Separation of Male and Female Orange-crowned Warblers by Crown Patch and Wing Chord

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ABSTRACT

Here we used cap grades and wing chord measurements of museum specimens and netted birds to create a series of scatter diagrams that should aid in the field separation of the sexes of Orange-crowned Warblers (Oreothlypis celata). *Many of these scatter diagrams are directly applicable to sexing "AHY/ASY" individuals ("adults") in the spring and early summer. We determined some "approximate adjustment factors" (AAFs) that account for wing tip wear which occurs between fall and spring, or wing chord differences among sex/age groups. We applied these AAFs to our adult/spring scatter diagrams to develop graphs that should aid in sexing adults in the fall, and subadults at any season.*

INTRODUCTION

Separation of sexes often is important for avian field research (Holmes 1986, Otahal 1994 and 1995, Fridolfsson and Elegren 1999, Ackerman et al. 2008, Bedrosian et al. 2008). For example, the sexes of many species function ecologically almost as different species (Grubb 1982, Parrish and Sherry 1984, Holmes 1986, Morton 1990) and analyses of the behaviors of the two sexes need to be distinct. For strongly dimorphic species, sexual separation can be made in the field based on obvious plumage or other morphological features (Parrish and Sherry 1984, Morton 1990). For monomorphic or weakly dimorphic species, sexual separation in the field during the breeding season often can be based on sexually distinctive behaviors, such as singing or brooding, and can be based on more subtle behavioral differences (Grubb 1982, Holmes 1986). In the hand, sexes often can be separated during the breeding season by examining primary sexual features such as cloacal protuberance or brood patch (Stutchbury and Robertson 1987, Brown and Brown 1996). Dissection and examination of gonads are commonly used to sex collected specimens at any time of year, and laparoscopy of gonads or DNA-based genetic analyses can be used for sexing live, netted individuals (Fridolfsson and Ellegren 1999, Redman et al. 2002, Bedrosian et al. 2008). When none of these "in the hand" means for direct sexing is practical, it would be advantageous to use a reliable means for sexing based on more subtle morphology features. For some species, such as the Wilson's Warbler (*Cardellina pusilla*), Caspian Tern (*Hydroprogne caspia*), and Clapper Rail (*Rallus longirostris*), workers have used discriminate function analyses to determine combinations of morphological features which best separate the sexes (Weicker and Winker 2002, Ackerman et al. 2008, Overton et al. 2009). For many avian species detailed measurement of different morphological features are stated in general banding references, and these can be used to separate sexes (Pyle et al. 1987, Pyle 1997, 2008). For example, two studies (Otahal 1994, 1995) used information in Pyle et al. (1987) to sex spring-migrating Orange-crowned (*Oreothlypis celata*) and Wilson's warblers. Sexing based on published morphological measurements may require the dismissal of data from many field-netted individuals the measurements (for example, of wing chord) of which lie within the ranges of overlap of the sexes (Otahal 1994, 1995). The need for more detailed information on secondary sexing and aging, for many avian species, is stated by Pyle et al. (1987), and Pyle (1997, 2008).

In this study we explore a secondary sexing methodology for Orange-crowned Warblers based on measurements of wing chords and evaluation of the grades of orange crown patches (subsequently "caps;" see Gilbert and West 2013). We present findings for different subspecies of Orange-crowned Warblers in a series of scatter diagrams presented here, and these graphs should facilitate sexing of both adult and subadult individuals.

METHODS

Reference material: aging terminology. We examined 265 specimens of Orange-crowned Warbler, all collected in the spring or early summer, from three natural history museums: The Museum of Vertebrate Zoology; University Of California-Berkeley; The California Academy of Sciences, San Francisco; and The Museum of Natural History, University of Arizona, Tucson. These specimens included samples from all four subspecies, *O. c. celata*, *O. c. orestera*, *O. c. lutescens*, and *O. c. sordida*. WMG also obtained data from 105 *O. c. lutescens* netted in the spring and early summer in central California, and we used data from 32 *O. c. celata* netted in the spring and 630 netted in the fall at the former Alaska Bird Observatory (ABO) in Fairbanks, AK. We separated all reference material into sex and age groups. Following Gilbert and West (2013), we designated age groups using modified Canadian Wildlife Service/Bird Banding Laboratory (CWS/BBL) calendar year terminology (Pyle 1997). We referred to individuals in formative plumage (Pyle 2008) as "HY," individuals in their first alternate plumage as "SY," the combined group of "HY" and "SY" birds as "HY/SY," and all individuals in definitive plumages as "AHY/ASY". These modifications of CWS/BBL calendar year terminology allowed us to better fit that terminology to breeding and molt cycles of Orange-crowned Warblers. To lessen confusion of our use of calendar year terminology with the established use by the CWS/BBL, we have placed quotation marks around our use of the terms in this paper (e.g., "HY").

Even though it may be appropriate to use established CWS/BBL terminology to designate age groups, museum reference material and published material often state ages by using alternative terminology (Gilbert and West 2013). It also has been suggested that molt and plumage terminology might be applied to breeding cycle stages, since molt and breeding cycles tend to parallel each other (D. Humple, pers. comm.). We see the advantage in acknowledging these equivalents and have listed them in Table 1.

Passerine reference material obtained in the spring and early summer (subsequently called "spring-collected" or "spring-netted") often has not been aged, using any terminology, to differentiate "SY" birds from "AHY/ASY" birds. There appears to have been an implicit assumption, at least in older records, that since all passerines are sexually mature by spring, that all should be considered to be "adults." This assumption ignored important morphological and behavioral differences between "SY" birds in their first breeding season and "AHY/ASY" birds in at least their second breeding season (Pyle 1997, Germain et al. 2010, Penteriani et al. 2011, WMG (*unpubl. data*)). We suggest the term "spring yearlings" to informally designate "SY" individuals (Table 1). The important distinction for birds in the spring would be between adults and spring yearlings (i.e., "AHY/ASY" vs. "SY" individuals).

Table 1. Terminologies considered in this paper. Plumage terminologies roughly conform to aging terminologies.

Modified CWS/BBL aging terminologies	"Traditional" or "Informal" terminologies	Plumage terminologies (Howell et al. 2003)
"HY"	"Immature"	Formative Plumage
"SY"	"Spring yearling"	1st alternate plumage
"HY/SY"	"Subadult"	Formative/1st alternate
"AHY/ASY"	"Adult"	Definitive plumage (2nd + basic, 2nd + alternate)

Reference material: aging criteria. No spring-collected museum specimen we examined had been aged as being adult versus spring yearling, or by any parallel terminology, and this distinction was critical to our study. A well-accepted methodology for aging passerines in the spring and early summer is based on molt limits seen in specific wing feathers (Mulvihill 1993, Pyle 1997). We found molt limits very difficult to assess in museum specimens, but that features of the rectrices appeared to separate most spring-collected individuals into "AHY/ASY" versus "SY" specimens. In addition to criteria mentioned in Pyle (1997), including texture and sheen of rectrices and shape and wear of tips, WMG found that differences in relative wear of whitish borders of rectrices, and relative wear of the two central rectrices (r1, Pyle 1997) were useful in aging (WMG, *unpubl. data*).

Reference material: "primary sexing". Our analyses of museum specimens and netted individuals were mostly based on "primary-sexed" individuals; i.e., individuals sexed by some unequivocal determinant such as gonads, brood patch, cloacal protuberance, or distinctive behavior, such as singing. A large majority of museum specimens we examined were unacceptable for our analyses, since no primary sexing criteria were indicated, and many may have simply been sexed based on plumage. Primary-sexed female specimens were especially scarce in museum collections we examined. WMG was able to expand our pool of primary-sexed female specimens by closely examining specimens stated by collectors or museum preparers to be female (but lacking gonadal or other confirmation), and determining if those specimens showed an extensive, bare "latent brood patch" on the underside. We considered specimens found to have such brood patches to be primary-sexed females. The only exceptions to our primary-sexing protocol were a small number of *O. c. sordida* female specimens, and a sample of ABO fall-netted *O. c. celata* which were sexed based on crown patch measurements.

