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Age and sex criteria for the hihi (*Notiomystis cincta*) with additional details on moult patterns

CHRIS SMITH*
Institute of Zoology, Zoological Society of London, Regents Park, NW1 4RY, London, United Kingdom, and Wildlife Department, Humboldt State University, 1 Harpst Street, Arcata, California, USA

LEILA K. WALKER**
Institute of Zoology, Zoological Society of London, Regents Park, NW1 4RY, London, and Department of Zoology, University of Cambridge, Downing Street, Cambridge, CB2 3EJ, United Kingdom

JOHN G. EWEN
Institute of Zoology, Zoological Society of London, Regents Park, NW1 4RY, London, United Kingdom

Abstract The hihi (*Notiomystis cincta*) is a small threatened passerine endemic to New Zealand, for which few methods are known for ageing and sexing wild unbanded individuals. We monitored hihi on Tiritiri Matangi Island over 3 years, studying moult and other sexing and ageing techniques. Juvenile hihi before their first partial moult can be sexed by the white bases of primary coverts on males, which appear brown in females. After juveniles undergo their first partial moult, they appear similar to adults; however juvenile males retain old feathers in their primary coverts, alulae, or sometimes greater coverts or inner primaries, while adults undergo a complete moult. These patterns can be difficult to see in juvenile females, but wear of juvenile tails is much greater than in adults at any given time of year, making ageing of females reliable. Moult in the outer primaries and secondaries in autumn also indicate adult birds. This information should help inform future translocations and attempts to monitor viability of wild populations. Finally, we also comment on alternative definitions for ageing criteria from Melville (2011), based not on suspected birth-dates, but on appearance of plumage in hand.

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Keywords hihi; stitchbird; *Notiomystis cincta;* moult; ageing; sexing

INTRODUCTION

Hihi, or stitchbirds, (*Notiomystis cincta*) are small passerine birds endemic to New Zealand that are currently listed as Nationally Threatened by New Zealand (Miskelly *et al.* 2008) and Vulnerable by the IUCN's Red List (IUCN 2014). Current populations are small and mostly restricted to predator-free offshore and mainland islands. Current management focuses on establishing additional populations through translocation and closely supporting these with ongoing management (*e.g.,* provisioning of nest sites and supplementary food; Ewen *et al.* 2013). Additionally, these populations are subject to variable levels of monitoring. An important facet

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*Correspondence: *cscjsmith805@gmail.com*
**Current address: RSPB Centre for Conservation Science, UK Headquarters, The Lodge, Sandy, Bedfordshire, SG19 2DL, United Kingdom

of monitoring in most hihi populations includes determining their age structure and sex ratio which is important for determining population viability. Sexing juvenile hihi and ageing hihi in their first year of life has proved difficult, especially in populations where nests are not accessible.

Plumage colour, moult extent, skull ossification, body measurements, and presence/absence of brood patches and cloacal protuberances are all typical ways to determine the age and sex of small passerines (Svensson 1992; Jenni & Winkler 1994; Pyle 1997) however, none of these techniques, except body measurements and plumage colour, have been developed for hihi (Higgins *et al.* 2001; Low 2006; Thorogood *et al.* 2009). Specifically, information regarding patterns of hihi moult are lacking and only represented by the examination of 8 museum specimens (Higgins *et al.* 2001).

Despite a paucity of information regarding age and sex criteria for the species, a number of earlier studies have provided several techniques to classify age and sex. For example, adult hihi can be easily sexed by plumage, as males have black hoods with white ear tufts and females are dull grey-brown (Higgins *et al.* 2001). However, recently fledged male and female juveniles appear similar to adult females, making the sexing of sub-adults difficult. Ageing young birds after their first partial moult is also problematic, as these birds look like adults of their corresponding sexes. Approximately 75% of nestlings at 21 days of age can be sexed using weight and tarsus length in a discriminant analysis function, although within single years as few as 46% of males may be accurately assigned (Thorogood *et al.* 2009). Bell and Bell (2012) suggest that juveniles can be sexed by the colour of lesser coverts, however, Thorogood *et al.* (2009) could only accurately assign sex to 72.9% of nestlings at 21 days old (58.2% of males and 88.1% of females) using this character. Low (2006) found that wing length for juvenile females and males (mean ± 95% CI: 88.1 ± 3.4 mm with n = 6 and 94.8 ± 1.9 mm with n = 14, respectively) showed no overlap with those of adult females and males (here presented as measurements for birds in their second basic plumage: female: 92.2 ± 1.2 mm with n = 7 and male 101.8 ± 1.3 mm with n = 14). However, more research is needed to verify this criterion because passerine wing chords across individuals of the same sex usually show variation on the order of several millimetres (Svennson 1992; Jenni & Winkler 1994; Pyle 2008), suggesting this pattern may be due to the small sample sizes reported in Low (2006).

