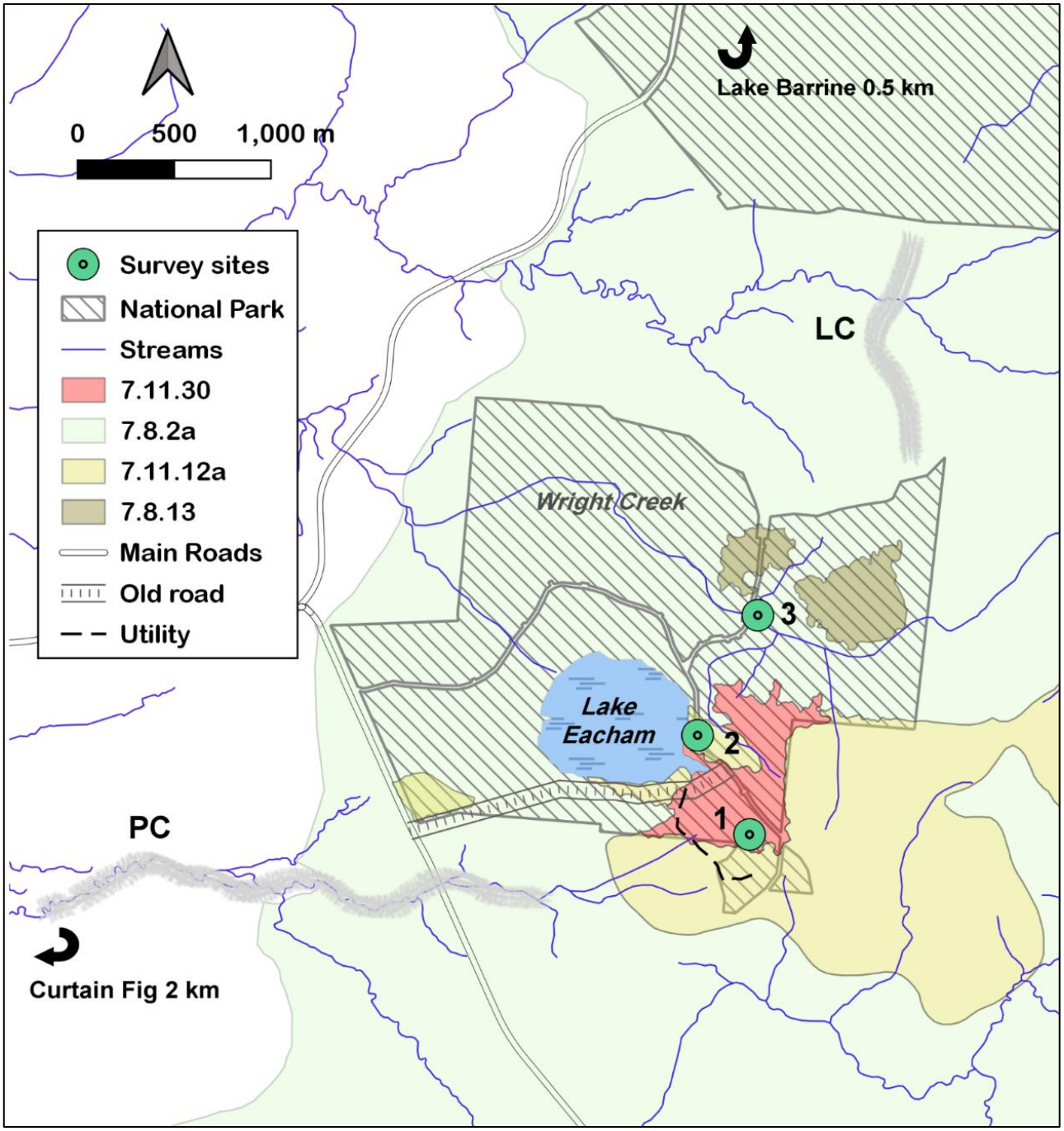

Figure 1. Bird survey sites 1993-1998 and pre-clearing habitats in and around the Lake Eacham Section of Crater Lakes National Park. Numbers indicate Regional Ecosystems.
LC=Lakes Corridor, PC=Peterson Creek Corridor (approximate locations). Details of Regional Ecosystems (REs) are in App. S2; pre-clearing habitat to the west (white) was 'Mabi' forest (RE 7.8.3). Site 3 includes Vision Falls. The utility corridor carries water and power between Queensland Parks and Wildlife Service buildings (Site 1) and the day-use area (Site 2). For details of 'old road', see text.

Sightseers photographed Lake Eacham from the 1880s (Anon. 1889) and by 1930 there were ”thousands of tourists” and “all” were taken to view Vision Falls (Anon. 1929, 1932). Lakeside clearings and infrastructure catered for picnics, swimming and boating and in 1962 J. A. Bravery (unpublished diaries) commented that Lake Eacham was “a good area [for birds] when seen on weekdays when traffic is less”. A survey conducted over an unknown period in 1975 recorded 5,186 vehicles entering the Park (Thomae 1980; Kikkawa 1991). Interviews with 517 groups of people found that half visited Lake Eacham to view and photograph scenery; 32% came for picnics and swimming; 12% to see plants and wildlife; and 6% to walk (calculated from Thomae 1980). Over half the visitors were from northern Queensland; those from elsewhere avoided the site when crowded (Thomae 1980, p. 68). At the time of our study the main walking track circumnavigated the lake with shorter tracks south of the lake and at Vision Falls. The designated ‘day-use area’ (Fig. 2) contained swimming facilities, picnic tables, barbeque shelters, toilets, grassed areas and limited hard-surface parking, and was bisected by a through road. In the first year of our study, 1993, traffic and other surveys recorded 369,082 visits to Lake Eacham (MRTEC 1994 in Driml 1996, p. 117), the highest number for any Wet Tropics site excluding lookouts. The traffic volume associated with this level of visitation is unknown. In 2017 the north-east road within the Park carried 90 light vehicles per day, but it was not the main access (D. Crawford personal communication).

Birdlife at the crater lakes attracted early specimen collectors (e.g. Jackson 1909) and birdwatchers (Mayo 1931; Bourke & Austin 1947) and, after WWII, scientists studying the ecology of individual species included Crome & Moore (1990) who reported a 1983 breeding record for the Southern Cassowary (*Casuarius casuarius*) at Lake Eacham. In 1973-1976 Kikkawa (1982) surveyed habitats and birds at upland and lowland sites in the Wet Tropics, and at Lake Eacham he observed and mist-netted birds in three states of notophyll vine forest: ‘disturbed’ forest with rattans (*Calamus* spp.) bordering the picnic ground; similar forest with undergrowth cleared; and intact forest near a road. He reported only fourteen of the 57 bird species he recorded at Lake Eacham (Kikkawa 1982, pp. 327, 339). Warburton (Table 6.6 in

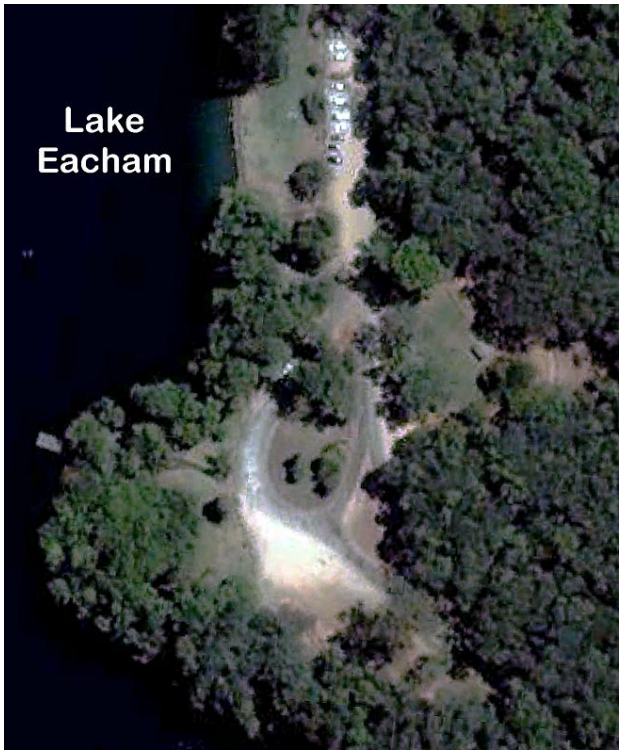

Figure 2. Site 2, Lake Eacham day-use area, 2002. Photograph: Google Earth.