Evaluating crown patches. Gilbert and West (2013) described four crown patch (cap) grades found in Orange-crowned Warblers. A grade 4 cap is one that has a relatively saturated orange color, is longer anterior to posterior than it is wide, and that frequently is noticeable without lifting or parting the crown feathers. A grade 3 cap is one that usually is relatively dull in color, is about equally long anterior to posterior as it is wide, and that infrequently is noticeable without lifting or parting the crown feathers. A grade 2 cap is one that shows no distinct orange cap in the crown, but does show traces of dull orange in some barbs of some crown feathers. A grade 1 cap is one that shows no distinct orange cap nor traces of orange in any crown feather. The crown feathers of grade 1 caps also tend to be the same shade of green or gray-green as the neck and back feathers of a bird, whereas the crown feathers of grade 2 caps tend to be a lighter, more chartreuse green. We assigned one of the four cap grades to each primary-sexed "AHY/ASY" or "HY/SY" spring-collected specimen or spring-netted individual we examined.

Nonparametric analysis of variance (ANOVA) indicated no significant differences among the mean cap grades of the four Orange-crowned Warbler subspecies for respective sex/age groups (Table 2). This similarity of mean cap grades among subspecies led us to pool cap grade data in developing graphs for separating the sexes of "HY/SY" individuals.

Gilbert and West (2013) determined that for netted individuals, reported cap measurements >14 mm were equivalent to cap grade 4, measurements 10 <14 mm were equivalent to cap grade 3, measurements 0 < 10 mm were equivalent to cap grade 2, and reported cap measurements of 0 mm were equivalent to cap grade 1. We used these cap grade/measurement equivalents to determine the cap grades of fall-netted ABO *O. c. celata*, based on their reported cap measurements. We subsequently used the determined cap grades to derive the sex of these fall-netted birds. These fall-netted ABO *O. c. celata* were not primary sexed, which did not conform to our usual protocol. However, our data from primary-sexed spring-collected or netted "AHY/ASY" *O. c. celata* males showed that nearly 88% (42/48) had grade 4 caps, 12% (6/48) had grade 3 caps, and none (0/48) had grade 1 or 2 caps. Ninety-six percent (25/26) of spring collected or netted "AHY/ASY" *O. c. celata* females had either grade 1 or grade 2 caps, and just one had a grade 3 cap. Cap grades change little once individuals have passed through their second basic molt, at least in males (Foster, 1963). Thus, we were reasonably confident that fall-netted ABO *O. c. celata* with reported cap measurements equivalent to cap grade 4 were males, as also were most individuals with measurements equivalent to cap grade 3. We assumed that ABO fall-netted "AHY/ASY" individuals with cap measurements equivalent to cap grades 1 and 2 were all females. We did not use this derived autumn ABO data to graph the sexes of fall *O. c. celata*. The data was useful for determining the differences between fall and spring "AHY/ASY" wing chords, and between fall "AHY/ASY" and "HY" wing chords, and thus for determining AAFs (see below).

Table 2. Analyses of variance for cap grades and wing chords of like sex/age groups among subspecies of Orange-crowned Warblers. No cap grade comparison is significant, while most wing chord comparisons are significant. Comparisons which are based on just three subspecies exclude *O.c. sordida.*

Sex - age	Feature compared	# Subspecies	Range of means	Total *n*	*p*	Test
Male - AHY/ASY	Cap grade	4	3.88 - 4.00	74	0.7	Kruskal-Wallace
Female - AHY/ASY	Cap grade	4	1.44 - 2.18	42	0.37	" - "
Male - SY	Cap grade	3	2.88 - 4.00	24	0.21	" - "
Female - SY	Cap grade	3	1.00 - 1.33	13	0.28	" - "
Male - HY	Cap grade	3	2.06 - 2.27	48	0.77	" - "
Female - HY	Cap grade	3	1.00 - 1.25	28	0.0746	" - "
Male - AHY/ASY	Wing Chord	4	58.82 - 62.69	75	<0.0001	1-way ANOVA
Female - AHY/ASY	Wing Chord	4	55.18 - 58.64	45	<0.0001	Kruskal-Wallace
Male - SY	Wing Chord	3	58.00 - 61.09	23	0.0331	" - "
Female - SY	Wing Chord	3	53.67 - 57.88	16	0.0003	1-way ANOVA
Male - HY	Wing Chord	3	58.88 - 59.92	44	0.079	1-way ANOVA

Evaluating wing chords. We measured the unflattened wing chord of each museum specimen and field-netted Orange-crowned Warbler that we used in this study, or accepted the wing chord measurements of the ABO for its field-netted *O. c. celata* material. All data we used were from individuals obtained in the spring or early summer, with the exception of some ABO data from individuals ("AHY/ASY," $n = 137$; "HY," $n = 493$) netted in the fall or late summer. Unlike for cap grades, parametric or nonparametric ANOVA of wing chords for respective sex/age groups indicated significant differences among four of five different sex/age groups evaluated. The remaining group ("HY" males) had a $P = 0.079$ (Table 2). We did not evaluate "HY" females, for which we considered we had insufficient data. We made all wing chord analyses based on means and distributions, and developed variance error bars indicating the 95% confidence limits for each population sample. All wing chord data were subspecies specific.

"Wing chord approximate adjustment factors" (AAFs). The wing chords of passerines in the spring characteristically are shorter than those of the same birds in the fall, a result of overwinter primary tip wear (P. Nott, pers. comm.). The wing chords of "HY" passerines are naturally shorter than those of "AHY/ASY" passerines in the fall, and this difference becomes even greater by the spring since the juvenal primaries of "SY" individuals have worn faster over the winter than the adult primaries of "AHY/ASY" individuals (Pyle 1997). Sexing can be accomplished without considering these seasonal and age differences in wing chords, but doing so requires a bander to only sex individuals at the outer limits of wing chord length, and requires dismissal of measurements that fall within the relatively broad zone of male/female wing chord overlap. To refine sexing methodology based in part on wing chord measurements, we considered seasonal and age differences in wing chords. This consideration involved adjusting graphs which were directly based on empirical wing chord data to develop graphs for which we had no empirical wing chord data. We accomplished these adjustments using wing chord approximate adjustment factors (AAFs) linking different seasonal (spring *vs* fall) or age ("AHY/ASY" vs. "HY/SY") groups.

We determined AAFs using empirical guideline data of wing chord differences based on season or age of ABO field data for *O. c. celata*, or on wing chord differences based on age of MVZ specimens of three subspecies. Determining the most reasonable AAFs was an iterative process that also considered established knowledge of age and seasonal wing tip wear differences among different groups. For example, it would not be reasonable for an AAF between "AHY/ASY" individuals in the fall and spring to be greater, or even the same as, an AAF between "HY" individuals in the fall and "SY" individuals in the spring, since juvenal primaries wear faster than adult primaries (Pyle 1997). Although we determined some reasonable AAFs by simply rounding empirical data to the nearest 0.5 mm, we determined other reasonable AAFs based on applying to empirical data our knowledge of age and wing tip wear differences and/or on extrapolation from empirical data. Since the wing chords of female passerines tend to be shorter than those of males (Pyle 1997) and to wear at different rates (P. Nott, pers. comm.), we developed AAFs separately for males and females.

Cap grade and wing chord scatter diagrams. From our original spring/early summer reference material, we plotted six scatter diagrams applicable to separating the sexes of "AHY/ASY" individuals based on their paired cap grades and wing chord measurements. From the original data we also plotted two scatter diagrams applicable to separating the sexes of some "HY" and "SY" individuals based on cap grades only. We pooled data from different subspecies in developing these last two graphs. We also plotted six graphs, by applying AAFs to our original spring/early summer "AHY/ASY" data, which were applicable to sexing fall/late summer "AHY/ASY" individuals based on their paired cap grades and wing chord measurements. Finally, we plotted twelve graphs by applying AAFs to our original spring/early summer "AHY/ASY" data which were applicable to sexing "HY" and "SY" individuals based on their wing chord measurements only.

We attempted no statistical analyses which might provide probabilities of accurate sexing based on various combinations of cap grades and wing chord measurements. We did, however, statistically evaluate cap grades and wing chords separately. We applied Fisher's Exact Test to evaluate the frequencies of cap grade 4 versus combined cap grades 1 and 2 between paired male and female groups of specimens or netted birds. We also determined and plotted means and limits of variance for wing chords of each sex in each graph where wing chords were considered, as indicated by an "x" for means and brackets for variance limits ([--x--]). These variance limits show the span of male – female wing chord overlap based on 95% probabilities for each gender.

