

A METHOD FOR DISTINGUISHING FLIGHT CALLS OF SEVERAL WESTERN BIRDS

CEDAR MATHERS-WINN, 1008 South Church Ave., Bozeman, Montana 59715;
thuja.sp@gmail.com

DEBBIE LEICK, 7071 Uncle Robert Lane #10, Missoula, Montana 59803;
deborahleick@hotmail.com

KATE STONE, 1001 S. Higgins Ave., Suite A3, Missoula, Montana 59801;
kstone@mpgranch.com

ABSTRACT: Billions of birds migrate under the cover of darkness, making them difficult to detect except by calls given in flight. Recording and identifying these calls can document the species of birds passing overhead and provide an index to their numbers. However, flight calls of some species are quite similar and difficult to tell apart. We investigated a method of identifying calls of several species whose calls are difficult to distinguish: the Solitary (*Tringa solitaria*) versus Spotted (*Actitis macularius*) Sandpipers and the White-crowned (*Zonotrichia leucophrys*) versus Brewer's (*Spizella breweri*) and Clay-colored (*S. pallida*) Sparrows. We generated audiospectrograms of diurnal flight calls of known identity and inspected these for qualitative criteria by which the calls could be distinguished without the need for measurements or statistical software. We then tested the efficacy of these criteria on a new set of previously identified flight calls. Consideration of multiple criteria allowed identification of ~50% of one of the two types of sandpiper calls analyzed and ~60% of the sparrow calls, so a significant fraction remained unidentifiable by this method. Nevertheless, we hope researchers and sound recordists will apply this guide to improve our understanding of migration throughout western North America. We also encourage recordists to contribute additional visually verified recordings to allow us or others to perform similar tests on other species and species groups.

Many bioacoustical studies gather and archive large volumes of audio recordings, but characterizing these recordings often proves significantly more difficult and time-consuming than their collection (Frstrup and Mennitt 2012). Though technologies such as autonomous recording units allow us to study species we cannot easily observe (Clark et al. 1996, Frstrup and Clark 2009, Frstrup and Mennitt 2012), software for analyzing acoustic data has not kept pace with analytical needs (Keen et al. 2014, Salamon et al. 2016). In many cases, researchers must identify calls individually, listening to recordings and visually inspecting audiospectrograms (visual representations of sound, commonly used in bioacoustics) of each. In the absence of software capable of sorting through and accurately categorizing calls, researchers need tools to aid species identification. This is particularly true in cases where different species produce similar calls, further complicating identification and analysis.

Autonomous recording units are useful in studying the nocturnal migrations of birds, as many species give characteristic vocalizations (nocturnal flight calls) in migration (Libby 1899, Graber and Cochran 1959, Evans and Mellinger 1999, Evans and O'Brien 2002, Farnsworth 2005, Farnsworth and Russell 2007). Although the nocturnal flight calls of many species are distinctive, some are similar to one or more other species, and researchers often

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resort to lumping indistinguishable calls into categories that may contain many species (Evans and O'Brien 2002, Sanders and Mennill 2014a, Watson et al. 2016, Evans 2021). The content of these categories (e.g., the warbler and sparrow species in the “double-banded upsweep” and “zeep” complexes of nocturnal passerine calls) may even vary regionally, according to presumed distributions and migratory pathways. This limits the use of nocturnal flight calls for exploring questions concerning the natural history and conservation of these species, such as population trends, migratory pathways, and species' responses to natural (Sanders and Mennill 2014b, Smith et al. 2014) and anthropogenic (Evans 2000, Watson et al. 2016) barriers to migration. Very few studies have attempted to distinguish species within such complexes (e.g., Landsborough et al. 2018).

We carried out an acoustical study of avian nocturnal migration in Montana and Idaho from 2012 to 2019. On the basis of the identification challenges experienced in this work, we present here a set of guidelines that we hope will allow researchers to distinguish between two groups of birds with similar flight calls. We investigated flight calls of known identity from the Solitary and Spotted Sandpipers (*Tringa solitaria* and *Actitis macularius*, two call types). We also compared flight calls of the White-crowned Sparrow (*Zonotrichia leucophrys*) with those of Brewer's (*Spizella breweri*) and Clay-colored Sparrows (*S. pallida*), the latter two considered together as a group. To accomplish this goal, we identified distinctive features visible in spectrograms of these calls and developed visual identification tools to enable researchers to classify calls without specialized software or statistical tests.