Warburton 1987; Warburton 1997) surveyed thirty remnants and two intact forest reference sites for 62 bird species known to occupy rainforest on the Atherton Tablelands, and listed 44 species for Lake Eacham. Reference sites at Lake Eacham have been included in recent landscape-scale studies of multiple biota in different styles of revegetation on the Tablelands (e.g. Catterall *et al*. 2004) and in bird monitoring for two revegetation linkage projects commenced in the late 1990s. These are the Peterson Creek and Lakes corridors (Fig. 1; Freeman *et al*. 2009; Jones 2016), which aim to connect Lake Eacham rainforest with that at the Curtain Fig and Lake Barrine, respectively.

In 1993 the Wet Tropics Management Authority (WTMA) and Queensland Parks and Wildlife Service (QPWS) recruited community volunteers to help present WTWHA values to the public and support related activities (Parkin 2008; WTMA 2022), including research field work (e.g. Laurance & Laurance 1995; Laurance 1997). A QPWS interpretive ranger coordinated a group based at Lake Eacham, the Tablelands National Park Volunteers (TNPV) (Terrain 2016; TNPV 2022). TNPV conducted public bird walks, reviewed and collated bird records and produced a bird list brochure (TNPV 1995; Scambler unpublished), which relied primarily on

opportunistic sightings because studies of the Lake Eacham avifauna had been limited. In 1993 TNPV initiated a project to survey birds at Lake Eacham, concentrating on areas of high visitor use, and in this article we report results of monthly bird counts from 1993-1998 at three publicly-accessible sites. We also consider possible impacts of high visitation and other disturbance on birdlife and the remnant's role in natural and planned revegetation in the surrounding landscape.

Methods

Study area

The study was conducted in the WTWHA of Far North Queensland in the (then) Lake Eacham NP (17°17'S, 145°37'E, 770 m ASL, Fig. 1: hereafter 'the Park'), ~40 km south-west of the city of Cairns. The 52 ha lake lies in a maar (a crater formed by explosions of magma and steam), surrounded by 450 ha of remnant forest. The nearest extensive rainforest is 3 km to the east. Most of the Park is on fertile basalt soil supporting larger-leaved complex rainforest, but forest types with smaller leaves and simpler structures occur on less fertile metamorphic soils in the south-east and south-west (Tracey 1982; Queensland Government 2020; App. S2). *Acacia*-dominated regrowth occurs in formerly-cleared areas in the south-east. No streams flow into or out of the lake, but Wright Creek flows through the Park with several waterfalls, notably Vision Falls. Roads inside the Park are ~6 m wide with some canopy overhang and surfaced with either bitumen or 4 m of bitumen with gravel verges. The utility corridor is wider with a more open canopy, trimmed to protect the power line. Narrow linear clearings may suffer limited edge effects (Laurance & Goosem 2008). However, Laurance (1997) found significant damage (e.g. treefalls, many lianas and rattans) at Lake Eacham in the forest interior 50-100 m from roads, some estimated to date from Tropical Cyclone Winifred in 1986 and some from earlier events. The old access road was heavily used in WWII but deteriorated from the 1950s and was closed in the 1970s (Petrina Callaghan, personal communication). It was still accessible on foot in 1998, when conditions were similar to those found by Laurance (1997) elsewhere in the Park (ECS & P. J. Daly personal observation). Other tracks were cleared in the early 20th century for bullock teams and walkers (tourists), but have not been mapped and are no longer evident.

We defined seasons as Wet (January-April), Cool (May-August) and Dry (September-December). Rainfall and temperature were recorded daily 80 m from the north-eastern corner of the Park (1 km from Site 3) by P. J. Daly. From 1993-1998 average temperatures in the Wet Season were 19-27° C, in the Cool Season 13-23° C and in the Dry Season 16-27° C, with a range of 8-35° C in most years. Rainfall averaged 1,604 mm p.a. (range 1,286-1,873 mm), which was 76-110% of the 16-year average for the site (1990-2005). Most rain fell in the Wet Season from January-April, but the early Cool Season was characterised by periods of drizzle and the late Dry Season by intermittent storms. Severe Tropical Cyclone Justin (Bureau of Meteorology 2023a) delivered 350 mm of rain on 22-23 March 1997, felling branches and some trees in the Park and scouring the banks of Wright Creek.

Survey sites

We established three sites of ~2 ha, at least 590 m apart (Fig. 1; see App. S1 for site coordinates). All were accessible to the public, giving long-term access by counters without vegetation removal or markers, and all were within 50 m of a road. Site 1 comprised *Acacia*-dominated regrowth adjacent to QPWS buildings and simple vine forest (App. S2; Fig. 3A) 20 m either side of a gravelled walking track. Site 2 was in the day-use area, and was largely cleared, with regrowth and small remnants similar to Site 1, and grassed areas with trees including large figs (*Ficus* spp.) (Fig. 2). Eleven Hoop Pines (*Araucaria cunninghamii*: native to North Queensland but exotic to the site) were removed from this site in early 1997. Site 3 was in the gully of Wright Creek including Vision Falls (Figs 3B, 3C) in more complex forest. It had been divided by a road and bridge constructed in 1939 (Anon. 1939) and birds were counted 20 m either side of a narrow track winding through the forest, across the creek and under the bridge.

