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Fea he i e a al i di c i i a e age-cla e f We e , Lea , a d Se i al a ed a d i e he age e h d a e eliable

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juveniles cuales fueron crecidas en latitudes altas en el a˜

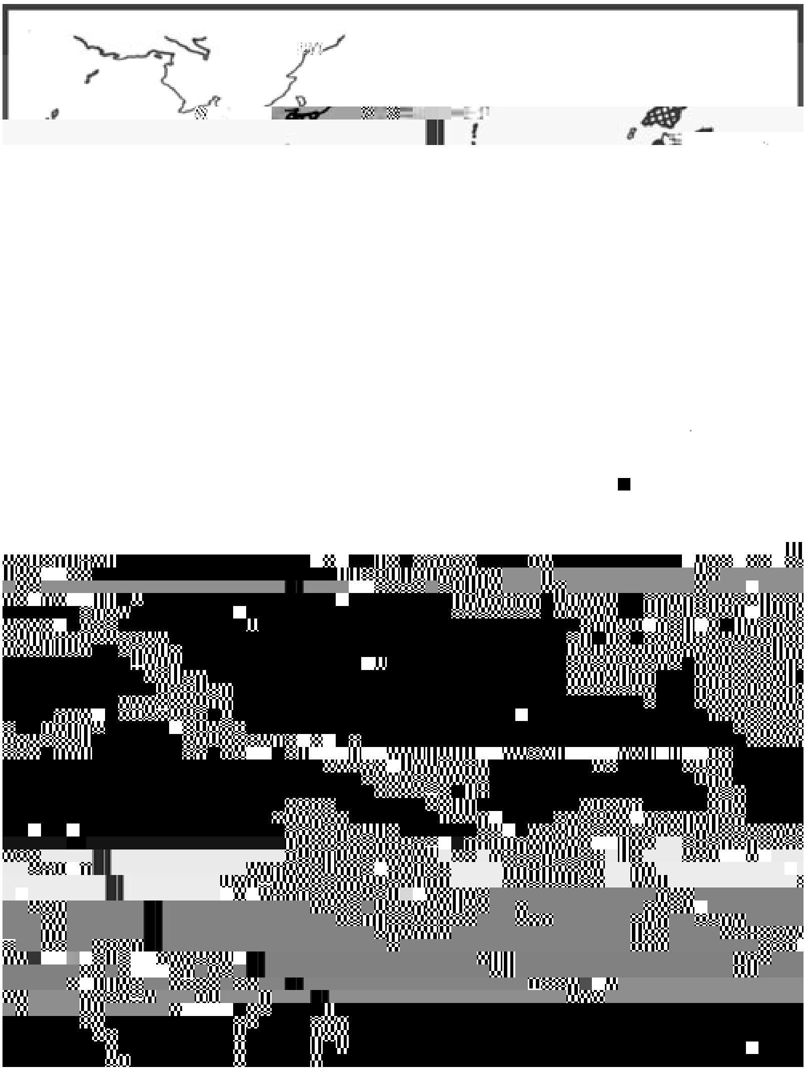

Fig. 2. Location of sampling sites. Southward migrants (solid dots) were captured in the Fraser River Delta and Kansas. Wintering birds (hatched dots) were captured in California, México, and Panamá.

wear (adapted from DeSante et al. 2008, Fig. 3). Flight feathers were collected from adults for isotope analysis. Where possible, the first primary was collected. However, for adults molting flight feathers, the next old feather to be molted was collected. To avoid removing a freshly grown primary from juveniles and creating an undue handicap, breast feathers were collected for δD_f. We assumed that because both breast and flight feathers from juveniles grow at the same time on the breeding grounds, they should have similar δD_f values.

Southward-migrating Western Sandpipers were also captured at Boundary Bay, a stopover site in the Fraser River Delta (FRD), British Columbia, Canada (49°06′N, 122°59′W) (Fig. 2). We collected first primaries from two juvenile birds and two adults captured on 10 and 13 August 1999 and ninth primaries from 55 adults captured from 11 to 13 July 2007. Birds captured in 2007 were aged in the field as adolescents if buffy edging was seen and as adults (includes both adolescents and true adults) if buffy edging was not seen (Prater

Fig. 3. Example flight feather condition (FF) scores on a scale of 1–5, where 1 is the most worn and 5 is

Table 1. Bimodality test and cluster analysis results of δD_f (‰) by species, site, and age.