METHODS

Target Species

We selected target species from the species or species groups that presented identification challenges in the thousands of hours of recordings amassed from autonomous recording units operating in both western and eastern Montana and near Boise, Idaho, from 2012 to 2019 (Table 1). Our initial list included a variety of sparrows, warblers, thrushes, and shorebirds. We attempted comparisons only if we could acquire at least 10 recordings from each species or set of species that we wished to compare. Given the dearth of recordings from some of these species, this arbitrary cutoff seemed reasonable. The final species included in our analysis were the Solitary Sandpiper, Spotted Sandpiper, Brewer's Sparrow, Clay-colored Sparrow, and White-crowned Sparrow.

Descriptions of these species' flight calls vary, and in some cases diurnal contact/location calls are given at night. In developing this method, we defined the calls involved by using the following terms, descriptions, and spectrograms. The Solitary and Spotted Sandpipers do not have specific flight calls (Nichols 1920, Oring 1968, Moskoff 2020, Reed et al. 2020) but do frequently call during migration (Paulson 1993). We analyzed the two most frequent shared call types recorded: “weet” calls and “short” calls (possibly the same as other authors' “peet” calls, Reed et al. 2020). The Brewer's, Clay-colored, and White-crowned Sparrows all give similar “sip” or “tsip” calls in

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TABLE 1 Numbers and Sources of Calls Compared

Analysis set and species	Number of calls	Number of individuals	Source of calls ^a	Number of calls in comparison
Training set				
Sandpiper “weet”				706
Solitary	435	32	A	
Spotted	271	22	A	
Sandpiper “short”				288
Solitary	173	11	A	
Spotted	115	8	A	
Sparrow				382
Brewer’s / Clay-colored	200 / 48	15 / 8	A	
White-crowned	134	34	A	
Validation set				
Sandpiper “weet”				992
Solitary	189	14	A, R	
Spotted	803	30	A, R	
Sandpiper “short”				2530
Solitary	1252	24	A, R	
Spotted	1278	21	A	
Sparrow				920
Brewer’s / Clay-colored	107 / 11	13	A, R	
White-crowned	802	20	A, R	

^aA, public archive; R, other researcher.

a variety of contexts, including migratory flight (Hill and Lein 1985, Grant and Knapton 2020, Rotenberry et al. 2020).

We used a variety of methods to assemble calls for analysis. We asked researchers and community scientists for recordings of flight calls of known identity. We also acquired recordings from two public archives, the Macaulay Library (<https://www.macaulaylibrary.org>) and Xeno-canto (<https://xeno-canto.org>); these recordings accounted for the majority of the calls in our dataset. For each target species, we searched the archival databases for recordings tagged as “flight call” or simply “call.” We listened to each recording to ensure the desired flight calls were clearly audible and not significantly overlapped by other sounds, as either could influence the results of our analysis. To ensure that species were identified correctly, we used only recordings where the species’ identity was visually verified by the recordist or came from an established collection or scientific study. Because of the scarcity of recordings of flight calls of most of our target species, we did not limit our selections to recordings made in the western United States; some recordings were made in other parts of the country or in the species’ winter range in South America, Central America, or Mexico. By including calls from disparate regions, we hope to include different regional dialects (if any) so that our findings might be useful in areas outside of the western United States.

We amassed a total of 6606 calls from our target species (Table 1). Of these, we used 1913 as our initial training set and the remaining 4693 as a validation set to verify our findings. The calls in the training dataset came from Xeno-canto; most of those in the validation set came from the Macaulay Library, supplemented with some provided by other researchers.