Data collection

TNPV members and others familiar with local bird species led training on seven dates in June-July 1993 (21 x 20 minute training surveys). Trainees were also familiarised with calls through tapes available for loan, e.g. Griffin & Swaby (1993). Counters provided their own binoculars and field guides. Sixty morning surveys, comprising one

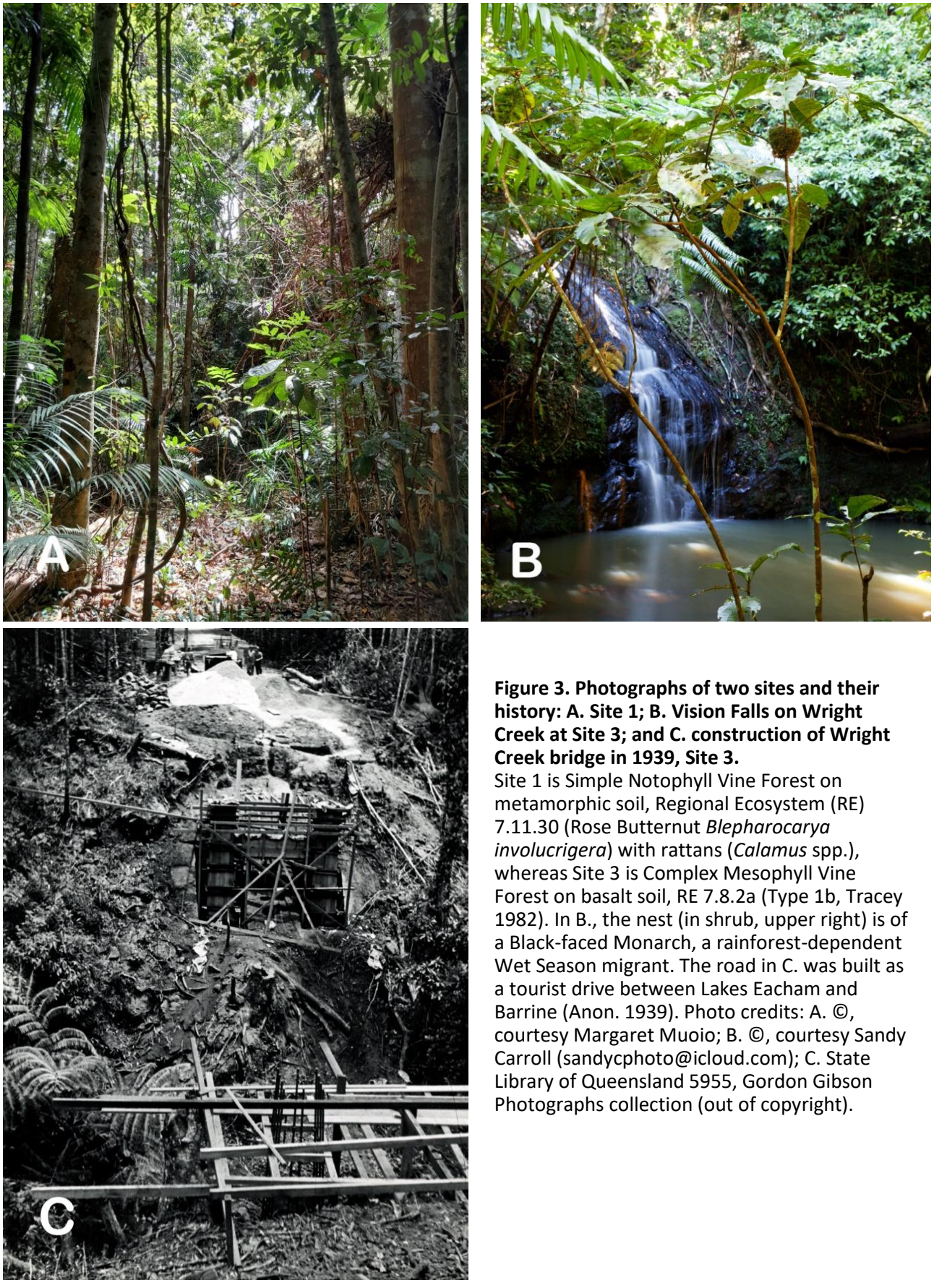

Figure 3. Photographs of two sites and their history: A. Site 1; B. Vision Falls on Wright Creek at Site 3; and C. construction of Wright Creek bridge in 1939, Site 3.
Site 1 is Simple Notophyll Vine Forest on metamorphic soil, Regional Ecosystem (RE) 7.11.30 (Rose Butternut *Blepharocarya involucrigera*) with rattans (*Calamus* spp.), whereas Site 3 is Complex Mesophyll Vine Forest on basalt soil, RE 7.8.2a (Type 1b, Tracey 1982). In B., the nest (in shrub, upper right) is of a Black-faced Monarch, a rainforest-dependent Wet Season migrant. The road in C. was built as a tourist drive between Lakes Eacham and Barrine (Anon. 1939). Photo credits: A. ©, courtesy Margaret Muoio; B. ©, courtesy Sandy Carroll (sandycphoto@icloud.com); C. State Library of Queensland 5955, Gordon Gibson Photographs collection (out of copyright).

search of each of the three sites, were conducted from July 1993 to June 1998 (twenty monthly surveys in each season). ECS led 58 surveys, SBB attended 42 and seven others attended 10–38, with an average of four counters per survey, one acting as recorder. Each of the three sites was searched for 20 minutes. Surveys began at 0730 h (45 min to 1 h 53 min after sunrise) and were completed within 3.5 h of sunrise (Geoscience Australia 2021). Site 3 was always counted last because of lower light conditions on the creek. A single nocturnal survey of all sites was held in November 1993.

Birds were identified visually or by calls, and at each site care was taken to avoid counting individuals more than once. Unidentified birds were noted, and birds estimated to be outside the 2-ha sites were recorded as 'off site'. Opportunistic records were made of signs of breeding (birds attending a nest or feeding dependent young, or sightings of recently fledged young) and flowering and fruiting of vegetation. Surveys could not be rescheduled so some were held during rain or noise from cicadas. These factors, and others that we considered might affect bird behaviour or detection of birds, were noted. Disturbance from people or traffic was noted during six surveys at Site 2 and loud cicadas were recorded on six dates in January or February, mostly at Site 3. Waterfall noise was noted at the far eastern end of Site 3 in 80% of Wet Season surveys, and rain greater than light drizzle occurred during three surveys at Sites 1 and 2 and one at Site 3. Leaf drip (see Anderson *et al*. 2015) was recorded in five surveys, mostly at Site 1.

Incidental records were also made of non-avian species including frogs, reptiles, mammals and notable insects. However, no attempt was made to obtain a comprehensive list of these groups or to measure their abundance. Birds 'off-site' and those recorded in the nocturnal survey were excluded when calculating results. Records of aquatic birds in Site 2 were also excluded from analysis, as they primarily used the open water habitat of the Lake. Records of unidentified birds were excluded from all analyses, except for those of detectability.

Species classification

We classified the survey species according to three functional categories (see App. S3 and references therein). These were degree of rainforest dependency; diet guilds; and movement ecology. We ranked rainforest dependency into seven classes, from non-rainforest birds (RF0) to obligate rainforest species (RF6; Williams 2006), and combined adjacent classes in some analyses, where appropriate. We classified species as resident or migratory, based on knowledge of their movement patterns (App. S3). We use 'birds' or 'records' to refer to every bird counted, although (especially with territorial species) some would have been recounted in successive surveys at the same site. We calculated two simple estimates of relative abundance. Firstly, we classified each species according to the proportion of survey dates (N = 60) on which a species was recorded. Secondly, we calculated abundance (mean number of records) of a species over all site counts (N = 180) and applied relative abundance classes developed on a logarithmic scale as presented by Chapman & Kofron (2010): rare (<0.010); uncommon (0.010-<0.100); common (0.100-1.000); and abundant (>1.000). For results of statistical analyses, we use the term 'abundance' to report mean numbers of birds recorded.

