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Errors associated with using colored leg bands to identify wild birds

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ABSTRACT. Avian field studies commonly employ colored leg bands to follow individual birds without recapturing them. However, this technique is subject to several types of reporting errors. In a laboratory setting under ideal conditions, we marked model birds with colored band combinations to examine resighting rates and errors made by trained and untrained observers. We varied both the time of exposure and the number of birds presented to observers in a series of replicate trials. We found large variation in the number of incorrectly recorded combinations among both trained and untrained observers. The mean error rate for trained observers was 5%, and for untrained observers was 16%. In both groups, error rates significantly increased when observers were exposed to more birds or observation intervals were short. The most common type of error involved switching band combinations on left and right legs. In some cases incorrectly recorded combinations matched actual combinations used on other birds. We also found that resighting probabilities depended on the particular colors used. Because this study was performed under indoor lighting conditions and at a relatively close distance (to mimic conditions under which birds are viewed at nearby feeders), we suggest that the error rates we observed likely represent low estimates and that error rates under field conditions will be higher.

SINOPSIS. **Errores asociados con el uso de bandas coloreadas para las patas para identificar aves silvestres**

Estudios de campo con aves a menudo usan bandas de patas coloreadas para seguir aves sin recapturarlas. Sin embargo, esta técnica está afectada por varios tipos de errores de reportaje. Marcamos modelos de aves con combinaciones de bandas de patas en condiciones ideales creadas en un laboratorio para examinar las tasas de redetección visual y los errores cometidos por observadores entrenados y sin entrenar. Variamos tanto el tiempo de exposición como el número de aves presentadas a los observadores en una serie de pruebas. Hallamos una gran variación en el número de combinaciones incorrectamente registradas tanto entre observadores entrenados como entre los no entrenados. La tasa de error promedio en observadores entrenados fué de un 5% y en los no entrenados fué del 16%. En ambos grupos las tasas de error aumentaron significativamente cuando los observadores se expusieron a más aves o cuando se acortó el intérvalo de observación. El tipo de error más común fué confundir la combinación de bandas entre las patas derecha e izquierda. En algunos casos las combinaciones incorrectamente registradas coincidían con combinaciones reales usadas en otras aves. También hallamos que la prohabilidad de redetectar visualmente depende el los colores particulares utilzados. Debido a que este estudio se llevó a cabo bajo condiciones de luz interior y a una distancia relativamente corta (para imitar las condiciones bajo las cuales las aves se ven en comederos cercanos) sugerimos que las tasa de error que observamos prohablemente representen estimados bajos, y esperamos que bajo condiciones de campo las tasas de error sean mayores.

Key words: bird identification, color banding, mark-recapture, passerine, resighting

Banding birds with combinations of metal and plastic color bands is a common technique used by ornithologists to mark individuals. In fact, during 2001, 19 out of 105 research papers published in the Auk used color bands to identify individual birds. By marking birds with colored leg bands, it is possible to record their presence in a population or group using "sight recoveries" without recapturing them (Kikkawa

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1997). Furthermore, there are few documented negative effects of colored leg bands on behavior or survival of birds (Weiss and Cristol 1999; Bart et al. 2001), although certain band colors may influence the breeding status of males of selected species (Johnsen et al. 2000).

Color banding has many applications, particularly in the fields of behavioral ecology and population biology. Methods hinging upon this technique are used in many studies, e.g., to estimate annual return rates and survival (Rogers et al. 1991; DiQuinzio et al. 2001), reproductive success (e.g., Kempenaers et al. 1992), disease prevalence and host recovery (Nolan et al. 1998; Hartup et al. 2000), and the interaction between feeding and vigilance (Slotow and Rothstein 1995). Two general types of field protocols are associated with color banding as a means of identification. First, individual color-banded birds on nesting territories can be followed extensively throughout the breeding season. Second, individuals or groups of birds may be resighted at standardized intervals or locations, where a single bird may be seen for only a very short period of time. This approach usually involves researchers watching birds at a fixed location for standardized time intervals. One common application of this procedure involves observing color-banded birds at feeding stations, either at sites with supplemental food spread on the ground or at bird feeders (e.g., Slotow and Rothstein 1995; Hartup et al. 2000).

In both types of studies, it is possible for observers to make mistakes when recording band combinations. Although careful screening can remove some errors from the data set (e.g., by searching for non-existent combinations), some incorrectly recorded combinations may affect data analysis and interpretation. Furthermore, studies involving observing birds at feeders usually require a much higher level of skill in data collection, as many birds may rapidly enter and exit the observers' field of view. As such, we chose to simulate this type of study in the present paper.

