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SEX AND AGE IDENTIFICATION OF PALILA

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Abstract.—Methods to sex and age Palila (*Loxioides bailleui*), an endangered Hawaiian finch restricted to subalpine woodlands on Hawai'i, were identified on the basis of measurements and plumage characteristics of 17 museum specimens and 96 known-age, live Palila. Palila undergo a single annual molt during September–December following the breeding season. Presence of a complete or partial wingbar distinguishes hatch-year and second-year Palila from after-second-year birds. Adult male Palila are distinguished from females by a distinct napeline and <30% gray feathers intermixed with yellow feathers on the head. The black or gray feathers of the lores and chin of males are darker than those on the back, whereas the lores and chin of females are lighter or of the same shade as back feathers.

IDENTIFICACIÓN DE LA EDAD Y EL SEXO EN *LOXIOIDES BAILLEUI*

Sinopsis.—Se desarrolló un método para identificar la edad y el sexo de individuos de Palila (*Loxioides bailleui*), el cual es una especie en peligro de extinción. Esto se hizo utilizando medidas y características del plumaje de 17 especímenes de museo y 96 individuos de Palila. El ave muda una vez al año entre septiembre-diciembre, luego que pasa la época de reproducción. La presencia parcial o total de una barra en el ala diferencia a los individuos de primer y segundo año de otros de mayor edad. Los machos adultos de Palila se diferencian de las hembras por una línea peculiar en la nuca y por tener un 30% menor de plumas con color entremezclado de gris y amarillo en la cabeza. El color negro o gris de las plumas de los lores y la barbilla en los machos es más oscuro, que la misma coloración en la espalda, mientras que los lores y la barbilla de las hembras son más claros o de la misma tonalidad que las plumas de la espalda.

The Palila (*Loxioides bailleui*) is an endangered Hawaiian finch (Fringillidae: Subfamily Drepanidinae) restricted to native forests above 2000 m on Mauna Kea, Island of Hawai'i. It was formerly more widespread on Hawai'i (Perkins 1903) and in the archipelago (Olson and James 1982, Scott et al. 1986); estimated population size was 1371 Palila in 1992, and has not exceeded 6500 birds during the past 13 yr (U.S. Fish and Wildlife Service, unpubl. data). Immature seeds of the mamane tree (*Sophora chrysophylla*) are the staple food of Palila, which also use mamane extensively for nesting and shelter. Browsing by feral ungulates was thought to have been a major cause of Palila decline (Scott et al. 1984).

The U.S. Fish and Wildlife Service (FWS) conducted surveys of the Palila population in the mid-1970s (Scott et al. 1984), and, in 1987, began intensive studies of factors limiting Palila population growth. An impor-

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tant requirement for studying demography of Palila is to identify the age and sex of individuals. Our objective was to develop methods for sexing and aging Palila in the field, and to provide the first description of plumage and molting patterns for this species.

METHODS

Between June 1987 and January 1992, we established and operated banding stations near Pu'u La'au (19°50'N, 155°35'W) and Kanakaleonui (19°52'N, 155°23'W) on the western and eastern slopes of Mauna Kea volcano on the Island of Hawai'i. Palila were captured as nestlings during the breeding season (n = 172) or in mist nets (n = 646); 183 Palila were captured more than once in mist nets. Each Palila was photographed, weighed in a cloth bag with a 100-g Pesola scale, and banded with a metal FWS and a unique combination of three colored plastic bands. Wing chord (WING), from the bend to the tip of the longest primary of the unflattened wing, was measured to the nearest millimeter with a plastic rule. Wing tip was measured from the tip of the longest primary to the tip of the longest secondary of the folded wing with a plastic rule. Exposed culmen and tarso-metatarsus lengths were measured to the nearest 0.1 mm with dial calipers (Pyle et al. 1987). Tail length was measured to the nearest millimeter by inserting a plastic rule between the two central rectrices and pressing it firmly against the point of insertion of the feathers.