RESULTS - *Reference APPENDIX for Figures and Captions*

Scatter diagrams for spring/early summer "AHY/ASY" individuals. Figures 1A-F show plots of paired cap grades and wing chords for both sexes of spring-collected or netted "AHY/ASY" individuals of each Orange-crowned Warbler subspecies. "AHY/ASY" males usually had "higher" cap grades than females, and 90% (236/262) of "AHY/ASY" males of combined subspecies displayed grade 4 caps. Grade 3 caps were found in 9.5% (25/262) "AHY/ASY" males, and 0.5% (1/262) "AHY/ASY" males (an individual of the *sordida* subspecies) had a grade 2 cap. No "AHY/ASY" male had a grade 1 cap. While 47% (38/81) of "AHY/ASY" females had grade 1 caps, 31% (25/81) had grade 2 caps, 18.5% (15/81) had grade 3 caps, and 3.5% (3/81) had grade 4 caps.

The distribution of "AHY/ASY" wing chord lengths in the spring and early summer varied among subspecies, and wings tended to be longer in

O. c. orestera and *O. c. celata*, and shorter in *O. c. lutescens* and *O. c. sordida*. For all subspecies, "AHY/ASY" males tended to have longer wings than "AHY/ASY" females, and wing chord measurements for long-winged females overlapped those of short-winged males.

Wing chord approximate adjustment factors (AAFs). We determined seasonal-related wing chord approximate adjustment factors (AAFs), ± 1.5 mm for "AHY/ASY" males and 1.0 mm for "AHY/ASY" females, roughly based on fall-to-spring differences in ABO wing chord data for *O. c. celata* (Table 3). These differences presumably result from overwinter wear of primary feather tips. We lacked sufficient empirical data to directly determine seasonal AAFs between "HY" and "SY" individuals of either sex, but extrapolated a seasonal AAF of ± 2.0 mm between "HY" and "SY" males, and ± 1.5 mm between "HY" and "SY" females, based on comparative age-related AAFs (Table 3). We determined an age-related AAF between autumn "AHY/ASY" and "HY" males of ± 1.0 mm roughly based on ABO wing chord data for *O. c. celata* (Table 3), but also based on the fact that juvenal primaries tend to undergo greater overwinter tip wear than do adult primaries (Pyle 1997). We had insufficient empirical data to determine an age-related AAF between autumn "AHY/ASY" and "HY' females, but assumed that it would be similar to the ± 1.0 mm AAF between fall "AHY/ASY" and "HY" males (Table 3). We determined age-related wing chord AAFs of ± 1.5 mm between spring "AHY/ASY" and "SY" individuals for both males and females, roughly based on MVZ specimen data for three *O. celata* subspecies (Table 3). We illustrate all wing chord AAFs we determined among seasons and ages for males and females, respectively, in Figs. 2A-B.

Scatter diagrams for autumn/late summer "AHY/ASY" individuals. Figures 3A-F show plots of paired cap grades and wing chords for both sexes of fall/late summer "AHY/ASY" individuals of each OCWA subspecies, based on applying AAFs (Table 3 and Figs. 2A-B) to spring/early summer wing chord data in Figs. 1A-F. The cap grades for fall/late summer birds remain the same as for spring/early summer birds, but we plotted the wing chords of fall/late summer males to be 1.5 mm longer than for spring/early summer males, and we plotted the wing chords of fall/late summer females to be 1.0 mm longer than for spring/early summer females.

Because of the greater overwinter wing tip wear in adult males than in adult females, the overlap in wing chord lengths between adult males and females is less in the fall than in the spring.

"HY/SY" individuals. Figures 4A-B show cap grade plots for pooled subspecies of fall-collected "HY" and spring-collected "SY" specimens, respectively. Wing chord lengths, although plotted, have no application in separating the sexes since subspecies data is pooled. Figure 4A shows that in the fall 75% (15/20) "HY" males had grade 1 or grade 2 caps, while 10% (2/20) had grade 3 caps, and 15% (3/20) had grade 4 caps. Grade 1 caps were found in 89% (8/9) of "HY" females, and the remaining "HY" female had a grade 2 cap. Figure 4B shows that by their first spring breeding season 56% (30/54) of "SY" males had grade 4 caps, 17% (9/54) had grade 3 caps, 20% (11/54) still had grade 2 caps, and 7% (4/54) still had grade 1 caps. In the first spring breeding season 85% (17/20) of "SY" females still had grade 1 caps and the remaining 15% (3/20) had grade 2 caps.

Figures 5A-F and 6A-F for "HY" and "SY" individuals respectively for the four subspecies are derived from applying appropriate AAFs (Figs. 2A-B, Table 3) to spring "AHY/ASY" wing chord data. These graphs show wing chord, but not cap grade, differences between the sexes, and are subspecies specific. Similar to adults, the overlap in wing chord lengths between the sexes is less in the fall than in the spring as a result of greater overwinter wing tip wear in males than in females.

DISCUSSION

Aging terminologies. Using CWS/BBL calendar year terminology in avian research results in imperfect matches in terms of breeding and molt cycles. For example, our "SY" designation, if presumed to include all calendar second-year birds, should include some non-breeding individuals in formative plumage and some post-breeding individuals in definitive basic plumage, in addition to potentially breeding individuals in first alternate plumage. We needed to isolate individuals in their first season of sexual maturity, and thus designated "SY" to apply only to the last-mentioned group. We included the first and second groups in our "HY" and "AHY/ASY" designations respectively (Gilbert and West, 2013). Our modification of CWS/BBL calendar year aging terminology to fit specific purposes may be similar to the modifications of Pyle (1997) in combining calendar year designations (e.g., AY/SY [Aug-Jul]) to indicate individuals existing during the one-year span midway between the start and end of calendar years. It should be stressed that our designated meanings for calendar year terminology do not conform to CWS/BBL meanings, nor do our combined designations ("AY/SY" and "AHY/ASY") conform to the HY/SY and AHY/ASY meanings given by Pyle (1997). The potential conflicts created by these alternative uses of the same terminology are unfortunate. There currently are no parsimonious, officially recognized aging terminologies that can be applied to specific stages of the breeding cycle (e.g., the first season of sexual maturity), or to specific stages of the molt cycle (which tend to parallel stages in the breeding cycle, e.g., the stage of first alternative plumage; Howell et al. 2003). These realities hopefully justify our alternative use of CWS/BBL terminologies here and in Gilbert and West (2013). Stating parallel informal age terminologies and plumage/molt cycle terminologies (Table 1) should help clarify our use of modified CWL/BBL terminologies.

Wing chord overlap between sexes. Our scatter diagrams for "AHY/ASY" individuals of both sexes (Figs. 1A-F, 3A-F) suggest that the degree of male/female wing chord overlap varies among subspecies, with the greatest overlap being in *orestera* and the least in *celata*. This suggests that wing chord length may be more usable for sexing some subspecies than others. Our graphs are derived from relatively small sample sizes. This should be considered in sexing using our graphs, since wing chord ranges of total subspecies populations would be greater than those indicated by our samples. Error bars for variance of wing chord distributions, plotted for each graph, precisely indicate the 95% confidence limits for samples of each sex. The error bars also indicate the precise extent of male-female wing chord overlap based on these confidence limits. Although these confidence limits can be useful in sexing based on wing chords, they do not indicate the extent and number of possible wing chord outliers that could exist in the entire population beyond the indicated confidence limits.

Applying scatter diagrams for sexing "AHY/ASY" individuals in spring and early summer. Our "spring" "AHY/ASY" scatter diagrams should apply directly for sexing "AHY/ASY" Orange-crowned Warblers during spring migration. Our scatter diagrams also can be used for sexing on breeding grounds if primary means of sexing (e.g., brood patch or cloacal protuberance) are unavailable. In either case, we suggest that a worker first evaluate the cap grade of a netted individual and follow with a wing chord evaluation. Adult birds in the spring/early summer with grade 1 or 2 caps likely can be considered to be females, since we found just one (of 260) "AHY/ASY" male (a specimen of the *sordida* subspecies) had a grade 2 cap. Most netted birds with a grade 4 caps likely can be considered males, although three (of 81) females did display grade 4 caps. Two of these three females were of the *lutescens* subspecies, and females of the other subspecies appear less likely to develop grade 4 caps (Foster 1967, Gilbert and West 2013). A netted bird with a grade 3 cap should not be sexed based on cap grade, since substantial numbers of both sexes (24 and 15 respectively for males and females) displayed this cap grade.