Another challenge in ageing hihi by New Zealand's current standards (Melville 2011), is that ageing them requires knowledge of their hatch date. As noted by Melville (2011), the calendar-based system that much of Europe and North America uses designating birds as hatch-year, second-year, and so forth, is not useful in New Zealand where species can breed year round or across the December-January time period (Svensson 1992; Jenni & Winkler 1994; Pyle 1997; Howell *et al.* 2011; and see Wolfe *et al.* 2010 for further details). Melville (2011) states that his system "relates to year of life of the bird" and "requires knowledge of the likely hatch date". Typically however, researchers holding a bird do not have precise knowledge of its likely hatch date. For example, a hihi caught in November which was born the previous January, will look the same as a hihi born the previous October. However, because hihi breed from October to February, technically, these birds should have different ages (1Y vs. 2Y, respectively). Banders holding this bird would technically be unable to age it because its hatch date is ambiguous; this dilemma occurs over nearly 1/3 of the year for hihi because of their breeding season length. An alternative method for defining age classifications, commonly used in the neotropics where similar dilemmas occur, relies on ageing a bird by its plumage (Wolfe *et al.* 2010). This system has several advantages, namely: (1) it allows for accurate ageing year round because it is based on the start of moult, a criteria readily visible in hand, (2) it works for nearly all bird species, because age transitions are delimited by the yearly prebasic moult that most birds exhibit (including nearly all bird families in New Zealand and Australia; Howell *et al.* 2003, Miskelly *et al.* 2008), (3) it easily relates to the number of years a bird has bred because the prebasic moult is a consistent annual event within a species (Howell *et al.* 2003), and (4) it naturally works well for banders using moult limits, a common technique critical for ageing hihi and useful for ageing many other birds in New Zealand (Bell & Bell 2012; Higgins *et al.* 2001; Higgins & Peter 2002; Higgins *et al.* 2006). Therefore, because of the clarity of this system and the importance of moult limits for ageing hihi, we use terms from Melville (2011) with slightly altered age class definitions based on the start of a bird's moult.

In this paper, we describe the moult of hihi, and provide alternative and more accurate methods for ageing and sexing hihi juveniles and nestlings by detailing information on skull ossification, gapes, brood patches (BP's), and cloacal protuberances (CP's).

METHODS

Defining useful age classes and other definitions

Age categories used here closely follow the standard for New Zealand (Melville 2011), but definitions are slightly modified (Table 1). We also include parenthetical references to the Wolfe-Ryder-Pyle system of ageing birds (a system for

Table 1. Ageing terminology used by Melville (2011), Wolfe-Ryder-Pyle system abbreviations for banders outside of New Zealand (Wolfe *et al.* 2012), and modified definitions for age categories based around timing of a bird's moult.