Plumage characteristics, including any evidence of molt, were recorded in detail for each Palila, and birds were photographed for later reference. We noted the presence or absence of wingbars on the middle or greater coverts, and recorded any missing or growing flight feathers, coverts, tail or body feathers. In describing molt patterns, we classified primaries, secondaries and tertials as flight feathers and greater and middle coverts as coverts. Lesser coverts and upper- and under-tail coverts were classified as body feathers. Each Palila was assigned a napeline code (NAPELINE) of 1–6 by presence or absence of a distinct line separating the yellow feathers on the head and neck from the gray feathers on the back, and the amount of gray feathers in the nape area (Fig. 1). Feathers of the lores and chin were categorized as (1) lighter than back feathers, (2) same shade as back feathers or (3) darker than back feathers. The gray of the back feathers was similar for all birds. Upper and lower bill color were categorized as (1) all dark, (2) dark with a light tip, (3) dark with a yellow tip or (4) mostly yellow. An index of fat accumulation in the furcular region was assigned as (0) no fat in furculum; (1) trace of fat along sides of furculum; (2) furculum 20–40% filled with fat, mostly along edges; (3) furculum filled with fat with some covering clavicles, but area is not bulging; and (4) furculum bulging with fat, with fat covering clavicles.

Plumage coloration was described by one observer from specimens at B. P. Bishop Museum in Honolulu, Hawai'i (ASY male: #3549 and #178301; ASY female: #3550 and #178300; HY mummy: #177087).

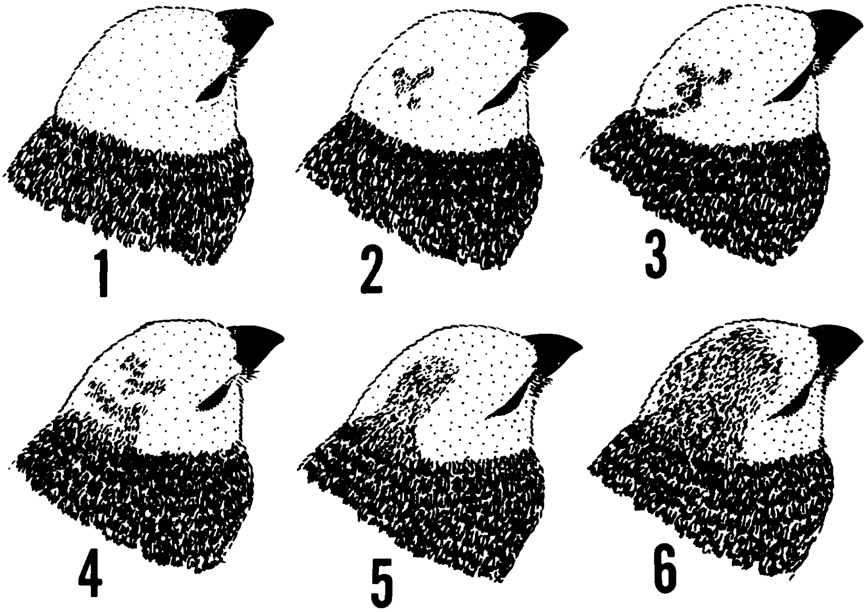

FIGURE 1. Codes used to classify appearance of napeline. Males (NAPELINE = 1–3) had a distinct napeline with <30% gray feathers intermixed with yellow head feathers. Females (4–6) had an indistinct napeline.

Leg, bill, and eye coloration were described from live birds or photographs of live birds in the hand. We include Munsell notations (Hue Value/Chroma) to describe colors of specimens (Munsell Color 1977).

Seventeen museum specimens were measured and inspected by one observer using the same methods as for wild birds, except that weight and fat measurements were excluded. Data for museum specimens were analyzed separately from those for live Palila because of possible differences caused by shrinkage and fading.

Ages of birds were based on the calendar year as used by the FWS Bird Banding Laboratory and classified as Local (L, still in nest), Hatch Year (HY), Second Year (SY), After Second Year (ASY), After Hatch Year (AHY) and Unknown (U). Palila were assigned a preliminary age and sex at the time of capture by plumage characteristics and presence or absence of a brood patch or enlarged cloacal protuberance (Pyle et al. 1987). We randomly selected and analyzed only one observation for Palila captured more than once while in the same age category to avoid problems with pseudo-replication.