Following evaluating cap grade to determine sex, a bander should evaluate wing chord. If the wing chord lies outside of the range of male/female overlap for a given subspecies, and the cap grade (grade 4 for males, grades 1 and 2 for females) conforms with the determination indicated by the wing chord, then the netted individual likely is the sex indicated by both cap grade and wing chord evaluations.

If there is a conflict between the sex indicated by cap grade and wing chord measurement (e.g., should a bird with a grade 1 cap have a wing chord

measurement in the male range), then one first should consider a possible error. Possibly the wing was incorrectly measured, or the subspecies or age was incorrectly determined.

If no error is indicated, then possibly the bird is an intergrade between two subspecies (Gilbert and West 2015), or an outlier for wing chord measurement and/or cap development.

Applying scatter diagrams for sexing "AHY/ASY" individuals in the late summer or fall. No easily discerned primary sexing criteria exist for "AHY/ASY" Orange-crowned Warblers after the breeding season, and performing a laparoscopy or laparotomy to examine gonads, or applying genetic analyses, might not be practical on living birds in the field. Our scatter diagrams therefore potentially should have wider applicability in the late summer and fall than in the spring. We made our spring scatter diagrams compatible with sexing in the fall by applying AAFs to the data. Sexing "AHY/ASY" Orange-crowned Warblers in the autumn/late summer should proceed the same as in the spring/early summer, except that the AAF-converted graphs should be used.

Applying scatter diagrams for sexing "HY/SY" individuals. We lacked sufficient sample sizes to plot subspecies specific cap grade and wing chord graphs for "HY/SY" individuals in either the spring or the fall. A bander can sex a "HY/SY" bird by first comparing a netted individual's cap grade with our pooled "HY/SY" scatter diagrams (Figs. 4A-B). These figures show that 35% (7/20) of "HY" males, and 74% (40/54) of "SY" males, displayed grade 3 or 4 caps, while no (0/20) "HY" or "SY" female did. Any netted "HY" individual in the fall, or "SY" individual in the spring, with cap grades 3 or 4 likely would be a male. Conversely, no "HY/SY" female can be sexed with certainty based on just having a grade 1 or 2 cap, since 65% (13/20) of "HY" males, and 26% (14/54) of "SY" males, also had one of these "low" cap grades.

Following preliminary evaluation of a "HY/SY" bird's sex based on cap grade, a bander should make a determination based on wing chord. The bander should compare the netted bird's wing chord with subspecies-specific graph(s) in Figs. 5A-F for a "HY" individual in the fall, and with subspecies-specific graph(s) in Figs. 6A-F for a "SY" individual in the spring. Sexing of subadults based on wing chord should proceed as for adult birds, with individuals within the range of male-female overlap being questionable. If there are discrepancies between the sexes indicated by the cap grade and wing chord determinations, a bander should consider a possible error, outlier, or intergrade as discussed for "AHY/ASY" individuals.

Applying AAFs: general considerations. The fall-to-spring AAFs we determined for "HY/SY" birds (± 2.0 mm for males and ± 1.5 mm for females; Table 3, Figs. 2A-B) are greater than the comparable seasonal AAFs for "AHY/ASY" birds (± 1.5 mm for males and ±1.0 for females; Table 3, Figs. 2A-B). These differences support the conclusion that juvenal primaries undergo greater seasonal abrasion than do adult primaries (Pyle 1997). The age-related (HY/SY vs. AHY/ASY) AAFs that we determined for both males and females (± 1.0 mm in fall, ± 1.5 mm in spring; Table 3, Figs. 2A-B) support the conclusion that juvenile passerine wing chords naturally are about 1-3 mm shorter than those of adults Pyle (1997). Employing AAFs to account for seasonal or age differences in wing chords needs to be considered as an aid in making analyses, and one that makes those analyses more accurate than if no adjustment(s) were made, even while acknowledging that those adjustments may not be perfect. We are unaware of another empirical study which evaluates fall-to-spring wing tip wear for a passerine species, or natural wing chord differences between "AHY/ASY" and "AY/SY" individuals in either the spring or the fall.

Sexing Orange-crowned Warblers: final considerations. Our scatter diagrams reflect relative probabilities, rather than certainties, for accurate sexing. The methods we present may not be completely applicable if the age and/or subspecies of a netted bird have not been accurately determined. Age often is determined in the autumn by skull ossification, although features of the primaries and/or rectrices also are indicative (Pyle, 1997). In the spring evaluating molt limits in the wings usually is the preferred method, although features and condition of the primaries and/or rectrices also are useful (Pyle 1997, WMG, *unpubl.*

Table 3. Wing chord differences between various sex/subspecies/age/seasonal groups of Orange-crowned Warblers, and approximate adjustment factors (AAFs) determined in part from those differences. Final AAF values determined by rounding wing chord differences to the nearest 0.5 mm, by considering what previously has been known about age and seasonal wing chord differences, and/or by extrapolation from the originally determined AAFs. x=relevent comparison. y = larger value. z = AAFs, used to plot graphs, which were derived from comparisons involving spring AHY/ASY birds. For further detail on deriving AAFs, see text.

Sex	Subspecies	Age	Season	Mean (mm)	SE (mm)	Range (mm)	*n*	Source	Difference	*P*	AAF (mm)
AAFs based on differences in empirical data and/or prior knowledge regarding wing chord differences.											
Male	*O.c. celata*	AHY/ASY	Autumn ^{x,y}	62.67	9.15	59-67	88	ABO			
Male	*O.c. celata*	AHY/ASY	Spring ^{x}	61.00	0.36	58.64	21	ABO	1.67	<0.0001	± 1.5^{z}
Female	*O.c. celata*	AHY/ASY	Autumn ^{x,y}	58.64	0.28	56-62	36	ABO			
Female	*O.c. celata*	AHY/ASY	Spring ^{x}	58.00	0.36	56-59	11	ABO	0.64	0.352	± 1^{z}
Male	*O.c. celata*	AHY/ASY ^{x,y}	Autumn	62.67	0.15	59-67	88	ABO			
Male	*O.c. celata*	HY^{x}	Autumn	61.35	0.07	57-66	493	ABO	1.34	<0.0001	± 1
Male	*O.c. orestera*	AHY/ASY^{x,y}	Spring	62.68	0.25	59.5-66	36	MVZ			
Male	*O.c. orestera*	SY^{x}	Spring	61.09	0.41	57.5-64	17	MVZ	1.59	0.001	± 1.5^{z}
Female	*O.c. celata*	AHY/ASY^{x,y}	Spring	57.16	0.45	52.5-61.5	25	MVZ			
Female	*O.c. celata*	SY ^{x}	Spring	55.46	0.6	52-58.5	13	MVZ	1.7	0.0301	± 1.5^{z}
Female	*O.c. lutescens*	AHY/ASY^{x,y}	Spring	55.18	0.34	52-5-56.5	11	MVZ			
Female	*O.c. lutescens*	SY^{x}	Spring	53.67	0.56	52-55.5	6	MVZ	1.51	0.0391	± 1.5^{z}
AAFs extrapolated from AAFs determined above.											
Male		HY ^{x,y}	Autumn^{x,y}								
Male		SY^{x}	Spring ^{x}								± 2
Female		HY ^{x,y}	Autumn ^{x,y}								
Female		SY ^{x}	Spring^{x}								± 1.5
Female		AHY/ASY ^{x,y}	Autumn								
Female		HY ^{x}	Autumn								± 1
Male		HY ^{x,y}	Autumn^{x,y}								
Male		AHY/ASY^{x}	Spring ^{x}								± 0.5^{z}
Female		HY^{x}	Autumn^{x}								
Female		AHY/ASYx	Spring x								±0.0^{z}

data). Subspecies should be determined mainly by geography and, to a lesser extent, by distinctive plumage (Dunn and Garrett 1997, Gilbert et al. 2010). Individuals whose age and/or subspecies are questionable should be sexed conservatively, especially when sexing is based mainly on wing chord measurement.

If a possible intergrade between two Orange-crowned Warbler subspecies is captured, the wing chord measurement and assessed cap grade can be contradictory for one or the other sex of the bird's assumed subspecies. Currently, a zone of secondary contact and introgression has been demonstrated genetically to exist in southern Alaska, based on *O. c. celata* captured in central Alaska, and *O. c. lutescens* captured in southeast Alaska (Bull et al. 2010). We have evaluated morphologically specimens and netted Orange-crowned Warblers from the apparent zone of contact and introgression (Gilbert and West 2015). No other regions of secondary subspecies contact currently are known or suspected. Sexing in an area of known secondary contact of subspecies should be done based mainly on cap grades, and with an understanding that subspecies-specific wing chord ranges indicated in our graphs likely would not apply to intergrades.