Birds that consume fruit but do not crush seeds in the bill or in digestion provide important seed-dispersal functions in rainforest and when they visit fragments and revegetation plantings in the wider landscape (Moran *et al*. 2004; Jansen 2005). We term these species 'disperser frugivores', which includes all specialised frugivores and some species from other diet guilds such as Silvereye and Pied Currawong (omnivores) and Scarlet Honeyeater (a nectarivore). Specialised frugivores with large gapes – able to consume larger fruits whole, such as Tooth-billed Bowerbird – are particularly important for rainforest seed dispersal (Moran *et al*. 2004; Jansen 2005). We obtained details of gape size and disperser function from Moore (1991), Grant & Litchfield (2003) and Moran *et al.* (2004). Recent population trends and conservation status were obtained from Williams & de la Fuente (2021) and Garnett & Barker (2021). Bird common and scientific names follow BirdLife Australia (2023). For simplicity, in the main text, we use only the common names of birds recorded in the Park (see App. S4 and App. S6 for scientific names), and omit the prefix 'Wet Tropics' from the common names of endemic subspecies.

Statistical analysis

All statistical comparisons were conducted in MS Excel, with the Real Statistics Resource Pack (Zaiontz 2023) used for Analysis of Variance (ANOVA). We conducted three-factor ANOVA to investigate differences in abundance of each species and functional category, by site, by season and between years. For these tests we quarter-root transformed count data to reduce the impact of occasional large flocks of some species, and combined rainforest dependency classes RF0-2 and RF5-6 respectively. Given that visibility was likely to be greater in the pole-like forest in Site 1 and the very open habitat of Site 2, as compared with more complex forest in Site 3, we used Chi-squared tests for goodness of fit to compare the sites by the numbers of birds recorded by sight alone, hearing alone or by both sight and hearing.

Results

Survey results

In the 60 morning surveys across all three sites at Lake Eacham, we recorded 7,496 bird observations and 87 species, including 28 species or subspecies endemic to the Wet Tropics (App. S4). Forty species were obligate insectivores, 11 specialised frugivores, 22 (from a range of diet guilds) disperser frugivores (including 11 with large gapes), and 69 residents (App. S4). Eight species or subspecies were considered Endangered or Vulnerable and four Near Threatened by Garnett and Barker (2021). Twelve species were abundant, 39 common, 28 uncommon, and eight rare. These patterns are explored in more detail below.

Incidental records excluded from our analysis were of five aquatic species from Site 2 (App. S6) and birds recorded in the single nocturnal survey – two Southern Boobooks at Site 2, an Azure Kingfisher disturbed while roosting at Site 3, and a Lesser Sooty Owl (a Wet Tropics endemic) heard at Site 3 (App. S4). A further 226 excluded observations were of unidentified species: 159 had been glimpsed flying within foliage, and there were 71 unidentified calls – three noted as overwhelmed by loud cicadas. Species recorded only opportunistically outside the survey periods were two rainforest specialists, the Southern Cassowary and endemic Atherton Scrubwren, and the wide-ranging Channel-billed Cuckoo, all at Site 1. Incidental records of non-avian species included two insect species, two frog species, four reptile species, and six mammal species (App. S6). Of these, the Musky Rat Kangaroo was the most frequently seen, followed by the Red-legged Pademelon.

Detectability

Forty-nine percent of records were made from calls alone, 36% from visual observation, and 15% of records were both 'seen and heard' (App. S5). Of the most frequently observed species, at least 60% of Brown Gerygones, Golden Whistlers, Eastern Whipbirds and Grey Fantails, 57% of Lewin's Honeyeaters, and 45% of Grey-headed Robins were recorded by calls alone. The number of records detected by call versus sight differed significantly between sites ($\chi^2_{(d.f.=2,\ N=7,496)} = 623.9$, $p < 0.00001$: Table 1). Proportionally more records were made visually and fewer by hearing alone at Site 2, than at the other sites, particularly Site 3. Proportionally fewer birds were both seen and heard at Site 3 than at the other sites, and this applied for species more abundant at Site 3 than at the other sites, and for species less common there (App. S5).

Functional classifications

Most species (57%) and birds recorded (84%) were rainforest-dependent (RF5, RF6), or used rainforest as their main habitat (RF4) (App. S4; Fig. 4). These included Wet Tropics endemics (nine species and nineteen subspecies), of which four were rainforest obligates (RF6: Bower's Shrike-thrush, Brown Gerygone, Mountain Thornbill and Tooth-billed Bowerbird). Two endemics (Bower's Shrike-thrush and Victoria's Riflebird) were seen feeding fledged young at Site 2. The only Wet Tropics endemic expected to occur at mid-altitudes, but not recorded, was the Fernwren (*Oreoscopus gutturalis*).

Table 1. Frequency of bird detection methods by site.

Method		Seen & heard	Seen only	Heard only	Uniden-tified
Site 1	No.	432	630	1,278	84
	%	17.8	26.0	52.7	3.5
Site 2	No.	522	1,658	1,225	53
	%	15.1	47.9	35.4	1.5
Site 3	No.	157	401	1,193	89
	%	8.5	21.8	64.8	4.8

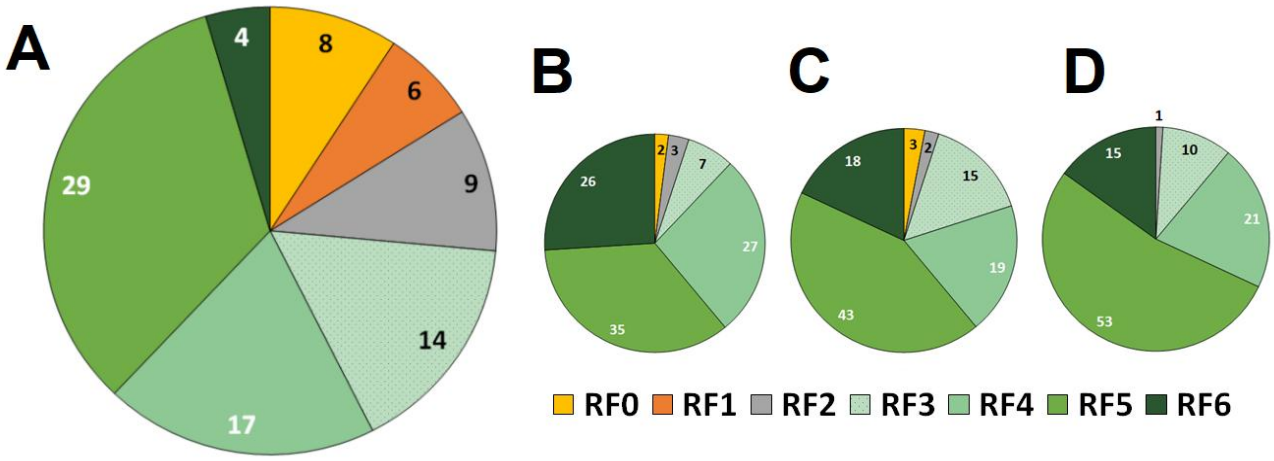

Figure 4. Rainforest-dependency of birds recorded in 60 monthly morning surveys across three sites at Lake Eacham, 1993-1998: A. number of species (N = 87) recorded across all sites; and percentages of bird observations (B, C,D) at Site 1 (B, N = 2,340), Site 2 (C, N = 3,405), and Site 3 (D, N = 1,757).
For RF (rainforest-dependency) classes see App. S3. Classes with percentage < 1 are not shown.

Two Wet Tropics endemic species and five endemic subspecies were abundant, and five endemic species were common. Brown Gerygone, Lewin's Honeyeater, Eastern Whipbird, Grey Fantail and Golden Whistler were the most frequently recorded species, and constituted 38% of all records. The first three of these are rainforest-dependent, and rainforest is the main habitat of the last two in the Wet Tropics, although they are also frequently found in other habitats. The next most abundant species was the Sulphur-crested Cockatoo, a large conspicuous habitat generalist that constituted 4% of all records.