Melville (2011) terminology	Wolf-Ryder-Pyle system abbreviation	Definitions
Pullus (or Nestling)	FPJ (First prejuvenal moult)	Bird still in the nest, moulting its first coat of plumaceous feathers
Juvenile	FCJ (First-cycle juvenile plumage)	Bird has recently fledged out of nest, but has not undergone any further moult
1Y	FPF (First preformative moult) FCF (First-cycle formative plumage)	Bird is either in the process (FPF) or finished (FCF) moulting its first partial moult after leaving the nest
2Y+ or adult	DPB (Definitive prebasic moult) DCB (Definitive prebasic plumage)	Bird has either started (DPB) or finished (DCB) its next complete moult, delineated from 1Y by the symmetrical moulting of its first primaries. In most passerines these birds appear like adults, and all further plumages look similar and are classified into this category.

ageing other tropical birds that refers to commonly understood moult cycles introduced in Pyle (2008)) to help banders outside New Zealand understand terminology (Wolfe *et al.* 2010; Table 1). We also use the following definitions: complete moult refers to a moult where all feathers, including primaries and secondaries are lost; partial moult refer to a moult where only some (usually body feathers and wing coverts, but not primaries or secondaries) are lost. Moult limits, or 2 different ages of feathers in a birds' wings caused by a partial moult, will also be referenced using definitions from Pyle (1997); in hihi, these indicate 1Y (FCF) birds.

"Nestling" refers to a bird still in a nest (undergoing its first complete moult), "juvenile"(FCJ) refers to a fledged bird before its first partial moult, and "1Y" (FPF or FCF) refers to a bird in its first partial moult (FPF) or after its completion (FCF), after which most birds resemble adults. Individuals switch to the next age class with the start of the next, complete, prebasic moult. This is typically defined by the symmetrical moulting of the first primary feather on each wing (Wolfe *et al* 2010). A notation of 2+ or adult (DCB) indicates birds are typically greater than one year old. Hihi (as in most passerines) appear identical after their second complete moult.

Sampling hihi

We captured and recorded moult in hihi on Tiritiri Matangi Island from January to March (n = 141) and September to October 2010 (n = 92; L. Walker), from February to April (n = 123) and September to October 2011(n = 30; L. Walker), and October 2012 to April 2013 (n = 86; C. Smith). Data outside the 2012/13 season were only used to confirm timing, sequence, and absence of moult. Of the 86 birds caught in 2012/13, 46 were males and 36 females, including 8 juveniles (FCJ), 30 1Y (FCF) birds and 48, 2+ (DCB) birds. All hihi on the island are of known age and sex due to banding of nestlings in nest boxes. Every nest on the island except 1 or 2 natural nests per year is known along with parental identity; therefore timing of first egg laying is known for nearly every bird, giving unique data on the timing of CP's and BP's.

Several techniques were used to investigate moult. Birds were caught at sugar-water feeders and scored for moult, including the presence/absence of moult, relative length of each individual moulting primary, secondary, and tail feather, and relative percent of body in moult. In 2012/13, a system for scoring feather wear was also used for the tail and outer 4 primaries (Table 2), in addition to reporting conditions of CP's, BP's, and moult limits. Visual observations of moult using binoculars were also used in April 2012 to assess general moult timing in juveniles, especially males. In 2012/13, nestlings at 21 days of age and older also had the colour of the bases of their primary coverts noted as either white or brown (Fig 2). These nestlings were subsequently genetically sexed using methods detailed in Brekke *et al.* (2010), and both results compared.

RESULTS

Hihi moult patterns

Juvenile (FCJ) hihi on Tiritiri Matangi emerge from nest boxes (around 4 weeks old) between late November and mid-February, and finish their first complete moult 1-2 weeks later. The next partial moult that is found only in juveniles (FPF), was

Table 2. Feather wear scores used for primary and tail feathers (Ralph *et al.* 1993).

Score	Description
0	No wear; feather edges perfect with entire edge light colored, including tip
1	Slight wear; feather edges slightly worn with no fraying or nicks
2	Light wear; feathers definitely worn, but with little fraying or nicks
3	Moderate wear; considerable wear with definite fraying; nicks and chips obvious
4	Heavy wear; feathers very heavily worn and frayed; tips often worn completely away 1-2 mm
5	Excessive wear; feathers extremely ragged and worn; shafts usually exposed beyond vane, with all tips usually worn completely away

first seen in early February, with the earliest birds finishing body moult around 1 April, and most finishing by late April (*n* = 100 in 2011, *n* = 40 visuals in 2012; Fig. 1). During this time, males moult in black feathers on their head, white ear tufts, and yellow feathers on their lesser coverts. All 4 juvenile males with photos after mid-February showed either moulted primary or greater coverts, alula, or carpal covert at this time, suggesting moult limits are created at this time. One juvenile was replacing tail feathers as well. Moult patterns and wear seen in October 2012 suggested on rare occasion a few primaries are also moulted around this time (*n* = 3 of 24 1Y (FCF) males). Because birds were not monitored May-August, the possibility that there is another inserted moult in which similar feathers may be replaced could not be ruled out (although this seems unlikely given no birds were ever found with 3 ages of feathers).