Few papers have addressed the magnitude and causes of error in the recording of color band combinations. Weiss et al. (1991) calculated resighting errors for neck-banded Canada Geese (*Branta canadensis*) and found that 3.0% of the resightings were incorrect. They concluded that these errors can have a significant influence on the population parameters being estimated and stated that other marking techniques (such as color banding) share many of the problems associated with correctly identifying and recording neck band codes.

In this study, we conducted a series of tests using colored leg bands applied to model birds on a simulated platform feeder to determine the frequency and type of errors made by observers recording color-band combinations. We tested both trained and untrained observers, presenting different numbers of birds for long and short intervals. Our objectives were not only to measure the rates and causes of error, but also to recommend methods that might counter several common errors. Further, we examined whether particular band colors were more or less likely to be missed or recorded incorrectly, thus potentially biasing resighting probabilities. Finally, this experiment was designed to simulate conditions encountered by researchers observing birds at feeders at relatively close distances. Because our tests were administered in a laboratory under indoor conditions (i.e., consistent lighting, non-obstructed views, and at a close distance), our results should thus be considered conservative estimates of error rates encountered under most field conditions.

METHODS

Four trained and four untrained observers participated in a series of tests in which they recorded colored leg-band combinations of model birds. Trained observers had between six months and six years previous experience resighting wild color-banded passerine birds using binoculars. Untrained observers had no or little experience using binoculars or recording colored leg bands, and we demonstrated these techniques to untrained observers prior to the first trial. All observers used 8.5×42 binoculars.

We placed Hughes celluloid leg bands (A.C. Hughes Ltd.) on 10 cm-tall model birds that resembled Red-headed Woodpeckers (*Melanerpes erythrocephalus*). Each bird was assigned a randomly generated four-band combination consisting of two bands on each leg. One of the four bands was a metal USFW leg band, and the remaining three bands were chosen from the following colors: red, light blue, dark blue, purple, white, yellow, and orange. Band combinations were generated following the protocol of Aho et al. (1988) using a program written in GAWK (W. M. Hochachka, pers. comm.). Model birds were presented to observers on a wooden platform (resembling a platform bird feeder) at a distance of 3 m, which is similar to distances at which wild banded birds may be resighted at bird feeders near windows. The platform was slowly rotated during the observation period to vary the birds' positions and thus simulate natural conditions. Color bands were recorded in the following sequence based on each bird's orientation: top left, bottom left, top right, and bottom right.

To measure the effects of the number of birds and observation interval on error rates, each observer participated in 24 trials in which these two factors were varied. We simulated flock sizes of 1, 4 and 7 birds and presented banded birds for either 30 or 60 s. Each treatment was replicated four times per observer, and in each trial a unique set of randomly-derived color band combinations was used. Each observer then recorded as many band combinations per trial as possible. Upon the completion of all trials, we scored recorded combinations as correct or incorrect based on a master list of actual combinations displayed. Errors were further classified as one of the following types: left leg-right leg switch, top-bottom switch, incorrect color recorded, or compound (more than one) error. Combinations recorded twice in the same trial and incomplete combinations were discarded from the data set.

Statistical analysis. Error rates and successful observations were estimated in three ways. First, we measured overall error rates as the proportion of erroneous color combinations relative to all color combinations recorded per observer per trial. Second, we measured recording effort as the proportion of color combinations recorded (correct or otherwise) relative to the total number of combinations presented. Finally, productivity was estimated as the proportion of correct observations relative to the total number of color combinations presented per trial, and was therefore a product of both success (1 − error rates) and effort.

All proportional estimates were arcsine-square-root transformed to normalize the error variance. Results were analyzed using a mixed-effects nested analysis of variance in which each observer was treated as a random variable nested within training type (SPSS Inc. 1999; Model: response = training type + observer (training type) + flock size + time). Data from the first three trials per observer were omitted as we treated these as an "acclimation period" for observers to familiarize themselves with the protocols. Because we found that one observer (No. 6) achieved unusually high error rates throughout all trials (~60% incorrect), we analyzed the data set with and without these outlier data. Finally, we used post-hoc tests (Tukey comparison of means) to evaluate the effects of different levels of flock size on observation errors.