Visual Analysis

We attempted to differentiate between calls on the basis of features visible in audiospectrograms. These we generated in Raven Pro, setting the axes to the same scales: time axis 0.301 seconds/line, frequency axis 12,000 Hz/line. Visual features of the call spectrograms were greatly influenced by the axes' scales, so setting the axes to the same scales each time was absolutely crucial. We identified visual features that we could assess as being either present or absent in each call, such as a sudden jump in frequency at the outset. Additionally, we defined these features so that the presence of any feature in a given comparison always indicated one species, and the absence of that feature always indicated the other. Ultimately, the features we assessed were unique to each set of comparisons.

In describing call features, we followed the terminology of Pieplow (2019) wherever possible. "Monotone" indicates a steady pitch, appearing as a horizontal line on the spectrogram. A "slur" is a directional change in the frequency of a call, appearing as a frequency contour angled either up or down. "Upslur" indicates a rise in frequency, "downslur" a fall in frequency. An "underslur" is a call or portion of a call with an initial fall and subsequent rise in frequency. "Overslur" denotes the opposite, a rise in frequency followed by a fall. Additionally, we refer to the "dominant frequency contour" of call notes. This is a continuous sound that accounts for the majority of the note's duration, to the exclusion of brief sounds occurring before, after, or during any discontinuous change in frequency such as a voice break.

Voice breaks were a common type of discontinuity in our dataset, and in our analysis we made particular use of features related to voice breaks. A voice break is an abrupt rise or fall in frequency, analogous to switching between registers in the human voice. On a spectrogram, voice breaks appear as disjunctures between two vertically separated frequencies within a call. Despite the apparent discontinuity, a brief frequency contour connecting the starting and ending frequencies on either side of a voice break is often visible. We refer to this intermediate sound as an "inflection contour."

After identifying an initial set of features, we calculated the percentage of calls with those features for each comparison group, then eliminated features in which the groups did not vary substantially. This left three or four features in each comparison that might be useful for distinguishing the species in question. Next, for each comparison, we created several classification schemas that either identified each call by the presence or absence of these features or left it unclassified. For each schema, we determined the number of calls assigned correctly, incorrectly, or left unclassified. We then calculated confidence levels for correct identification in each schema. Schemas for each comparison varied from more to less conservative. Less conservative schemas made more identification errors and left fewer calls unidentified, while more conservative schemas identified fewer calls with higher accuracy and left more calls unidentified.

To estimate how well these methods should perform on other datasets, we validated our model by applying the same methods to a novel set of calls. Because in two of three comparisons the validation trial outperformed the initial trial on test data, we pooled results from both the test and validation

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trials to compute overall confidence levels. To make this classification tool more accessible to researchers and sound recordists, we also created an illustrated guide to facilitate its use (Appendix at www.westernfieldornithologists.org/Appendix-Mathers-Winn-WB54-3.pdf).

RESULTS

All comparisons yielded features allowing us to distinguish the species and groups analyzed with high accuracy. For each comparison, we present the percentages of calls that were classified correctly, incorrectly, and left unclassified, along with confidence levels for correctly classified calls. Besides the results of the training and validation datasets pooled, we also present the best-performing schemas for each comparison, those that correctly classified the highest percentage of calls with a confidence level of 95% or greater. See Appendix at www.westernfieldornithologists.org/Appendix-Mathers-Winn-WB54-3.pdf for descriptive statistics and a gallery of example spectrograms for each set of comparisons.

Solitary vs. Spotted Sandpiper: “Weet” Call

Four characteristics of the “weet” call distinguish the Spotted and Solitary Sandpipers: we designate these the “foot,” “knee,” “dip,” and “tail” (Figure 1).

Foot. A call has a “foot” if it begins with a short monotone or nearly monotone segment at a frequency lower than the dominant frequency contour and this segment precedes either a voice break or a more gradual upward slur before the start of the dominant frequency contour.

Knee. A call has a “knee” if near the onset of the note there is a voice break that contains a vertical or nearly vertical inflection contour joining the dominant frequency contour at a sharp angle, close to 90°.