Records of non-rainforest bird species (RF0-RF2) were low and variable. They came from 23 species, of which 18 were uncommon to rare. The six most common non-rainforest species (Red-browed Finch, Magpie-lark, Peaceful Dove, Willie Wagtail, Eastern Yellow Robin and Laughing Kookaburra) constituted 4% of all records. The first four were most frequently observed at Site 2, where they were recorded breeding. The last two were most common and breeding at Site 1. No non-rainforest birds were recorded in high numbers or breeding at Site 3. Although the introduced Common Myna (*Acridotheres tristis*) was well-established on nearby cleared farmlands (ECS unpublished data), none was recorded in the Park.

Most birds (86% of species, 92% of records) were resident; the most common migrant was Black-faced Monarch, present in highest numbers in the Dry and Wet seasons. Arboreal insectivores (24 species) comprised 38% of bird records, and ground insectivores (11 species) comprised 11% of records (App. S4, App. S5). Disperser frugivores from a range of diet groups comprised 25% of species and 28% of records. These included eleven large-gaped species (10% of records), of which two were abundant and five common. Southern Cassowary and Channel-billed Cuckoo, recorded outside the survey periods, are also large-gaped disperser frugivores. Four species were specialist nectar feeders (3% of records) and a further five were facultative nectar feeders (15% of records).

Comparisons between sites

Total bird abundance varied significantly between the three sites, as did the abundances in each rainforest-dependency class and most dietary guilds (App. S7). The three sites shared 51 species (Fig. 5). Species with five or more records and found only in one site were Eastern Yellow Robin (22 records at Site 1), Black-faced Cuckoo-shrike and Forest Kingfisher (eight and five records respectively, at Site 2) and Azure Kingfisher (10 records at Site 3).

Significant differences were found between sites in the mean numbers of bird records in all rainforest dependency classes and most dietary guilds, and in 37 species (43% of all species; Table 2; App. S7). Abundance decreased from highest in Site 2 to lowest in Site 3 for most functional categories and many species. However, abundance of arboreal insectivores, including Golden Whistler and Little

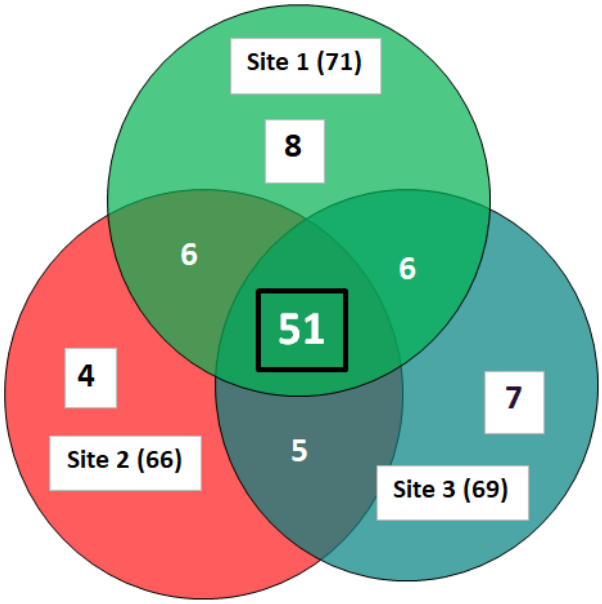

Figure 5. Species richness (number of species) (N = 87) recorded in 60 monthly morning surveys at each of three sites at Lake Eacham, 1993-1998. The number of species unique to each site is shown in white squares and the total number of species at each site is shown in brackets.

Treecreeper, was highest in Site 1 and abundance of Bridled Honeyeater, Yellow-throated Scrubwren and Superb, Wompoo and Rose-crowned Fruit-Doves was highest in Site 3. Ground insectivores, Grey-headed Robin, Macleay's Honeyeater and Mistletoebird were significantly more abundant in Site 3 than in Site 1. Species that showed no significant differences in abundance between sites included the Grey Fantail and Large-billed Scrubwren.

Annual and seasonal patterns

Bird abundance varied across years, peaking in 1997-98 in Sites 1 and 3, and in 1996-97 at Site 2 (Fig. 6; App. S8). These results were largely driven by significant peaks in specialist nectarivores, nectarivore/insectivores, Pied Currawong, Bridled Honeyeater, Bower's Shrike-thrush, Mistletoebird and Rainbow Lorikeet.

There were significant site-season interactions in the mean number of bird records (Fig. 7A; App. S10). Highest abundance at Site 1 was in the Wet Season, and at Site 2 in the Cool Season. Abundance at Site 3 was highest in the Dry Season and lowest in the Wet Season.

Seasonal differences between the sites were largely driven by changes in the abundance of particular species and functional groups. Abundance of disperser frugivores was highest in the Dry Season at Sites 2 and 3, and in the Wet Season at Site 1 (Fig. 7B). The endemic Tooth-billed Bowerbird (an important large-gaped disperser) was most abundant at Site 1, in the Dry Season. In contrast, the Australasian Figbird, also a large-gaped disperser frugivore, was found almost entirely at Site 2, particularly in the Dry Season, having fewer records in the Wet and almost none in the Cool Season. Abundance of Barred Cuckoo-shrike also peaked at Site 2 in the Dry Season. Arboreal insectivores showed a strong site-season interaction (Fig. 7C). Site 1 experienced its highest abundance for this guild in the Wet Season (notably of the Little Shrike-thrush), but this occurred in the Dry Season in Site 3. Conversely, this diet guild experienced its lowest abundance in Site 2 in the Dry Season, and in Site 3 in the Wet Season (notably for the Brown Gerygone). The Black-faced Monarch, a Wet Season migrant, was found breeding in Site 3, but it was less common there than it was in either Site 1 or 2. Abundance of terrestrial insectivores was steady through the year at Site 1, but varied at Sites 2 and 3 (Fig. 7D). For example, in the Dry Season, Eastern Whipbird and Northern Pale-yellow Robin were most abundant in Site 3, but in the Cool Season, there were far more records of the latter in Site 2 than at either of the other sites. Species that showed no seasonal differences in abundance included Grey Fantail and Orange-footed Scrubfowl.

Species of conservation significance

Of the 21 species recorded in the surveys that have been assessed as declining or at risk (Garnett & Barker 2021; Williams & de la Fuente 2021), six were abundant at Lake Eacham through the study period and eleven were common (Table 3).

Discussion

In 1993-1998, more than 80 years after the vegetation was cleared from the surrounding landscape, the Lake Eacham section of Crater Lakes NP supported significant numbers of rainforest-dependent birds even in sites heavily-frequented by tourists. The suite of rainforest species we recorded at Lake Eacham was comparable to that found in nearby rainforest reference sites (Table 6.6 in Warburton 1987), and was dominated by birds that favour rainforest over adjacent regrowth on the Tablelands (e.g. Laurance *et al*. 1996;

Table 2. Relative abundance (mean number of bird records across 60 monthly morning surveys ± standard error) in each survey site, for selected functional categories and species at Lake Eacham, 1993-1998.
[†]Species: E, Wet Tropics endemic species; ES, Wet Tropics endemic sub-species. Significant differences in abundance between sites (controlling for differences between seasons and years) calculated using a three-factor ANOVA are shown as: *, < 0.05; **, < 0.01; ***, < 0.001; ****, < 0.0001. Number of species is included in brackets. For scientific names see App. S4.