To examine the effects of particular colors on error rates and resighting probabilities, we scored each combination used according to the presence or absence of the seven colors used. We then used logistic regression (LOGISTIC procedure; SAS/STAT Software 2001) to examine the effects of color on the probability a combination was missed (i.e., not recorded) by each of the observers. Because combinations presented alone (when flock size = 1) were recorded correctly by everyone, we omitted these from our analysis. Moreover, because colors used in band combinations were randomized over all trials, our analysis did not include the effects of flock size, time, or observer. After using likelihood ratio tests to compare the full model (response = red + orange + yellow + white + light blue + dark blue + purple) against the null model (response = intercept only), we used analysis of deviance to quantify the effects of each color alone on variation in resighting rates. Likelihood ratios were constructed using the change in deviance between the simpler model (without the color of interest) and the full model, and were compared with the χ^2 distribution for hypotheses testing (Agresti 1996).

RESULTS

Mean error rates (percentage of incorrect observations relative to all combinations recorded per observer per trial) varied greatly both among individuals and between training types. The average error rate for trained observers was 5% (±0.92 SE), and 16% (±10.69 SE) for untrained observers. Variation among untrained observers was higher (7–54%) than among trained observers (4–8%; Table 1). Observer 6

Table 1. Mean error rate for each observer measured as the percent incorrect observations relative to the total number of combinations recorded. Sample size (number of recorded combinations) is given in parentheses, and reflects the number of recorded combinations after removing the first three trials.

Observer	Training status	% Error rate (*N*)
1	Trained	8 (61)
2	Trained	5 (73)
3	Trained	6 (64)
4	Trained	4 (72)
5	Untrained	12 (70)
6	Untrained	54 (71)
7	Untrained	7 (67)
8	Untrained	31 (59)

recorded an unusually high percentage of incorrect combinations (54%), more than twice the error rate of most other observers. The error rate averaged among all observers was 16.5% (±6.31 SE), but removing observer 6 reduced this to 10.5% (±3.43 SE).

Analysis of variance showed that time, flock size, and observer nested within training type were all important predictors of error rate, both with and without data from observer 6 (Table 2). Trained observers clearly made fewer overall errors than untrained observers (5% versus 16%). However, the main effect of training status in this analysis was not significant, probably because of the high variance among individual observers. Time interval had a significant effect on observer error, so that mean error rates for 30-s trials were more than two times higher than error rates for 60-s trials (15% compared to 5.9%; Table 3). Error rates also increased with flock size, and comparison of means showed that observers made significantly more errors for flock sizes of 4 and 7 relative to a flock size of 1 (Table 2).

Success indicators (effort and productivity). Both trained and untrained observers had similar degrees of recording effort, measured as the proportion of combinations (both correct and incorrect) recorded relative to the number of birds presented (Table 3). This suggests that training status did not affect the rate at which observers recorded data. As expected, the proportion of combinations recorded was lowest when flock sizes were large and time was limited. In fact, the proportion of recorded combinations for both trained and untrained observers dropped to 54% when seven birds were presented for 30 s, compared to 88–100% for all other trials. Analysis of variance showed that flock size, time, and observer (nested within training type) had significant effects on observer effort (Table 2). Post-hoc comparison of means showed significant differences ($P < 0.05$) between all flock size levels. Thus, as the number of birds viewed increased, observers were able to record fewer of the available combinations on the platform. Observers also recorded more combinations during longer (60 s) intervals (Table 3).

Mean productivity (measured as the product of effort and accuracy) was highest among trained observers, and decreased with both larger flock sizes and limited time (Table 3). In fact, when seven birds were presented for 30 s, trained observers recorded fewer than half of the maximum possible combinations correctly. Analysis of variance showed that flock size, time interval, and observer nested within training type all had significant effects on realized productivity (Table 2). Comparison of means

Table 2. Results from nested mixed-model analyses of variance of transformed error rates, recording effort, and productivity as a function of training type, time, flock size and observer (observer 6 excluded). Model = training type + observer (training type) + flock size + time, where observer was treated as a random effect.

		Error rate			Recording effort			Productivity		
Source	df	Mean square	*F* value	*P*	Mean square	*F* value	*P*	Mean square	*F* value	*P*
Training	1	1.12	3.77	0.11	0.007	0.064	0.808	3.365	2.276	0.182
Flock size	2	1.266	15.3	0.00	4.413	121.38	0.00	4.779	43.416	0.00
Time	1	0.663	8.01	0.005	1.757	48.333	0.00	2.535	23.035	0.00
Observer	6	0.297	3.59	0.004	0.118	3.241	0.005	1.478	13.431	0.00

Table 3. Mean error rates, recording effort, and productivity of trained and untrained observers for each treatment (see text for an explanation of each variable). All proportions were transformed to percentages (%) for the table below.