f

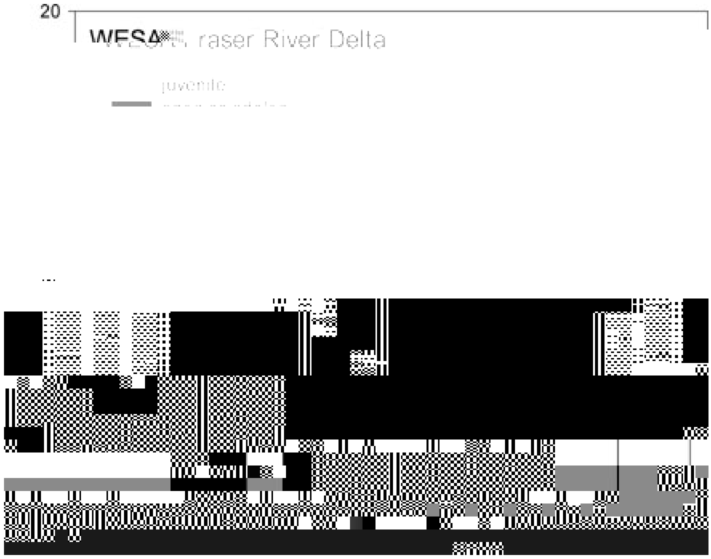

Fig. 5. δD_f distribution of Western Sandpipers captured in the Fraser River Delta and aged by plumage methods as adult (hatched bars), adolescent (black bars), and juvenile (open bars). $N = 55$ (2007), $N = 4$ (1999, 2 juvenile, 2 adult).

also fail to distinguish them if edges are worn or coverts are molting. Many adolescents were also undetected by plumage-based aging on the wintering grounds. Feather wear alone is an unreliable indicator of age-class at these times of year. The δD_f approach removes subjectivity and requires less expert knowledge and training.

Age-class discrimination was clearest for Least Sandpipers, presumably because the high-latitude values from this sample originate from an area with more negative δD_p values. In contrast, high-latitude values for Western Sandpipers appear to originate from an area with more positive δD_p values, whereas values for Semipalmated Sandpipers fell within a wider range between the values for Least and Western sandpipers. This corresponds with a priori knowledge about the range of δD_p in the far western Alaska breeding range of Western Sandpipers, and with what we believe to be the breeding ranges of Least and Semipalmated sandpipers migrating through Kansas that include eastern-Arctic areas with more negative δD_p values (Gratto-Trevor 1992, Cooper 1994, Wilson 1994, Chamberlain et al. 1997, Hobson and Wassenaar 1997, Bowen et al. 2005).

Previous investigators have used stable isotope analysis to delineate molt patterns in a range of avian taxa (Norris et al. 2004, Perez and Hobson 2006, Greenberg et al. 2007, Knoche et al. 2007, Reudink et al. 2008, Yerkes et al. 2008). However, the utility of δD_f for age-class discrimination depends entirely on a priori knowledge about the expected magnitude of difference in δD_p between breeding grounds and molting sites, and the timing and duration of flight feather molt in the species of interest. The expected magnitude of difference in δD_p between breeding and molting sites of species