Category or species[†]	Site 1	Site 2	Site 3
Total bird records**** (87)	39.00 ± 1.76 (71)	56.75 ± 2.46 (66)	29.18 ± 1.53 (69)
Arboreal insectivores**** (24)	18.85 ± 0.81 (20)	18.37 ± 1.13 (19)	10.35 ± 0.72 (19)
Terrestrial insectivores*** (11)	3.40 ± 0.26 (8)	6.42 ± 0.37 (7)	4.50 ± 0.39 (7)
'Disperser' frugivores**** (22)	9.58 ± 1.01 (18)	17.60 ± 1.11 (20)	7.03 ± 0.54 (18)
Nectarivore/insectivores*** (4)	0.92 ± 0.13 (3)	2.65 ± 0.29 (3)	2.28 ± 0.28 (4)
RF0-2**** (23)	2.10 ± 0.27 (15)	3.35 ± 0.41 (11)	0.25 ± 0.07 (7)
RF3**** (14)	2.85 ± 0.43 (11)	8.35 ± 1.50 (9)	3.07 ± 0.33 (14)
RF4**** (17)	10.57 ± 1.09 (15)	10.72 ± 0.85 (16)	6.20 ± 0.57 (17)
RF5-6**** (33)	23.48 ± 1.03 (30)	34.33 ± 1.20 (29)	19.67 ± 1.17 (31)
Australian Brush-turkey****	0.27 ± 0.08	2.23 ± 0.29	0.20 ± 0.05
Australasian Figbird****	0.10 ± 0.06	3.52 ± 0.54	0.15 ± 0.08
Brown Gerygone[ES]****	9.20 ± 0.52	9.70 ± 0.63	3.98 ± 0.42
Grey-headed Robin[E]****	0.55 ± 0.10	2.50 ± 0.22	1.35 ± 0.13
Macleay's Honeyeater[E]****	0.48 ± 0.09	2.15 ± 0.23	1.08 ± 0.16
Bridled Honeyeater[E]****	0.27 ± 0.08	0.30 ± 0.08	1.08 ± 0.17
Silvereye****	2.28 ± 0.80	0.63 ± 0.24	0.20 ± 0.12
Barred Cuckoo-shrike***	0.15 ± 0.08	0.77 ± 0.22	0.13 ± 0.06
Tooth-billed Bowerbird[E]**	0.52 ± 0.12	0.20 ± 0.07	0.17 ± 0.05
Victoria's Riflebird[E]*	0.77 ± 0.09	1.37 ± 0.19	0.73 ± 0.14

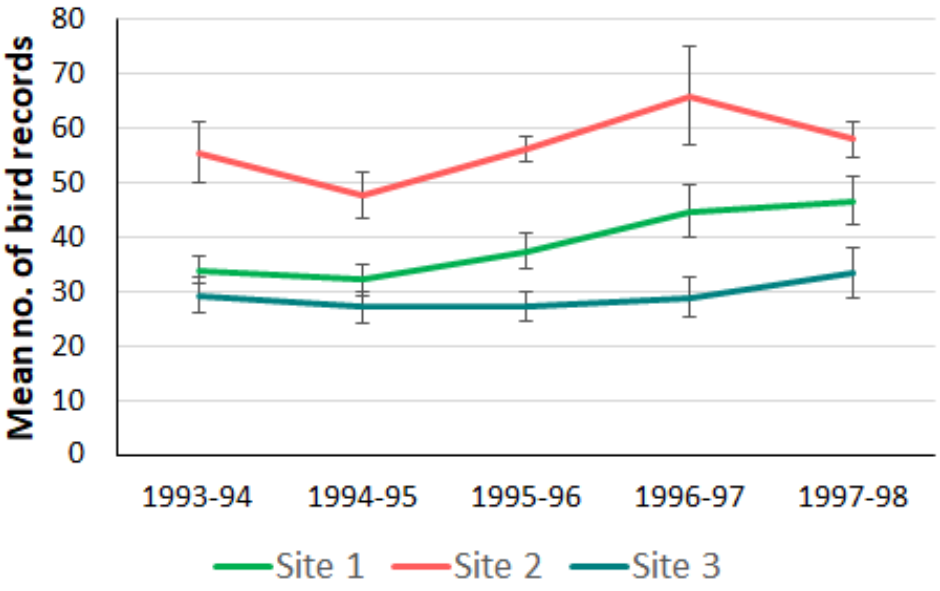

Figure 6. Annual changes in bird abundance (mean number of bird records across 60 monthly morning surveys ± standard error) at three sites at Lake Eacham, 1993-1998.

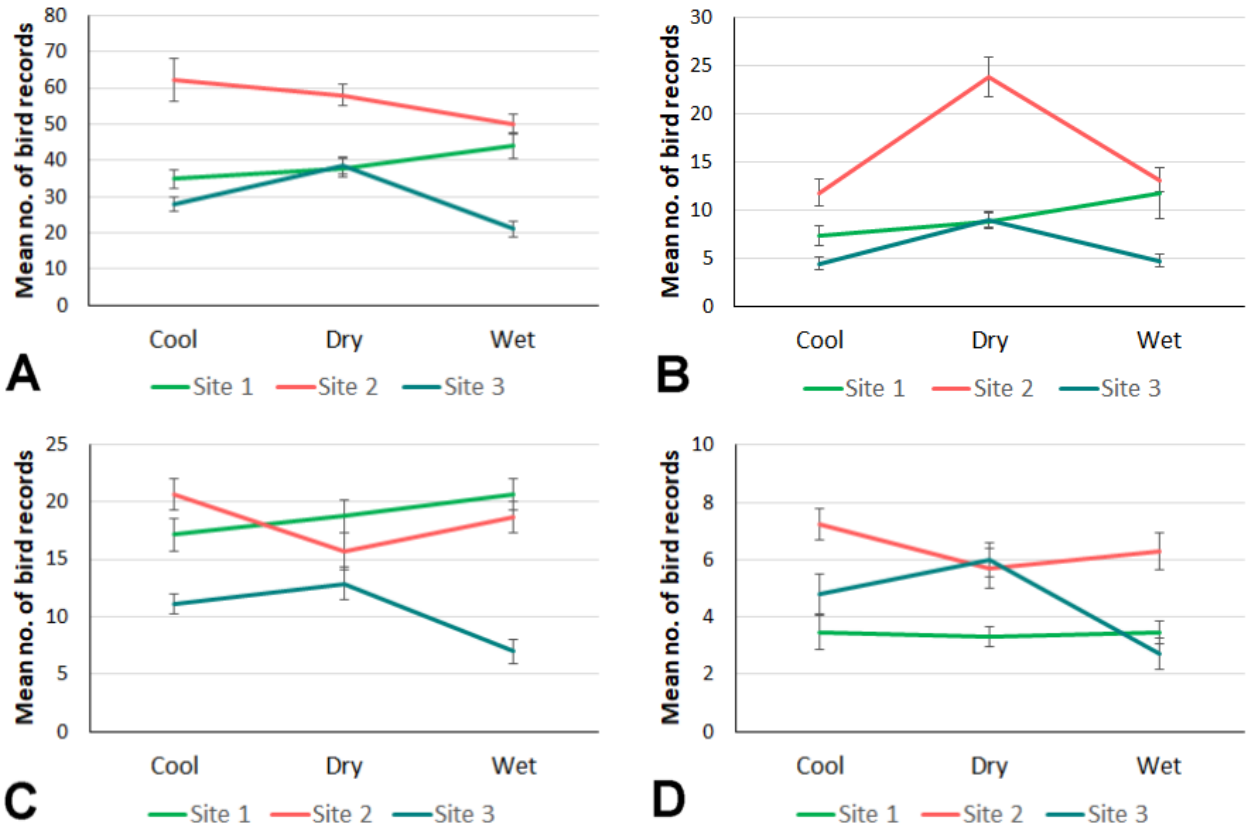

Figure 7. Seasonal changes in bird abundance (mean number of bird records across 60 monthly morning surveys ± standard error) in three sites at Lake Eacham, 1993-1998: A. all species; B. disperser frugivores; C. arboreal insectivores and D. terrestrial insectivores.