Time (s)	Flock size	Error rate		Recording effort		Productivity	
		Trained	Untrained	Trained	Untrained	Trained	Untrained
30	1	0	19	100	100	100	81
30	4	16	39	94	89	78	50
30	7	9	36	54	54	49	37
60	1	0	17	100	100	100	83
60	4	2	21	98	98	96	79
60	7	4	37	88	90	85	57

showed significant differences between all three flock sizes ($P < 0.001$), with increased flock size decreasing productivity of both trained and untrained observers (Table 3).

Error types. The most common type of error resulted from switching band combinations on left and right legs, so that 57% of all errors were left-right leg switches (Table 4). Although one observer (observer 6) accounted for a large proportion of these errors, these mistakes were also common among other observers. The second-most common error (17% of the 112 total errors) involved mistakes in recording a single color band. Approximately half (8/19) of these errors occurred when observers confused dark blue and light blue bands. Top-bottom switches were less common, accounting for less than 10% of all errors, and the remaining mistakes were compound errors (where multiple types of errors were made).

Color effects on resighting and error rates. Different colors affected the probability that combinations were missed (i.e., not recorded) by observers in trials where more than one bird was presented. The mean proportion of 'missed' combinations (i.e., combinations that observers did not attempt to record) was 30%, out of the total 88 combinations presented to eight observers (for a total of 704 possible combinations). Logistic regression analysis of the presence of each color (as yes/no categorical predictors) indicated that certain colors had strong effects on whether or not combinations were missed. Likelihood ratio tests of the full model (proportion missed = red + light blue + dark blue + yellow + orange + purple + white) against the null model (intercept only) were highly signficant (χ^2 = 24.31, df = 7, $P < 0.001$). Analysis of deviance for effects of individual colors showed that combinations with yellow, orange, or blue bands were significantly associated with whether or not bands were recorded (Table 5). The direction of slope for light blue bands was positive, suggesting that this color was more likely to be missed, whereas the slope direction for yellow and orange bands was negative, indicating these colors were less likely to be missed. Given that a combination was recorded by observers, color had no significant main effect on the proportion of errors (χ^2 = 8.402, df = 7, P = 0.298) when comparing the full model against the null model. Finally, we found no effects of repeated colors (i.e., whether a particular band combination had multiple occurrences of the same color) on either the proportion of combinations that were missed (χ^2 = 0.5597, df = 1, P = 0.4544) or the proportion of errors made in recording combinations (χ^2 = 0.5570 df = 1, P = 0.4555).

Table 4. Major types of errors made by each observer and their relative occurrence, here indicated by absolute number of errors rather than percentages.

Observer	Error type				Total
	Leg switch	One color wrong	Top-bottom switch	Compound	
1	8	1	0	0	9
2	2	1	1	1	5
3	6	1	0	0	7
4	0	1	2	0	3
5	6	6	2	2	16
6	31	1	2	8	42
7	3	1	2	1	7
8	8	7	2	6	23
Total	64	19	11	18	112

Table 5. Analysis of deviance likelihood ratio tests for color effects on the proportion of missed combinations. Because likelihood ratio tests of the full model (including all colors) against the null model were highly significant (last row), tests for each of the seven colors are shown. Colors marked with a double-asterisk were significant at the 0.05 level, and colors marked with a single asterisk were nearly significant.

Color effect (yes/no)	df	Wald χ^2 (Δ deviance)	Probability
Red	1	0.156	0.693
Light blue**	1	5.933	0.015
Dark blue	1	0.012	0.912
Yellow**	1	4.642	0.031
Orange*	1	3.427	0.064
Purple	1	0.067	0.796
White	1	1.376	0.241
Full model	7	24.31	0.001

DISCUSSION

Our study demonstrated that error rates associated with trained and untrained observers recording color band combinations averaged 5% and 16%, respectively. The experimental design simulated viewing one to seven birds at platform feeders at relatively close conditions and under favorable lighting. Thus, the error rates reported here likely underestimate the frequency at which errors occur under the majority of field conditions, where birds are seen at farther distances and under less favorable lighting. Although it is reasonable to assume that typical error rates of both trained and untrained observers in the field may be higher than what is reported in this study, our results should apply well to protocols based on resighting color-banded birds at feeders near windows, where lighting is favorable and distances are short.

A striking result of our comparison of error rates was the large degree of variation among untrained individual observers. This variation spanned 44 percentage points and clearly illustrates that there are large differences in peoples' abilities to observe and record color bands on model birds. Although certain untrained observers performed well, on average trained observers made far fewer mistakes. However, our analyses did not show a significant main effect of training status on error rates due to the large variation among individual observers.