Criteria for aging Palila were identified from 96 known-age Palila initially banded as L (n = 21), HY (n = 18) or SY (n = 57) birds that were recaptured in subsequent years. We noted from multiple recaptures of birds banded as nestlings that Palila lost their wingbars during the second prebasic molt. Consequently, Palila initially captured as HY birds were considered known-age if they were captured the following year and still had a wingbar, or two years later with ASY plumage. Palila that were first captured as SY birds were considered known-age if they were captured the following year with ASY plumage. We also classified SY birds as known-age if they were captured between January and April with worn feathers and a wingbar since >90% of Palila fledge after April.

Stepwise logistic regression (Press and Wilson 1978, Schlinger and Adler 1990) was used to identify the combination of morphometric and plumage variables that best discriminated between sex and age classes. When the dependent variable (i.e., sex or age class) is coded as a 0 or 1, the probability of a bird belonging to a sex or age class is

$$P = 1/(1 + e^{-L_x}),$$

where L_x is the logistic function. We coded males as 0 in analyses for sexing Palila. To discriminate between two age classes, we coded the younger age class as 0. We also compared means with separate two-tailed *t*-tests. Alpha values of $P \leq 0.05$ were considered statistically significant.

RESULTS

Description of plumages.—Adult Palila have a yellow head and breast, are gray dorsally and white ventrally, and have a greenish wing and tail. The head and upper breast of males are yellow (4Y 8.0/10.0), whereas females have a greenish-yellow head (5Y 7.0/10.0) and grayish-yellow forehead and superciliary (5Y 4.5/6.0). The head and upper breast of both sexes of HY birds are dull yellow-green (6Y 3.5/5.0). After the first prebasic molt, both sexes assume a head coloration approaching that of adult plumage. In males, yellow (or yellow-green in HY males) coloration extends down the back of the head and ends abruptly in a distinct napeline that contrasts with the gray (N 4.0/) back. Some SY males show a small amount of gray feathering on the nape. The indistinct napeline found in all age classes of females results from slight (>30%) to extensive (>90%) amounts of gray (N 4.0/) intermixed with yellow on the nape. Occasionally, gray extends up the back of the head, sometimes as far as the crown, or the crown alone may have a patch of gray. After the first prebasic molt, crowns of females are streaked with gray, whereas males never show streaking on the head. Head streaking results from feathers that are yellow at the margin and dark gray (N 3.0/) along the shaft. Lores are black (N 2.0/ to N 3.0/) in adult males and gray (N 4.0/) in immature males and females. The chin is gray (N 6.0/) in males and pale gray (N 7.0/) in females.

Body coloration is similar in both sexes and all age classes. The back is gray (N 4.0/) and the rump is light olive gray (5 Y 6.0/1.0). The flight and tail feathers are also gray but are edged with green (5 Y 4.5/6.0). The belly is white with gray shading on the flanks.

Hatch-year Palila have double wingbars formed by pale green tips (7.5 Y 7.0/4.0) on the greater and middle coverts until the first prebasic molt.

Some or all of the pale-tipped greater wing coverts are retained through the first prebasic molt, and a single complete or partial wingbar persists until the second prebasic molt.

In all Palila, the leg is black and iris is dark brown. The bill of nestlings is dull yellow; the yellow tip eventually fades to white in fledglings and young HY birds. The bill is usually entirely black after the first prebasic molt.

Timing of molt.—Soon after fledging, HY Palila initiate an incomplete first prebasic molt that includes all body and tail feathers. As a result of the extended Palila breeding season (March–September), molting birds were captured during all months until the summer of their second year (Fig. 2). All HY birds captured in May and June (n = 5) and 85% of HY and SY birds captured from July through May of the following year (n = 182) were molting body feathers. Second-year Palila retained some juvenal coverts until early fall (see Age identification). Juvenal flight feathers were also retained until the second prebasic molt; only 4 of 33 HY Palila captured in September and November had flight feathers in sheath.