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LITERATURE CITED

Ackerman, J.T., J.Y. Takekawa, J.D. Bluso, J.L. Yee, and C.A. Eagles-Smith. 2008. Gender identification of Caspian Terns using external morphology and discriminant function analysis. *Wilson Journal of Ornithology* 120:378-383.

Bedrosian, B., J. Loutsch, and D. Craighead. 2008. Using morphometrics to determine the sex of Common Ravens. *Northwestern Naturalist* 89:46-52.

Brown, C.R. and M.B. Brown. 1996. Coloniality in the Cliff Swallow. Chicago: The University of Chicago Press. Xiii + 571 pp.

Bull, R.D., A. McCracken, A.J. Gaston, T.P. Birt, and V.L. Friesen. 2010. Evidence of recent population differentiation in Orange-crowned Warblers (*Vermivora celata*) in Haida Gwaii. *Auk* 127:23-34.

Dunn, J.L. and K.L. Garrett. 1997. A field guide to warblers of North America. New York: Houghton Mifflin Co., xi + 656 pp.

Foster, M. 1967. Molt cycles of the Orange-crowned Warbler. *Condor* 69:169-200.

Fridolfsson, A.K. and H. Ellegren. 1999. A simple and universal method for molecular sexing of non-ratite birds. *Journal of Avian Biology* 30:116-121.

Germain, R.R., P.P. Marra, T.K. Kyser, and L.M. Ratcliffe. 2010. Adult-like plumage coloration predicts winter territory quality and timing of arrival on the breeding grounds of yearling male American Redstarts. *Condor* 112:676-682.

Gilbert, W.M. and G.C. West. 2013. Orange-crowned Warbler cap grades: a methodology supplemental to measuring. *North American Bird Bander* 38:55-68.

Gilbert, W.M. and G.C. West. 2015. Morphological expression in putative intergrades between two subspecies of Orange-crowned Warbler in the Kenai Peninsula of Alaska. *Wilson Journal of Ornithology* 127:29-42.

Gilbert, W.M., M.K. Sogge and C. Van Riper III. 2010. Orange-crowned Warbler (*Oreothlypis celata*). The birds of North America Online (A. Poole, Ed.). Ithaca: Cornell Lab of Ornithology. Retrieved from the Birds of North America Online: http://bna.birds.cornell.edu/bna/species/101doi:10.2173/bna.101

Grubb, T.C. Jr. 1982. On sex-specific foraging behavior in the White-breasted Nuthatch. *Journal of Field Ornithology* 53:305-314.

Holmes, R.T 1986. Foraging behavior of forest birds: male-female differences. *Wilson Bulletin* 98:196-213.

Howell, S.N.G., C. Corben, P. Pyle, and D.I. Rogers. 2003. The first basic problem: a review of molt and plumage homologies. *Condor* 105:635-653.

Morton, E.S. 1990. Habitat segregation by sex in the Hooded Warbler: experiments on proximate causation and discussion of its evolution. *American Naturalist* 135:319-333.

Mulvihill, R.S. 1993. Using wing molt to age passerines. *North American Bird Bander* 18:1-10.

Otahal, C.D. 1994. Sexual differences in spring migration of Orange-crowned Warblers. *North American Bird Bander* 19:140-146.

Otahal, C.D. 1995. Sexual differences in Wilson's Warbler migration. *Journal of Field Ornithology* 66:60-69.

Overton, C.T., M.L. Casazza, J.T. Takekawa, and T.M. Rohmer. 2009. Sexing California Clapper Rails using morphological measurements. *North American Bird Bander* 34:58–64.

Parrish, J.D. and T.W. Sherry. 1984. Sexual habitat segregation by American Redstarts wintering in Jamaica: importance of resource seasonality. *Auk* 111:38-49.

Penteriani, V., M. Ferrer, and M.M. Delgado. 2011. Floater strategies and dynamics in birds, and their importance in conservation biology: towards an understanding of nonbreeders in avian populations. *Animal Conservation* 14:233-241.

Pyle, P. 1997. Identification guide to North American Birds, Part I: Columbidae to Ploceidae. xi + 732 pp. Pt. Reyes Station, CA: Slate Creek Press.

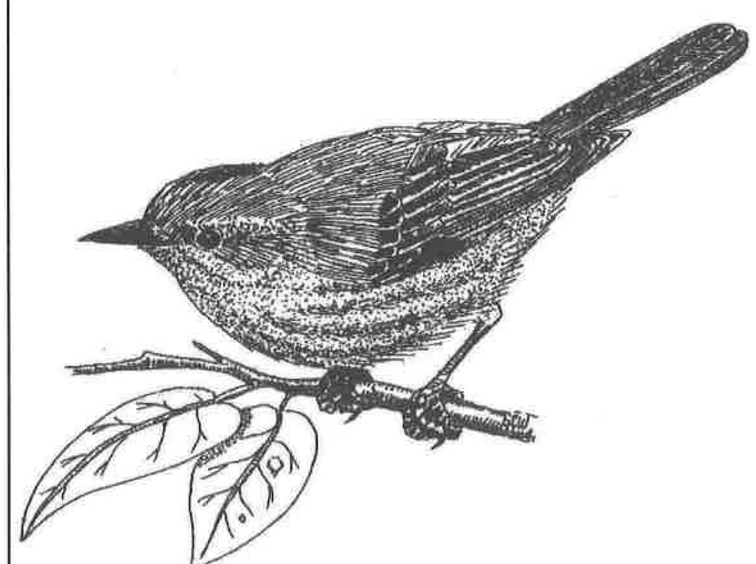
Pyle, P. 2008. Identification guide to North American Birds, Part II: Anatidae to Alcidae. xi + 836 pp. Pt. Reyes Station, CA: Slate Creek Press.

Pyle, P., S.N.G. Howell, R.P. Yunick, and D.F. DeSante. 1987. Identification guide to North American passerines. x + 278 pp. Pt. Reyes Station, CA: Slate Creek Press.

Redman, K.K., S. Lewis, R. Griffiths, S. Wanless, and K.C. Hamer. 2002. Sexing Northern Gannets from DNA, morphology and behavior. *Waterbirds* 25:230-234.

Stutchbury, B.J. and R.J. Robertson. 1987. Two methods of sexing adult Tree Swallows before they begin breeding. *Journal of Field Ornithology* 58:236-242.