Hihi do not appear to exhibit an alternate moult (an inserted, often partial moult found in many passerines; Pyle 1997) and all subsequent moults appear complete, as no adults (DCB) were ever caught with 2 ages of feathers. Additionally, no 1Y (FCF) wings showed 3 generations of feathers.

The second and subsequent complete moults follow a typical pattern for passerines, starting with P1, and progressing outwards towards P10, with secondaries starting soon after primaries, from S1 to S6 (towards the body); greater and primary coverts were replaced similar to their respective flight feather tracts, and tails were generally replaced symmetrically starting from T1 (centre) to T6 (outwards). Complete moults in adults start early in January with the primaries, primary and greater coverts, and occasionally tail, with earliest birds finishing primary moult in mid-March (Fig. 1). Tails are often the last flight feathers replaced.

Ageing and sexing juvenile hihi

1Y (FCF) birds, after completing their partial moult by late April, appear similar to adults except for the presence of moult limits. All 1Y (FCP) males caught from October-January (*n* = 24) showed obvious moult limits, usually with dull brown feathers next to dark black feathers among the alular feathers, carpal coverts, and sometimes primary coverts (less often within the primaries and greater coverts; Fig. 2). Juvenile male alular feathers and primary coverts are dark brown with a yellow edging, whereas 1Y (FCF) and adult alular feathers and primary coverts are black (alular feathers with yellow edging, primary coverts usually without). In 1Y females, the yellow edging to the first 3 greater coverts is often wide (~3 mm), whereas it is narrower in adult females (~1 mm wide); however this should be used with caution, as this character is difficult to see and wear decreases the width of the edging. Female moult limits were more difficult to discern, with 50% not showing recognisable moult limits (usually found among the alula or carpal coverts if present, with dark fresh feathers next to brown older feathers).

We found the majority of females and males can also be accurately aged by tail and primary wear. In general, juveniles (FCJ) grow all their feathers simultaneously, likely under nutrient-stressed conditions in the nest, while adults (DCB) grow only a few feathers at once from better nutrient reserves, creating higher quality feathers (Pyle 1997). Tails on 1Y (FCF) birds in April showed worn feathers (mean wear score: 3, range = 2-3), whereas adults showed fresh tails at this time (mean wear score: 1, range = 1). Occasionally, 1Y (FCP) birds replaced a few tail feathers; however, none of the 30 1Y (FCF) birds caught had replaced their entire tails (Fig. 2). By October, 1Y (FCF) birds show heavily worn tails (mean wear score: 5), whereas adults (DCB) are fresher (mean wear score: 3, range = 3-4; Fig. 3). Tail wear for adults (DCB) in December is similar to October, but more extreme in 1Y (FCF) birds. By early January, even adult (DCB) tails appear worn, but are still possible to tell from 1Y's (FCF). The same pattern is true of the outer 4 primaries (though they appear less consistent). By November, adults (DCB) may have