The second prebasic molt during September–December was a complete one. During October–December, 33% (n = 9), 17% (n = 6), 100% (n = 11), and 14% (n = 7) of SY Palila were molting flight feathers, tail feathers, body feathers and coverts, respectively. Sample sizes were small because most SY Palila first captured in the fall were aged AHY (see Age identification).

Palila, like other drepanidines (Amadon 1950, Baldwin 1953), do not undergo a prealternate molt. The third and subsequent prebasic molts are complete (see also Amadon 1950, Baldwin 1953). With few exceptions, flight feathers and coverts are molted during September–December, whereas tail and body feathers in sheath were found during all months (Fig. 2).

Molting and breeding may occur simultaneously for some Palila, as Payne (1969) and Foster (1975) found for other tropical species. We captured 11 breeding females and nine breeding males molting body, flight or tail feathers. Van Riper (1980) also found molting Palila during the breeding season at Pu'u La'au.

Age identification.—The presence of a complete or partial wingbar on the middle or greater coverts was the best characteristic for separating HY and SY Palila from ASY birds. Palila first captured in November or December, however, were aged as AHY birds because SY Palila lost their wingbar during the molt in September–December. Wingbars were present on 88 of 93 HY and SY Palila; all 19 known-age ASY Palila lacked a wingbar. Of four SY birds lacking a wingbar, three were captured in November after they had molted their coverts.

The logistic function for separating HY and SY birds required four variables (upper bill color, fat index, bill length and wing chord) and identified the correct age for only 40 of 59 (68%) Palila from an independent data set. The most useful characteristic for separating HY and SY birds was upper bill color. Dark bill tips were recorded for 59 of 67

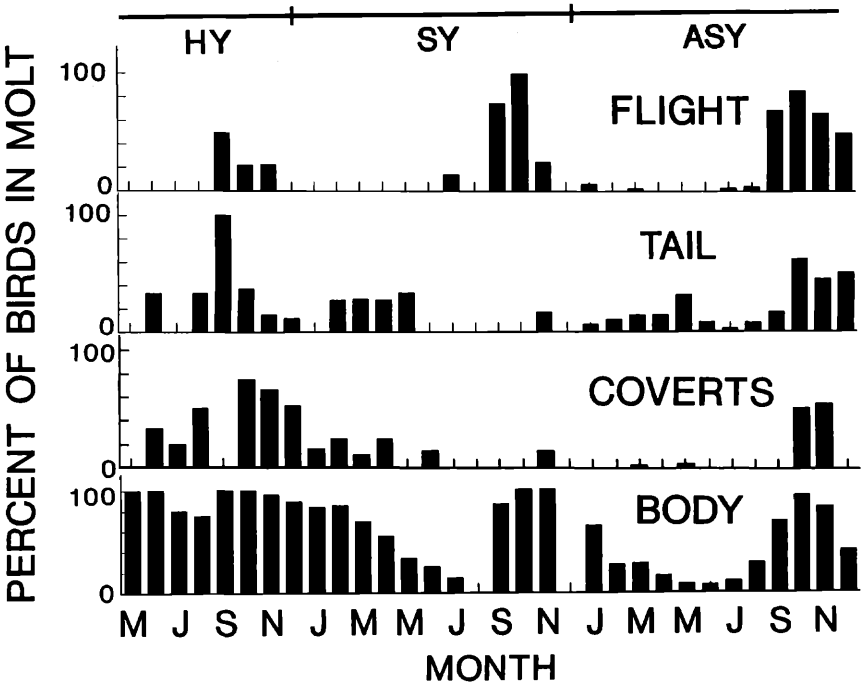

FIGURE 2. Percent of Palila captured each month with molting feathers. Flight feathers included primaries, secondaries and tertials. Greater and middle coverts were classified as coverts, whereas lesser coverts and upper- and under-tail coverts were classified as body feathers.

SY birds (88%); the remaining eight birds had a light-tipped bill. In contrast, only nine of 25 (36%) HY birds had dark bill tips; 14 had light-tipped bills, and two others had completely yellow or yellow-tipped bills.