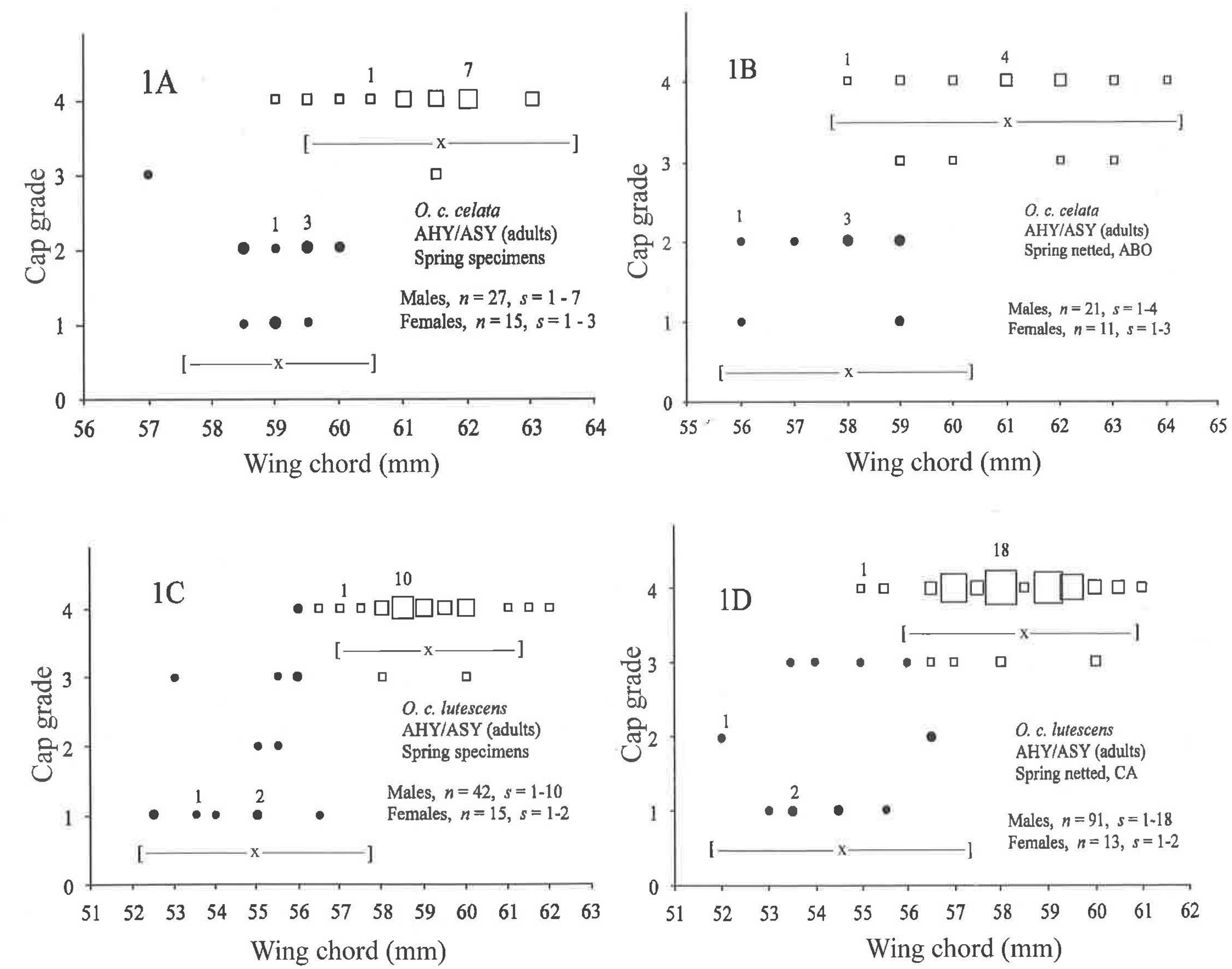
Weicker. J.J. and K. Winker. 2002. Sexual dimorphism in the birds from Southern Veracruz, Mexico, and other localities. III. Wilson's Warbler (*Wilsonia pusilla*). *Journal of Field Ornithology* 73:62-69.



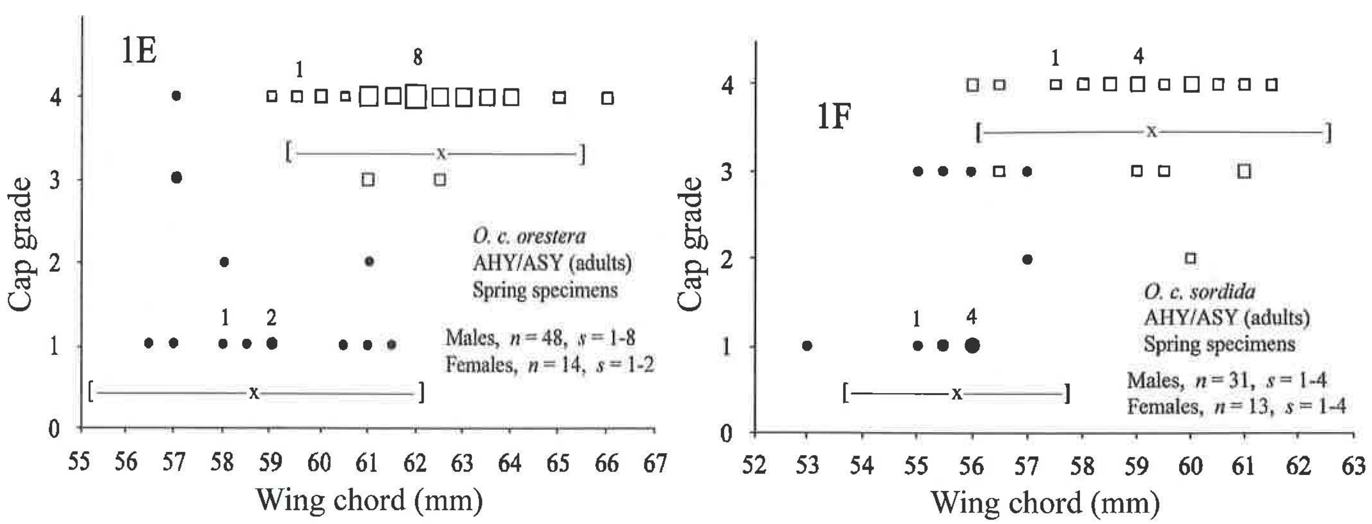
Orange-crowned Warbler by George West

APPENDIX: CAPTIONS AND FIGURES

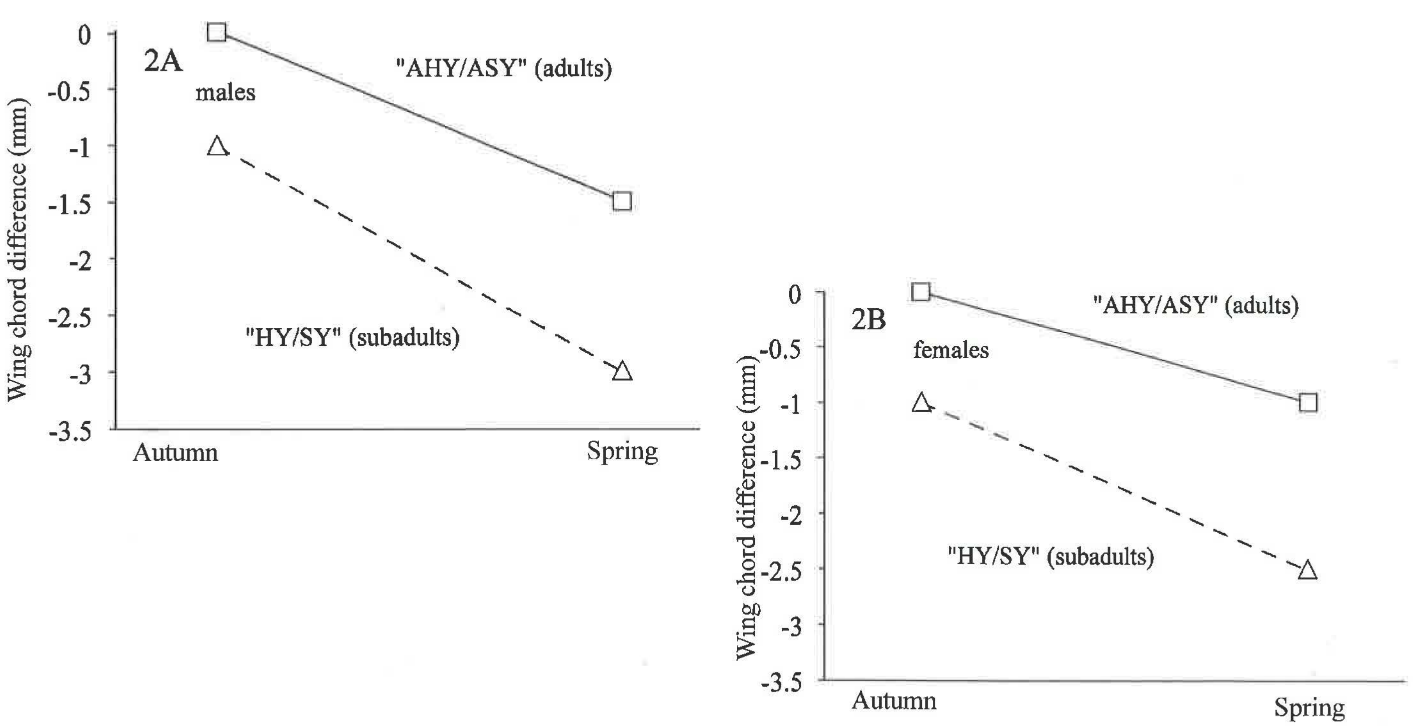
Figs.1A-4F Scatter diagrams showing the paired cap grades and wing chords for spring-collected or netted "AHY/ASY" (adult) male and female Orange-crowned Warblers. 1A - *O. c. celata* museum specimens, 1B – *O. c. celata* netted birds from former Alaska Bird Observatory (ABO). 1C – *O. c. lutescens* museum specimens, 1D – *O. c. lutescens* netted birds from central California, 1E – *O. c. orestera* museum specimens, and 1F – *O. c. sordida* museum specimens. Males are represented by square, hollow data markers, and females by circular solid data markers. The relative number of individuals represented by each data marker is reflected in the size of the marker, with the smallest markers representing the lowest values of the sex-specific ranges, and the largest markers representing the highest values. The span of number of individuals represented by data markers is indicated by *s*. The total number of individuals plotted in each graph is indicated in the sex-specific values of *n*. We indicate the variance in wing chords in male and female samples by error bars around the means (x). The error bars show male – female overlap of wing chords based on 95% probability limits.