Freeman 2015). The suite of rainforest birds at individual sites appears to be influenced by the dominant forest type, a relationship that would be worthy of further study in intact examples of each habitat.

Detectability

Detectability varies in bird surveys because of differences in habitats, species and weather conditions (Buckland *et al*. 2008; Anderson *et al*. 2015), and this undoubtedly affected some results of our study. Except for Silvereyes (most common in Site 1) and three fruit-dove species (most common in Site 3), more than half of all disperser frugivores were recorded in the day-use area (Site 2), where they were visible at all levels including the canopy of mature fig trees. This suggests that a limited view of the canopy caused us to under-report canopy-foraging frugivores in Sites 1 and 3, making it difficult to estimate the abundance of frugivorous birds at Lake Eacham, or their potential contribution to natural or planned revegetation in the surrounding landscape. Most Tooth-billed Bowerbirds were recorded at Site 1, where a number of lone male birds were observed at their courts in the Dry Season. However, even these observations were likely to underestimate the species' abundance, as tooth-bills often feed in the canopy and are largely silent when not breeding, and females are rarely observed (Frith & Frith 1994). The Eastern Whipbird is sedentary and territorial, but it reduces calling after breeding in the late Dry-to early Wet Season (Higgins & Peter 2002), and this was reflected in its lower recorded abundance at all sites in the Wet Season.

Of the insectivores, 57% of records of the Grey-headed Robin were at Site 2, where they were mostly seen quietly foraging on the edges of remnants and regrowth, and we probably underestimated them in our two more-intact forest sites where they were mostly detected by calls. By contrast, lower numbers of Brown Gerygone and Black-faced Monarch at Site 3 than at the other sites are unlikely to be due to under-detection, as both species were equally likely to be recorded by calls alone at all sites. Both species are

Table 3. Relative abundance of Lake Eacham bird species (1993-1998) that have been assessed in other studies as declining and/or at risk in 2021.
*E, Wet Tropics endemic species; ES, Wet Tropics endemic sub-species.
†Trends (Williams & de la Fuente 2021) are for intact rainforest at mid-altitudes, 2000-2016: STED, steep decline; MODD, moderate decline; MODI, moderate increase; ?, unclear trend.
‡Status (Garnett & Barker 2021): EN, Endangered; V, Vulnerable; NT. Near Threatened.
§Relative abundance (App. S4): +++=abundant, ++=common, +=uncommon, n.a.=not applicable. For scientific names see App. S4.

Common name*	Trend†	Status‡	1993-98§
Australian King-Parrot[ES]	STED[1]	EN	++
Atherton Scrubwren[E]	?	V	n.a.
Black-eared Catbird[ES]	MODD		+++
Black-faced Monarch	MODD		++
Bower's Shrike-thrush[E]	STED	V	++
Bridled Honeyeater[E]	MODD		++
Brown Cuckoo-Dove[ES]	MODD		++
Brown Gerygone[ES]	MODD	EN	+++
Eastern Whipbird[ES]	MODD	V	+++
Golden Whistler	MODD		+++
Grey-headed Robin[E]	MODD	NT	+++
Large-billed Scrubwren[ES]	MODD	V	++
Little Treecreeper[ES]	MODD	NT	+++
Mountain Thornbill[E]	MODI	V	+
Rufous Fantail	MODD		+
Satin Bowerbird[ES]	?	NT	+
Spectacled Monarch[ES]	MODD		++
Tooth-billed Bowerbird[E]	STED	NT	++
Victoria's Riflebird[E]	MODD	V	++
White-throated Needletail[2]	?	V	++
Wompoo Fruit-Dove[ES]	MODD		++

dependent on rainforest (Catterall *et al*. 2004; Williams 2006) but their prevalence in Sites 1 and 2 suggests a preference for the more disturbed habitats at Lake Eacham, which is consistent with their common occurrence in fragments, restoration plantings and suburban gardens at least 200 m from vegetated creeks (Crome *et al*. 1994; Warburton 1997; Freeman *et al*. 2009; ECS personal observation). Overall, small-bodied species, particularly insectivores, were possibly underestimated at Site 3, because of waterfall noise in the Wet Season, compounded by foliage density in the shrub layer affecting both aural and visual cues (Anderson *et al*. 2015).

Bird species and functional categories

The predominance of insectivores across all sites, especially of arboreal insectivores, implies resources of invertebrates that are sufficient, not only to support breeding, but to survive the nutritional stresses of the Dry Season (Frith & Frith 1985; Williams & Middleton 2008). Many studies of avifauna in tropical forest fragments have shown terrestrial insectivores to be at high risk of local decline and extinction. This is especially the case for uncommon species with limited dispersal ability (Stouffer & Bierregaard 1995; Curtis *et al*. 2021). A notable absence from our surveys was the insectivorous Fernwren, which has been recorded infrequently at Lake Eacham but commonly at Lake Barrine (J. A. Bravery unpublished; Kikkawa 1982; eBird 2022). The causes of Fernwren rarity at Lake Eacham are unknown, as it is unclear if it had been more abundant in the past, and its ecology has not yet been studied (Grant 2022; J.D.A. Grant personal communication). Chowchillas have also been recorded more often at Barrine than at Eacham. Neumann (2002) found Chowchillas in both 'wet' (creek) and 'dry' (non-creek) gullies at Lake Barrine, but only in 'wet' gullies at Lake Eacham. A patchy distribution at Lake Eacham is also suggested by our finding that Chowchillas were common, whereas Driscoll & Kikkawa (1989, p. 145) presumed they were absent. These avifaunal differences between the two sections of Crater Lakes NP may result from microhabitat differences affecting litter moisture and composition, essential for these ground-foraging insectivores (Neumann 2002; Higgins *et al*. 2006), rainfall differences due to topography, or differing effects of fragmentation.

While fewer frugivores were recorded than insectivores, all specialist frugivores expected at mid-altitudes in the Wet Tropics were found at Lake Eacham, mostly in the surveys, and large-gaped dispersers were particularly well-represented. Again, this suggests a rainforest habitat that is in good condition.