Presence or absence of a wingbar was the only variable to enter a logistic function for separating SY and ASY birds. Tail lengths of ASY Palila were greater than those for SY Palila ($t = 2.61$, $P = 0.011$; Table 1). Sixty-four of 69 SY Palila had tail lengths exceeding the minimum tail length for ASY birds (59 mm), however, and tail length by itself was of little value in discriminating between these two age classes.

Sex identification.—Sample sizes of HY birds of known sex were too small (four males and two females) to identify criteria for sexing HY Palila. For SY Palila, only NAPELINE was included in the logistic function ($\chi^2 = 10.02$, $P = 0.002$):

$$L_x = 1.421 \cdot \text{NAPELINE} - 5.754.$$

This function correctly classified 16 of 17 (94%) SY Palila of known sex. In separate t-tests, NAPELINE was the only variable that differed between sexes ($t = 3.89$, $P = 0.001$; Table 1).

NAPELINE and WING entered the following logistic function that correctly classified all 20 ASY birds by sex ($\chi^2 = 26.46$, $P = 0.001$):

TABLE 1. Measurements of Palila of known sex and age. See text for explanation of codes for napeline, fat, bill color and lores.

	Hatch year						Second year						After second year					
	Males			Females			Males			Females			Males			Females		
Measurement	*n*	Mean	SE	*n*	Mean	SE	*n*	Mean	SE	*n*	Mean	SE	*n*	Mean	SE	*n*	Mean	SE
Weight (g)	4	38.00	0.41	2	35.50	0.50	7	37.64	0.87	12	36.67	0.55	10	37.15	0.99	12	38.17	0.91
Wing (mm)	5	87.8	1.02	2	85.5	0.50	7	87.4	0.97	13	87.2	0.95	11	89.0	0.60	12	86.9	0.62
Tail (mm)	5	61.6	1.03	2	60.0	0.00	7	60.7	3.18	13	60.2	0.65	10	64.7	0.75	12	63.4	0.61
Bill (mm)	4	12.5	0.12	2	13.1	0.60	7	12.9	0.12	13	12.5	0.15	11	13.2	0.18	12	12.6	0.12
Tarsus (mm)	4	25.4	0.45	2	25.4	0.60	7	25.9	0.42	13	25.3	0.46	11	25.2	0.25	12	25.1	0.15
Napeline	4	3.75	0.48	2	4.50	1.50	7	3.14	0.34	10	5.30	0.40	9	1.22	0.15	12	5.33	0.33
Fat index	2	2.50	0.50	0	—	—	6	1.50	0.22	10	2.10	0.23	10	2.20	0.25	12	1.83	0.17
Bill color	5	1.60	0.24	2	2.00	0.00	8	1.00	0.00	12	1.08	0.08	9	1.00	0.00	12	1.00	0.00
Lores	3	1.67	0.67	2	1.00	0.00	5	2.20	0.20	7	2.00	0.22	10	2.70	0.21	11	2.00	0.00

$$L_x = 4.795 \cdot \text{NAPELINE} + 2.055 \cdot \text{WING} - 193.304.$$

We tested this function with independent data for 48 Palila with either a brood patch or cloacal protuberance that we aged as ASY by plumage characteristics. The function correctly classified 44 of 49 Palila (92%) by sex using only NAPELINE and WING. In separate *t*-tests, male ASY Palila had longer wings ($t = 2.40$, $P = 0.026$) and bills ($t = 2.89$, $P = 0.009$) than females, as well as lower NAPELINE values ($t = 11.28$, $P < 0.001$) and darker lores ($t = 3.45$, $P = 0.003$; Table 1).

A logistic function that included only NAPELINE correctly classified 100% of adult Palila museum specimens ($n = 16$; $\chi^2 = 21.67$, $P = 0.001$):

$$L_x = 4.108 \cdot \text{NAPELINE} - 10.293.$$

We excluded one specimen (BPM #3542) from our analysis because we believed it was sexed incorrectly: it was identified as an adult male on the museum tag, but had plumage characteristics of an ASY female (e.g., indistinct napeline with >70% gray feathers in nape area, light gray lores and chin).