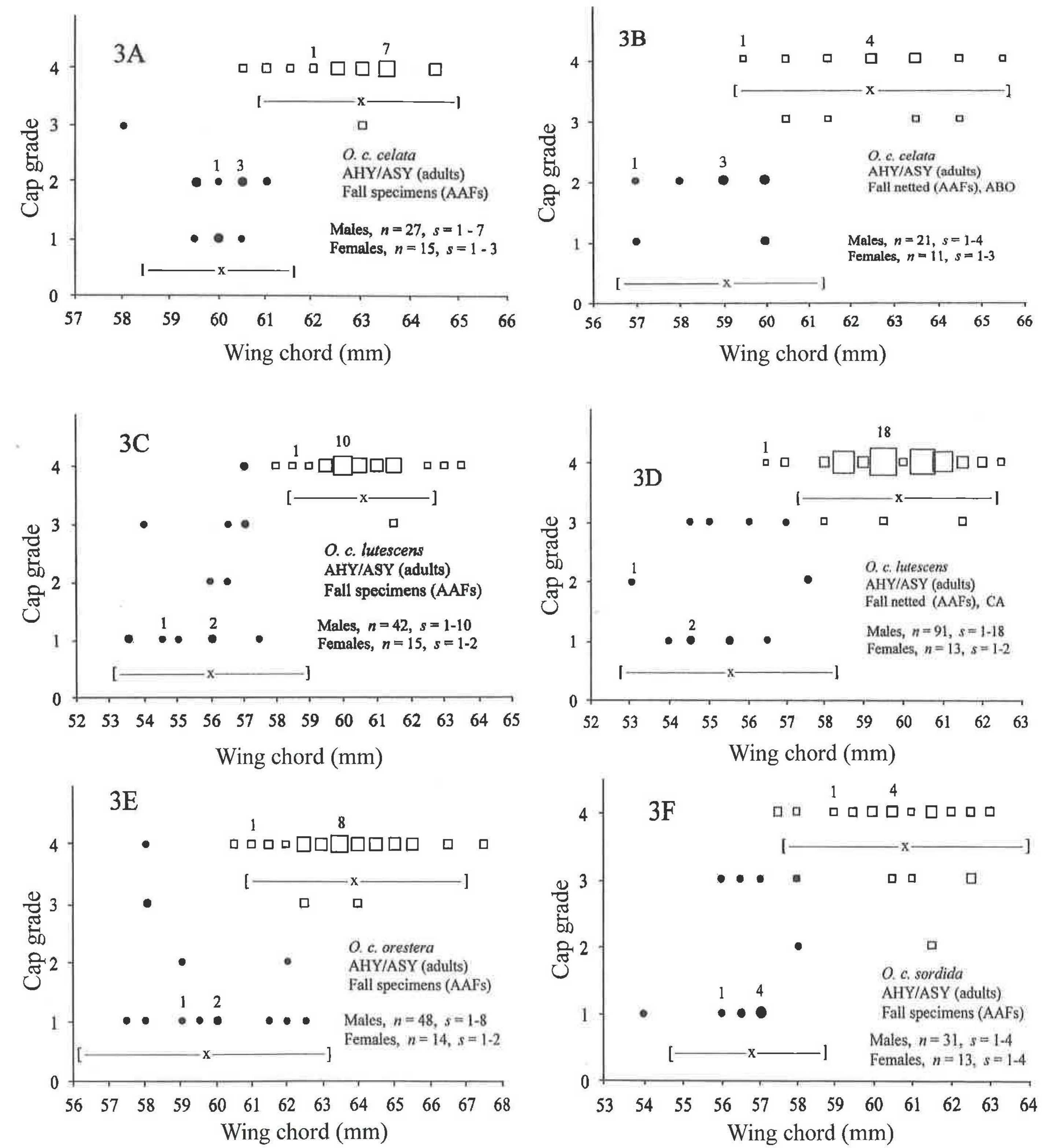
Figs. 1A -F continued



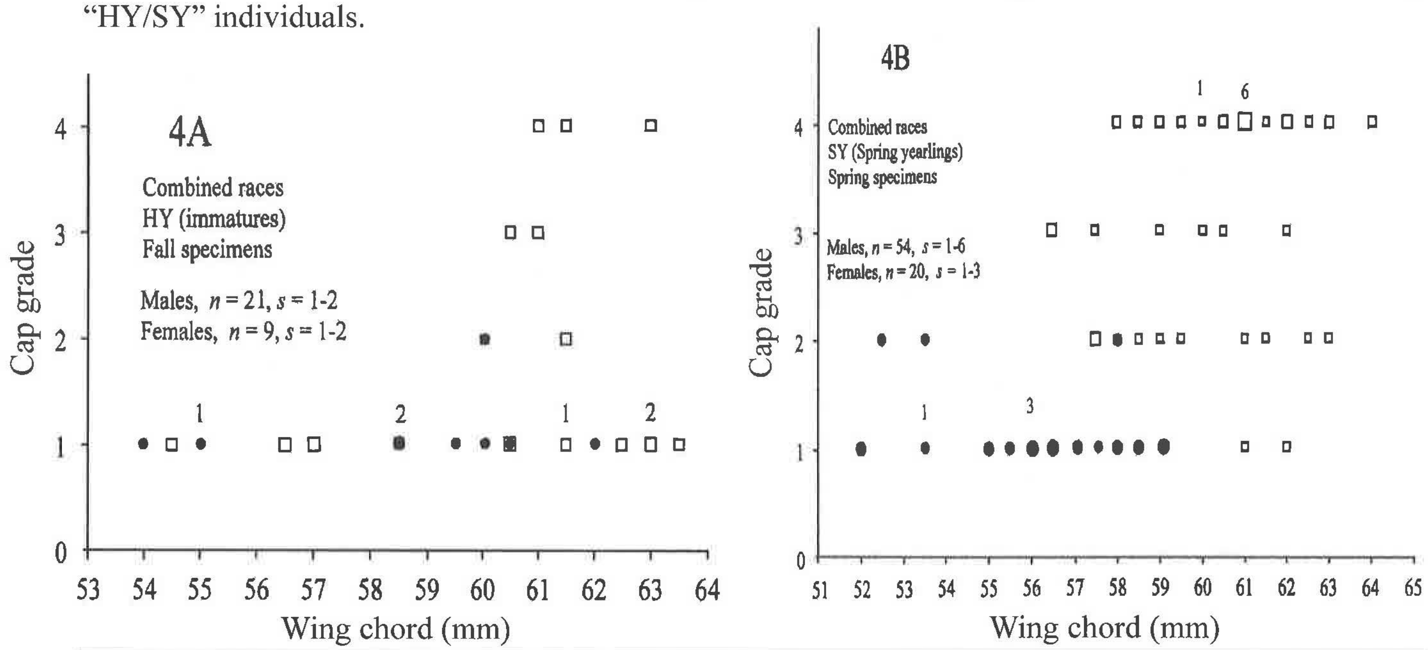
Figs. 2A - B. Approximate wing chord relationships related to age differences between "AHY/ASY" and "HY/SY" individuals, and to primary tip wear differences between fall and spring individuals, for males (2A) and females (2B). "AHY/ASY" individuals are represented by square data markers and solid regression lines, and "HY/SY" individuals by triangular data markers and dashed regression lines. The wing chord measurements of "AHY/ASY" males and females in the fall provide the baselines (set at zero) for subsequent reduced wing chord lengths based on age and/or season. Approximate wing chord relationships are based on empirical mean wing chord data presented in Table 2, and on knowledge of relative seasonal, age, and sex differences in wing chords. We assume wing chord relationships are similar for all *O. celata* subspecies.