Non-rainforest species

The low and variable numbers of most non-rainforest species suggest most were visiting from surrounding habitats to 'sample' resources at Lake Eacham. Their relative abundance reflects the habitat differences between the sites, with Site 3 having the least non-rainforest habitat, and Site 2 the most. Of the five common non-rainforest species found breeding in the Park, four also occupy various post-clearing habitats on the Tablelands. However, the source of the fifth, Eastern Yellow Robin, is speculative. This robin forages largely by ground-pouncing from a low perch and avoids habitats with dense undergrowth (Higgins *et al*. 2006). In the surveys, they were found in *Acacia*-dominated regrowth, mostly adjoining grassed areas near QPWS buildings (Site 1) and nearby stands of Rose Gums (*Eucalyptus grandis*) planted in 1983 (N. Tucker personal communication) and their progeny. Eastern Yellow Robins also occur in eucalypt habitats 3 km west of the Park (eBird 2022) and have been recorded in the Peterson Creek Corridor (Freeman *et al*. 2009), so may have colonised post-clearing habitat at Lake Eacham by the same pathways as other non-rainforest birds. However, in the Wet Tropics, Eastern Yellow Robin is the most abundant bird in wet sclerophyll forest with a grassy understorey (Chapman & Kofron 2010), which occurs as a variable narrow band between rainforest and eucalypt woodland (Chapman & Harrington 1997). In the absence of major disturbance (e.g. fire) rainforest colonisation of the understorey inhibits regeneration of Rose Gums (Tng *et al*. 2014). There are mapped patches of this 'moribund' (or successional) wet sclerophyll habitat (RE 7.11.14b) ~2 km east of Site 1 and several large relict Rose Gums survived some 200 m from Site 1 throughout the 1990s (N. Tucker, personal communication). Thus original habitats on metamorphic soil south of Lake Eacham may have included patches of wet sclerophyll occupied by Eastern Yellow Robins, the robin now persisting in suitable regrowth and planted eucalypts.

Seasonality and yearly differences between sites

Consistent with most birds in our surveys being resident rainforest species, bird abundance changed little through the year except at Site 3, where it was significantly elevated in the Dry Season and depressed in the Wet Season. Detection of birds at Site 3 in the Wet Season could have been hampered by the noise of the nearby waterfall. However, elevated Dry Season abundance at Site 3 indicates that this most complex and least disturbed forest, especially its moist creek gully, provides an important Dry Season resource for Lake Eacham birds. Even sedentary, territorial species may utilise those parts of their territories adjoining the creek more in the Dry Season than they do in the Wet. Further investigation of seasonal differences at Site 3 is therefore warranted. Overall, an understanding of both seasonal and year-to-year patterns in records will require detailed ecological studies of bird movements in relation to rainfall and food availability. One example is our study's finding about the seasonal patterns of the Australasian Figbird, which was virtually absent from all three sites in the Cool season, with a significant peak (at Site 2) in the Dry Season and a moderate presence in the Wet. Seasonal movements of this species on the Atherton Tablelands are not well understood (Nielsen 1996; Higgins *et al*. 2006). For example, as at Lake Eacham, figbirds were virtually absent from riparian vegetation in Atherton township in the Cool Season (ECS unpublished data 1997-2001), but in contrast with Lake Eacham, numbers in Atherton in the Wet Season were almost double those in the Dry.

Impacts of tourism on birds and sustainable use of the Park

The concentration of tourists at Lake Eacham has local historical origins but over time the Park has been developed as a high-volume visitor node, with protective works (e.g. hard surfacing of car parks and retaining as much canopy as possible) as recommended by Turton (2005) for minimising adverse impacts of tourism in the WTWHA. Impacts on avifauna of intense visitation in the Park were not evident in our study. Except for the clustering of Australian Brush-turkeys in the day-use area, where they scavenge at picnic sites, we observed no signs of habituation of birds to

people. Some bird species may avoid crossing gaps in tropical forest, including roads, whereas road kills can result from failed attempts to cross (Goosem 2007 and references therein). We found no data on avian mortality on Lake Eacham roads, but after our study speed bumps were installed and speed limits lowered, which would reduce any road mortality (Goosem 2004). The north-eastern road across Wright Creek was closed to traffic in 2020 and may remain closed, as safety of the 1939 bridge is in doubt (TRC 2022). In 2007, the road bisecting the day-use area was rerouted. It now directly abuts remnants and regrowth around the eastern edge of the clearing and the adjacent mown grass was converted to carpark. As a result, it is likely that terrestrial feeders such as Grey-headed Robin and Eastern Whipbird have since been deterred from using this edge, where they frequently foraged during our study, but the likely effects on other species (deterrence from using edge vegetation or increased risk from vehicle impact) are unknown.

Traffic noise potentially deters movements of – and communication among – rainforest birds (Arévalo & Newhard 2011). On the Kuranda Range (~7,000 vehicles per day), there was evidence of call moderation and significant edge avoidance by rainforest birds, potentially increasing predation risk and reducing breeding success (Dawe & Goosem 2008). In contrast, although noise penetrated 'deeply' (>200 m) into rainforest adjoining the Palmerston Highway, especially at canopy level (up to 2,201 vehicles per day, ~18% heavy vehicles: Armstrong 2009), birds apparently did not moderate their calls in response (Dawe 2004). Aside from detection issues (discussed above), and although we did not measure habitat features, we consider the evident differences in habitat between the three sites is a more likely explanation for the variation in their bird communities at the time of our study than the potential impacts of active disturbance from tourists and associated infrastructure. Increased development for tourism since our study may, however, have had an adverse impact (see below), but, even with high visitation rates, vehicular traffic at Lake Eacham and its associated disturbance is highly unlikely to reach that found along the Kuranda Range or Palmerston Highway.

Conservation implications and recommendations

It is concerning that even some of the most abundant bird species we recorded at Lake Eacham have apparently declined in intact mid-altitude rainforest in the Wet Tropics since our surveys concluded. These declines have mostly been attributed to climate change (Williams & de la Fuente 2021), with an increase in the frequency of hot days and evaporation rates (CSIRO and Bureau of Meteorology 2019). The additional effects from Severe Tropical Cyclone (STC) Yasi, the largest and most severe system to affect widespread areas of the Wet Tropics since 1918 (Bureau of Meteorology 2023b), cannot be discounted. Since our surveys, Lake Eacham was also impacted by STC Larry in 2006. In addition to these impacts, remnants such as the Lake Eacham rainforests may suffer subtle, ongoing changes caused by clearing and fragmentation (Laurance & Bierregaard 1997; Ewers & Didham 2006), and disturbance from intensive visitation and infrastructure works will inevitably continue.

The TNPV group disbanded in 2016 and we offer the full dataset (see Supplementary file) to give others the opportunity for comparative resurvey. We suggest for example, monthly surveys between July and June for one year. We completed our surveys just as two significant revegetation linkage projects began, aiming to connect rainforest at Lake Eacham with that at Lake Barrine and the Curtain Fig (Fig. 1). The two corridors are high-commitment projects in funds and human endeavour, but as yet it is unknown if Lake Eacham will become a donor or recipient site for rainforest birds in other remnants. Although the habitats of our survey sites were disturbed (in varying degrees), we believe that, given hyper-disturbance of the remnant overall, our data will provide a valuable resource for evaluating avifaunal change at Lake Eacham over time and the outcomes of the two corridor projects.

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Supplementary file

A supplementary Excel file accompanies this paper on its web-page. It contains ten worksheets:

- Appendix S1: Index to Appendices and Notes
- Appendix S2: Regional Ecosystems
- Appendix S3: Functional categories
- Appendix S4: Bird species
- Appendix S5: Survey data
- Appendix S6: Incidental records
- Appendix S7: Site comparisons
- Appendix S8: Yearly comparisons
- Appendix S9: Seasonal comparisons
- Appendix S10: Site-season comparisons

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