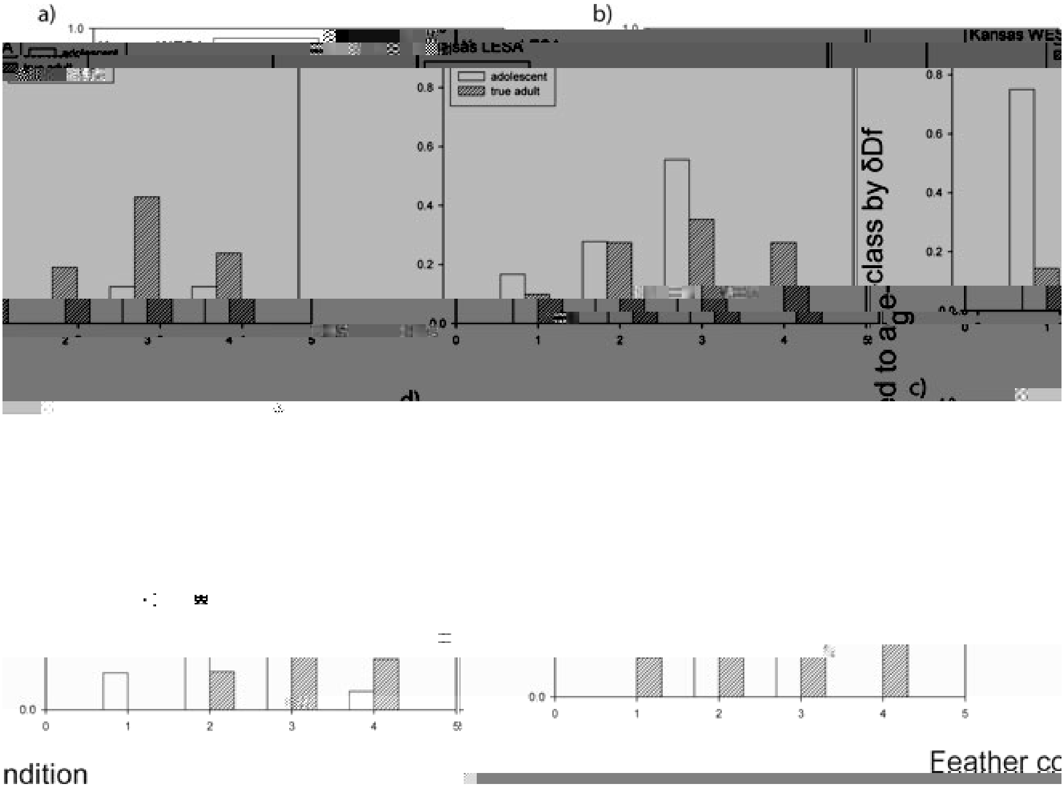

Fig. 6. Comparison of plumage-based (feather condition) versus isotope-based aging techniques for calidridine sandpipers. Feather condition scores indicate decreasing wear from left to right. Proportions of adolescents (open bars) versus true adults (hatched bars) based on age-class assignment criteria (see Table 1, age and site pooled results for Western and Least sandpipers, respectively). Semipalmated Sandpiper age-classes

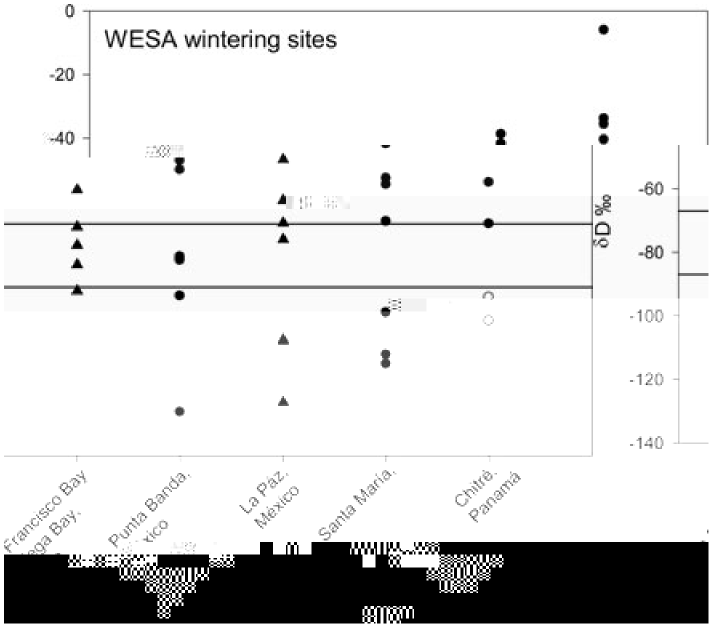

Fig. 7. δD_f values for Western Sandpipers sampled at five wintering sites, ordered left to right by decreasing latitude. Sandpipers were aged as either adult (filled symbols) or adolescents (open symbols), and were captured in either fall (triangles) or winter (circles). The area between the dashed lines (− 67 to −87‰) indicates δD_f values with > 0.05 probability of being in either component distribution (Table 1). Values ≤ −87‰ and ≥ −67‰ have a > 0.95 probability of falling into Arctic versus non-Arctic component distributions, respectively.

not, thus potentially incorrectly identifying age-class depending on the feather selected for analysis. Researchers interested in using δD_f to more accurately distinguish age-classes should first consider the expected range of δD_p for breeding and wintering ranges and the molt biology of their species. They should also consider that the mean δD_f values we present as identifying the two different adult age-classes for each species and site are relative rather than absolute. δD_f values may vary according to the population of the species sampled, the season or year of sampling or lab analysis, the location and hydrological edges are in good condition and adolescents can be distinguished by the presence of retained juvenal coverts with buffy edges. By late winter, however, buffy edges become harder to detect and distinguishing age-class using this criterion alone is more difficult. Feather wear may be helpful in assigning age-class in late winter and spring when comparing adolescent flight feathers grown on the breeding grounds to true adult flight feathers just grown on the wintering grounds, but has limited utility in the fall when it is an unreliable indicator of age-class. As spring and summer progress, covert edges become more worn and feather wear becomes more unreliable and, by the time a bird makes its second southward migration, plumage methods are unreliable for distinguishing age-class.

In summary, plumage methods are sufficient for discriminating adolescents from true adults in late fall through spring. However, plumage-based age-class discrimination becomes increasingly unreliable in later months, except in the case of partial primary molt with its strongly contrasting wear between outer and inner primaries. Although relatively more costly and time-consuming, δD_f enables more sensitive age determination in comparison to standard plumage methods, and in calidridine sandpipers, can distinguish adolescents at any time of year up until the second prebasic molt, except in the case of partial primary molt. Judicious combinations of plumage-based and δD_f methods may be useful in the future for determining age-classes of migratory birds.

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