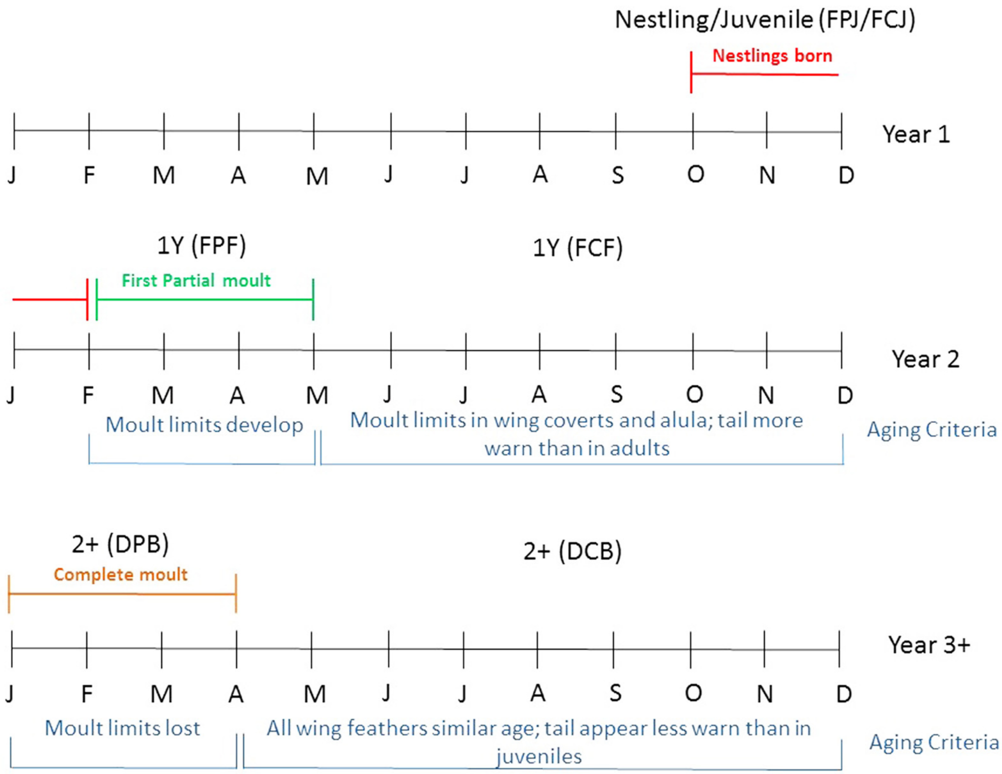

Fig. 1. Timing of important events in the hihi moult cycle, along with their corresponding age and ageing criteria. Birds that enter the 2Y+ (DCB) category look identical in successive years. Abbreviations are from the Wolfe-Ryder-Pyle system for ageing birds (for non-New Zealand Banders), including FPJ (First prejuvenile moult), FCJ (First-cycle juvenile plumage), FPF (First preformative moult), FCF (First-cycle formative plumage), DPB (Definitive prebasic moult), DCB (Definitive-cycle basic plumage). See Table 1 for further definitions.

1-4 mm tips broken off primaries, but most 1Y (FCF) show >5 mm tips broken or just the rachis remaining on outer primaries by this time, with extensive fraying to lower parts of the vane.

From January-April, 1Y females may be difficult to tell from adult females. However, 99% of adult birds were moulting primaries and secondaries between February 1 and March 31. None of the moulting juveniles (FCP) caught at this time showed symmetric moult of primaries or secondaries (however, 3/24 1Y (FCF) males caught in October showed moult limits in inner 1-3 primaries, suggesting a few birds may moult a few inner primaries, perhaps during February-March). Any birds symmetrically moulting outer primaries or secondaries around this time can safely be aged adult (DCB).

Sexing hihi nestlings

A total of 93% (76 of 82) of nestlings were correctly sexed by the colour of the base of primary coverts, with males having entirely white or white-edged bases of these feathers, while female primary covert bases were brown (Fig. 2). Of the 6 misidentified nestlings, 3 were on the first day of monitoring (possibly due to inexperience with the technique), and the remaining 3 misidentified within the next 2 days. Discounting the first day of monitoring as training, 96% of nestlings were sexed correctly. However, one bird was caught 3 months later with brown primary covert bases and was later genetically sexed as a male, suggesting some non-observer error associated with this technique. It is worth noting that several nestlings did not have the bases of primary coverts emerged at day 21, suggesting that checking nest boxes at a slightly later age may be necessary for this technique.