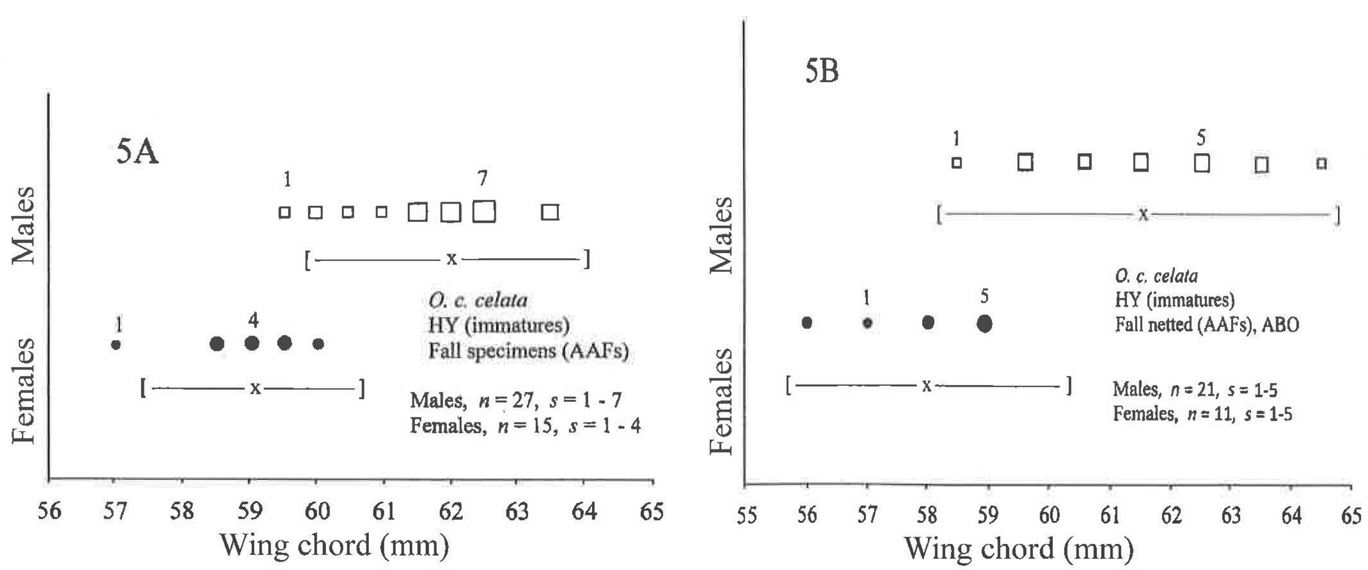
Figs. 3A - F. Scatter diagrams showing the paired cap grades and wing chords for "AHY/ASY" (adult) male and female Orange-crowned Warblers in the autumn. The subspecies, data marker relationships for sex and relative number of individuals, meanings of s and n, and the functions of error bars around means (x) are the same as in Figs. 1A – F. We have applied sex-specific approximate adjustment factors (AAFs) to the spring data in Figs. 1A – F to arrive at the approximate lengths of "AHY/ASY" wing chords that should exist in the fall.



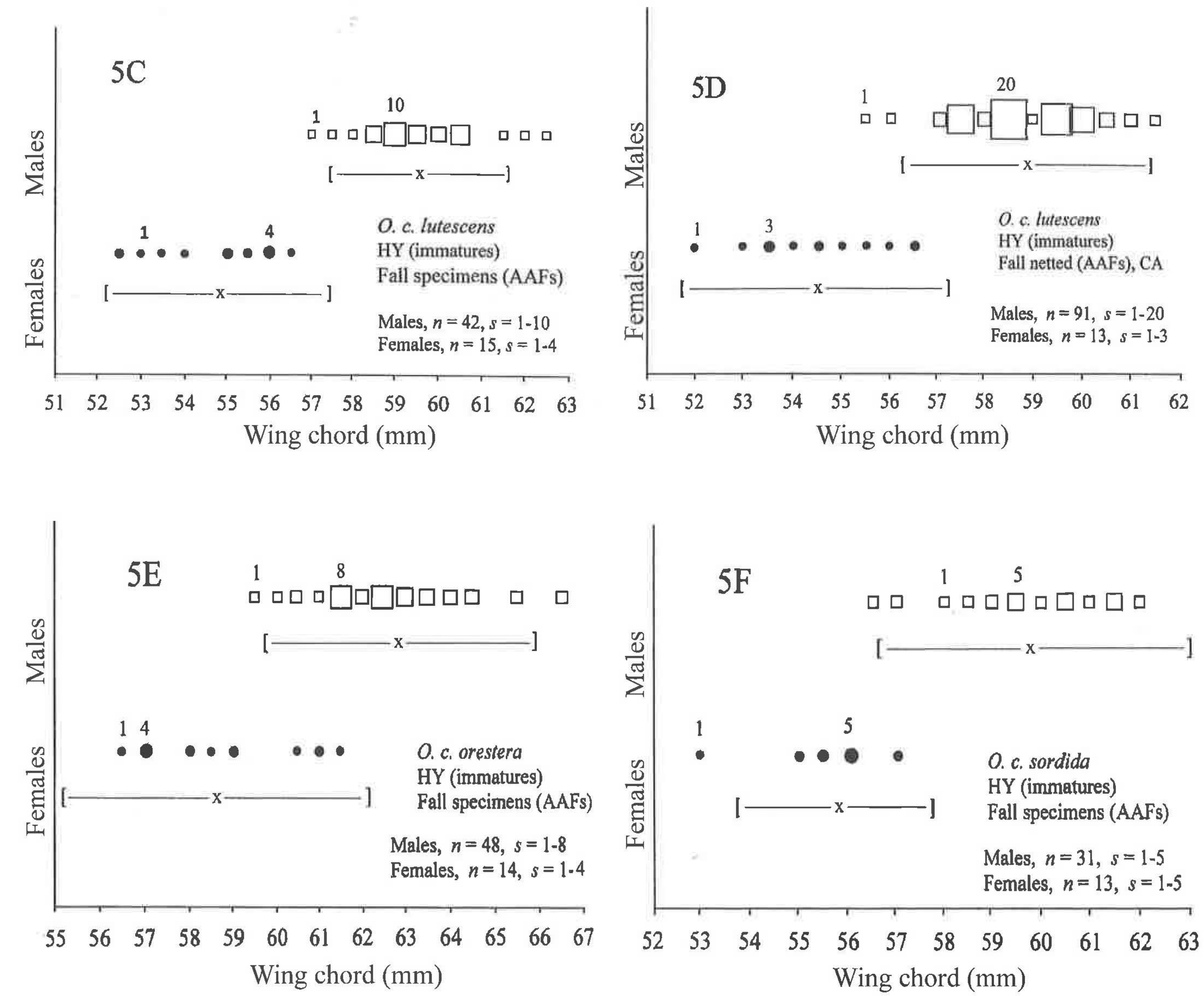
Figs. 4A - B. Scatter diagrams showing the paired cap grades and wing chords for male and female Orange-crowned Warbler museum specimens for pooled races of "HY" (4A, immature, fall) and "SY" (4B, spring yearling, spring) "HY/SY" (subadult) individuals. Only the cap grade relationships are applicable for sexing netted specimens, since wing chord ranges vary among subspecies. Data marker relationships for sex and relative number of individuals, and the meanings of *s* and *n*, are the same as in Figs. 1A – F. These graphs should be used in combination with wing chord information in Figs. 5A - F and 6A - F for sexing "HY/SY" individuals.



Figs. 5A – F. Scatter diagrams showing the wing chord lengths for "HY" (immature) male and female Orange-crowned Warblers in the autumn. The subspecies, data marker relationships for sex and relative number of individuals, meanings of *s* and *n*, and the functions of error bars around means (x) are the same as in Figs. 1A – F. We have applied sex-specific AAFs to the adult spring wing chord data in Figs. 1A - F to arrive at the approximate lengths of wing chords that should exist for "HY" individuals in the fall.



Figs. 5A -5F continued



Figs. 6A – F. Scatter diagrams showing the wing chord lengths for "SY" (spring yearling) male and female Orange-crowned Warblers in the spring. The subspecies, data marker relationships for sex and relative number of individuals, meanings of *s* and *n*, and the functions of error bars around means (x) are the same as in Figs. 1A – F. We have applied sex-specific AAFs to the adult spring wing chord data in Figs. 1A – F to arrive at the approximate lengths of wing chords that should exist in "SY" individuals in the spring.

Figs. 6A -F continued