NAPELINE values were compared for 14 females and 12 males that were initially captured as HY or SY birds and recaptured in one or more subsequent years. Twelve of the 14 females had napeline values of 5 or 6 (Fig. 1) when first captured, and had the same napeline value in a subsequent age class. Two HY females that were assigned napeline values of 3 were subsequently assigned values of 5 and 6, respectively, when recaptured 1 and 2 yr later. Eleven of the 12 males replaced gray feathers on the head with yellow feathers and developed a more distinct napeline with age; the remaining male was assigned a napeline value of 3 as both an HY and SY bird.

DISCUSSION

Freed et al. (1987:198) identified the Palila as sexually "monochromatic but males brighter," in comparison with other related genera (e.g., *Telespiza, Rhodacanthis*), which they characterized as sexually dichromatic. Although plumage differences between sexes of Palila are relatively subtle, females can be distinguished from males: the head color of females is more greenish, less yellow; the yellow is obscured by patches of gray on the back of the head and neck; and the lores are muted gray rather than contrasting black. Bright coloration of the head and lores of Palila may serve in social signalling since the body plumage is otherwise cryptic (Butcher and Rowher 1989).

The duller coloration of females may serve to reduce the number of aggressive encounters with males. Females also show more variability in head color than males (as measured by napeline scores), and differences in head color could also reduce predation on nesting females. Females sitting on their cup nests with only their dorsal surface exposed have the back of the head and neck obscured by gray. This crypticity supports the observation that in species preyed upon by birds, in this case Palila preyed upon by Short-eared Owls (*Asio flammeus*) and Hawaiian Hawks (*Buteo* *solitarius*), females show greater variability in dorsal color than males (Stamps and Gon 1983). Whether this variability derives from differential predation on nesting female Palila, sexual selection on males, or both, is undetermined.

Both sexes of Palila undergo delayed plumage maturation (DPM), as do at least two other Hawaiian finches, the Laysan Finch (*Telespiza cantans*) and Common 'Amakihi (*Hemignathus virens*; Banks and Laybourne 1977; van Riper 1979). After fledging during summer, HY Palila molt in the fall from a distinctive juvenal plumage to a first prebasic plumage that resembles adult plumage apart from retention of some or all barred wing coverts. Gray feathers on the head and nape of males are replaced with yellow feathers during the first and second prebasic molts, whereas in females the proportion of gray feathers on the head and nape changes little between the first prebasic and subsequent plumages. Both sexes attain adult plumage in their second prebasic molt.

Male Palila defend only their female and vicinity around the nest, yet forage widely in undefended areas (Fancy et al. 1993, van Riper 1980). By signalling subordinance through DPM, HY and SY males may experience fewer aggressive encounters with adult males and increase their access to better resources (Lyon and Montgomerie 1986). DPM in female Palila is less pronounced than in males; it is probably of less importance in status signalling because, with a sex ratio favoring males, females probably face minimal competition for mates, and in fact many nest as SY birds (U.S. Fish and Wildlife Service, unpubl. data). In contrast, we have never recorded breeding by SY males.

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APPENDIX A

KEY FOR SEXING AND AGING PALILA

1A Distinct napeline. Feathers on upper neck and head bright yellow or dingy yellow, with <30% gray feathers intermixed. Lores darker than or same shade of gray as back feathers .... Male (see 2)
1B Indistinct napeline. Feathers on upper neck mostly dingy yellow or gray, with ≥30% gray feathers intermixed. Lores lighter than or same shade of gray as back feathers .... Female (see 2)
1C Characters not as above .... (see 2)
 2A No wingbars .... see 7
 2B Wingbars complete on middle or greater coverts .... see 3
 2C Wingbars incomplete on middle or greater coverts. .... see 5
3A Bill mostly yellow .... HY
3B Bill with light tip .... see 4
3C Bill all dark .... see 5
 4A January–April .... SY
 4B May–December .... HY
5A January–September .... SY
5B October–December .... see 6
 6A Flight feathers new to slightly worn; no molt evident .... HY
 6B Flight feathers old and worn; molt evident .... SY
7A January–September .... ASY
7B October–December .... see 8
 8A Flight feathers new .... AHY
 8B Flight feathers old and worn .... ASY