Skulling and gapes

In many passerines, skulling is the most accurate technique to determine a bird's age (Pyle 1997; Jenni & Winkler 1994); however, a hihi tongue and its musculature wrap around the top of its head (like woodpeckers; Picidae), making skulling very

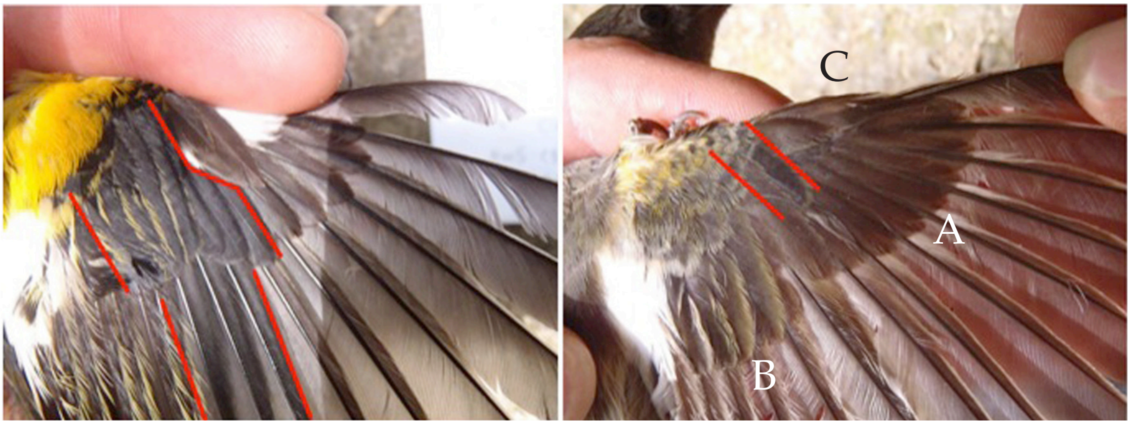

Fig. 2. Right wing of hihi, with 1Y (FCF) male on left and female on right. Both taken in November. Note white bases to primary coverts in males and brown bases in females. The male shows a typical moult limit between brown alula and outer primary coverts and black primary coverts, while the female shows an unusual moult limit in the carpal covert. An unusual molt limit within the male's primaries is visible as well. Feathers between lines have been recently replaced. In the photo on the right, A is below the primary coverts, B is below the greater coverts, C is above the alulae, and the lines also demark the carpal covert.

Fig. 3. Tail of a 1Y (FCF) hihi in December, showing mostly replaced fresher tail feathers and 2 central ragged retained juvenile tail feathers. The replaced tail feathers are of similar wear to adults at this time of year.

difficult, even though young are born with un-pneumaticised skulls that appear to close over time. Fleshy gape flanges (henceforth gapes) appear to last on birds for about 1 month, and caution should be taken, as corners of adult mouths are naturally yellow.

Cloacal protuberances (CP's) and brood patches (BP's)

Hihi females develop brood patches in the typical fashion, first losing breast feathers, and then developing puffy, vascularised skin on their belly and sternal area. However, they can show atypical patterns with brood patch development. For example, one female had a brood patch 41 days before she laid eggs, and 2 others developed a brood patch 10 days before eggs were laid; 2 females caught with brood patches were also never recorded as nesting, however it is possible these were from the few unmonitored natural nests that occur each year. All other brood patches correlated with females that were within a day of egg laying, incubating, or with nestlings. Of 5 females caught post-fledging, all showed no puffiness and only wrinkles on the outer sternum. There was also an island-wide association between our first detection of brood patches (October 31 in the 2012/2013 season) and timing of the first large number of females to start nesting; similarly, the last detection of puffy BP's was associated with the last few female renesting attempts.

Hihi CP's are large in relation to their body size, with some up to 1 cm in diameter (Castro *et al.* 1996). Like BP's in females, CP's on males appeared close to the start of breeding season and disappeared around the time the last of the nestlings on the island were fledging. Several males (n = 3) with no social partners developed CP's. Two males retained CP's >40 days after they fledged nestlings, suggesting the shift in hormones that causes the loss of CP's may be driven by the breeding season ending, not by the end of individual nesting events. The first documented males without CP's (post-breeding season) corresponded closely to the first appearance of moult in adult males, while the only females not moulting in February (n = 5) were the only birds with full brood patches, suggesting hormonal changes at the end of their final breeding attempt may trigger moult.