Recording effort did not vary between trained and untrained groups, indicating that both types of observers recorded data at approximately the same rate. We can derive an estimate of the average speed for both trained and untrained individuals by examining recording effort in trials where seven birds were presented. An average of 3.5 combinations per observer were recorded in the 30-s trials, and six combinations per observer were recorded in the 60-s trials. This suggests that observers required 8.6–10 s to record each observation, which may represent the maximum speed at which any observer could record color-band combinations. Whether the combinations were correct, however, depended to a large degree on the experience of the observer, as the accuracy of untrained observers was far less than that of trained observers.

Flock size and time clearly had significant effects not only the number of combinations recorded but also on error rates, and this trend was evident for both types of observers. When only one bird was present, combinations were correctly recorded by nearly all observers. However, as the number of birds increased, both effort and productivity fell, and error rates increased. The effect of flock size is also linked to the time available for recording data, so that flock size mattered most when time was limited. This result has important implications for studies of flocking passerines, where moderate to large aggregations may be observed over short time intervals.

Mean error rates of 5.75% among trained observers are not sufficiently high to consider color-banding an unreliable method for identifying individuals, particularly because many errors can be removed from the data set after careful screening. However, some erroneously recorded observations are likely to match combinations found on other birds. For example, we found that of the 112 incorrect combinations across all observers, eight errors (7%) matched combinations of birds used elsewhere in this experiment. In these cases, observers identified a bird that was not in front of them but that existed in another trial. This result has important implications for researchers studying large numbers of color-banded birds, especially if the birds flock in large numbers or are ephemeral in nature. For instance, if an observer records an incorrect combination that matches a combination on another bird in the study, the observer would inadvertently resight the "wrong" bird. This problem will clearly increase with the number of banded birds in the study area, and for field studies where resightings are impaired by intervening vegetation, poor light, and faded colors on band combinations.

Most reporting errors are likely to stem from one of two underlying causes. First, some mistakes are caused by incorrect reading of band order or band color, which may be more likely when a bird's orientation is different from the observers. A second possibility is that errors are made during the recording process. For example, the most common error type was that of a left-right leg switch, which may reflect a problem differentiating between right and left sides of the bird, or difficulty in writing them down in the correct order. One proposal to reduce this second cause of error is to use a small voice recorder for recording band combinations, hence eliminating the need to transcribe data in the field. This method has also been suggested by Kikkawa (1997), who found that this method increased the speed of recording and allowed more identifications to be made.

Particular colors affected the probability with which a combination was "missed," suggesting that certain colors could bias records of resighted birds towards those with more conspicuous bands. In particular, band combinations with bright colors such as orange and yellow were more likely to be recorded than combinations with light blue, probably because observers noticed these colors first. The prominence of a particular color probably depends on lighting, background, and bird markings, so that color conspicuousness may be difficult to predict. Furthermore, limitations on color choice may not be feasible where thousands of color combinations are required to satisfy banding needs. However, our results do suggest that color prominence is an important consideration when designing a banding scheme, and colors that blend easily into background substrates or bird markings should be avoided. Moreover, analyses of resighting probabilities should correct for extreme biases that could affect measures of survival rates or movement.

Surprisingly, we found no effects of repeat colors on either error rates or resighting probabilities, indicating that observers are not more likely to see or record birds with multiple bands of the same color. However, this lack of a main effect may be caused by certain colors having opposite effects on color-band prominence (i.e., if double combinations of certain colors increased prominence, but double combinations of other colors decreased prominence). This suggests that the effects of colors on resighting and error rates are more complicated that we initially suspected, and may be difficult to account for in data analysis.

Our study emphasizes that observers of color banded birds must be trained before they can generate reliable data, thus challenging the validity of resighting data from volunteer-based programs in which observers may not have the necessary training to reduce error rates to an acceptable level. Although the mean error rate we found for trained observers was small, this should be considered a conservative estimate, since our experimental setup was under ideal conditions of light and feeder configuration. The majority of field conditions (where birds are obscured by branches, lighting is poor, or where birds are viewed against a green background) would probably increase resighting errors, and future studies of this issue may help to clarify the actual error rates encountered under such conditions.

Based on our findings, we recommend that observers receive adequate training and periodic testing to minimize their potential error rates, as it is evident that there is a wide range in the natural abilities of untrained observers. We also suggest that voice recorders could be used to collect data whenever large numbers of birds are resighted on a regular basis. Finally we recommend that researchers avoid biasing results by choosing colors that are neither extremely bright (e.g., fluorescent colors) nor dull, and by factoring resightability indexes into data analyses.

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