DISCUSSION

We found that hihi do not appear to exhibit an alternate moult, with 1Y's (FCF) appearing to exhibit a partial moult that creates noticeable moult limits in males, especially within wing coverts. Moult limits in females are much more cryptic, but wear of tail and outer primaries allow for ageing most birds. The presence of symmetric moult in outer wing feathers also appears useful in ageing hihi during February-March. Nestlings are reliably sexed by the bases of their primary coverts (after bases have emerged) which appear white in males and brown in females. Skulling appears very difficult to use for ageing hihi because of tongue musculature. Finally, all males appear to develop CP's, while oddly some females may develop puffy BP's before breeding; the appearance of the first CP's and BP's closely matches the start of nesting season. Together with cautionary use of wing measurements suggested by Low (2006), we suggest moult limits, tail wear, and (during moult) growing outer primaries and secondaries are the most accurate ways to separate 1Y (FCF) and adult (DCB) hihi in hand.

Many of our observations align with those found in previous literature. Higgins *et al.* (2001) similarly found that 1Y birds retain juvenal tail feathers, and exhibit more wear than adults at similar times of year. They also suggest several colour differences between 1Y (FCF) and adult (DCB) male feathers, which were wholly supported by our data, including juvenile (FCF) male coverts and alulae appearing brown, while 1Y (FCF) and adult (DCB) feathers are black. Higgins *et al.* (2001) also mentions adult (DCB) females having brown bases of primary coverts, whereas males have white bases; however, they do not mention this difference for juveniles. Some characteristics presented in Higgins *et al.* (2001), such as the white bases of primary coverts in juvenile males being smaller than adult males, and the yellow edging on preformative female feathers being broader and duller than adult females, we found extremely difficult to see in hand and potentially not reliable because of substantial individual variation.

We also found ageing codes based on the hihi's plumage in hand to be extremely helpful. Although it may seem trivial to define bird age classes by the start of their moult, instead of their estimated hatch date, we believe it is an important distinction. It is unclear from Melville's system when a bird exactly transitions from age classes (*e.g.,* from 1Y to adult) because actual birth dates are impossible to know with enough accuracy to use to determine ages during the breeding season. Instead, we found that other researchers naturally assigned birds to age classes based on their plumage without realising it. The start of adult hihi complete moult also corresponds to the end of its breeding season (similar to most other passerines in New Zealand), making a plumage-based ageing system simple to relate to the number of seasons a bird has bred (Bell & Bell 2012; Higgins *et al.* 2001; Higgins & Peter 2002; Higgins *et al.* 2006). We suggest bird banders in New Zealand might benefit from this subtle, but important change in definitions of Melville's age classes.

Our study is the first to thoroughly address ageing and sexing hihi. Determining the size, age and sex structure of hihi populations with unbanded individuals is becoming increasingly difficult and important to managers as more translocations occur and existing populations increase in size. Accurate ageing and sexing techniques used for nestlings and juveniles can provide accurate information on sex ratios (which are sometimes skewed in hihi; Ewen *et al.* 2011) and help determine the sex of individuals for translocations without the use of genetic tests. Captures by feeders or mist nets at times when adults are undergoing wing moult and juveniles are not (around February-March) may also provide critical information on recruitment from the previous breeding season, helping managers assess population growth rates. With some experience, managers trapping unbanded hihi at other times of year can also now accurately age birds as either adults (DCB) or 1Y (FCF) birds using moult limits and tail wear.

Understanding moult patterns of island birds, such as hihi, is additionally important in helping further our understanding of the evolution of moult. Most of our current knowledge of moult patterns comes from landbirds on large continental landmasses (Svensson 1992; Jenni & Winkler 1994; Pyle 1997, 2008). Island bird populations are often characterised by exhibiting unique adaptations such as flightlessness and poor dispersal (Losos & Ricklefs 2009); these same adaptations may manifest in unique moult patterns that provide researchers with the tools to examine life history variation in an evolutionary framework.

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