Underslur. A call has an underslur if the frequency of the dominant fre-

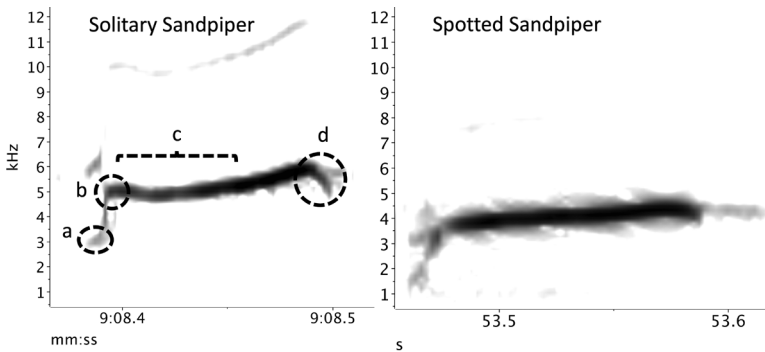


FIGURE 1. “Weet” call types given by the Solitary and Spotted Sandpipers during nocturnal migration. The Solitary Sandpiper call shows all four distinguishing features: (a) “foot,” (b) “knee,” (c) underslur, and (d) “tail.” The Spotted Sandpiper’s call lacks these features.

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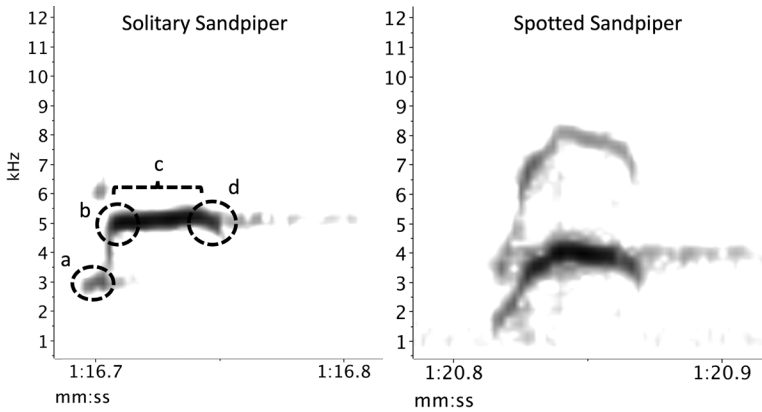


FIGURE 2. “Short” call types given by the Solitary and Spotted Sandpipers during nocturnal migration. The Solitary Sandpiper call shows all four distinguishing features: (a) “foot,” (b) “vertical,” (c) dominant frequency contour “straight or underslurred,” and (d) a “tail.” The corresponding call of a Spotted Sandpiper lacks a vertical onset, and its contour is not flat or U-shaped.

quency contour falls and subsequent rises. This feature is subtle, with the frequency changing only gradually over the duration of the note.

Tail. A call has a “tail” if there is a downslur at its end. This feature is typically brief and angled between 90° and 45° from the end of the dominant frequency contour.

Each of these four features was more common in Solitary than in Spotted Sandpiper calls, but the traits’ incidence in each species varied considerably (Table 2). The incidence of these features was correlated, with correlation probabilities ranging from 30 to 90%, but we used all four because this allowed us to correctly identify the most calls. There was some overlap between calls of these two species in the characters we analyzed, but we correctly classified a large number of calls. Under the most conservative schema, only calls with all four features are classified as the Solitary, and only calls with none of these features are classified as the Spotted Sandpiper. Of the 1536 “weet” calls, this schema classified 22.1% correctly, 0.6% incorrectly, and left 77.3% unclassified. The confidence level was 97%, meaning that if an identification was made, there was a 97% chance that it was correct.

TABLE 2 Incidence of Features of the “Weet” Call of the Solitary and Spotted Sandpipers

Feature	Solitary	Spotted
Foot	72.9%	6.5%
Knee	89.8%	24.0%
Underslur	44.0%	6.9%
Tail	74.5%	44.7%

Spotted vs. Solitary Sandpiper: “Short” Calls

For “short” calls, we used the “foot” and “tail” features as described for the “weet” call, in addition to two others: “vertical” and “straight or underslurred.”

Vertical. We defined a “short” call as having a “vertical” component if the inflection contour appears vertical at any point. This feature differs slightly from the “knee” as described above because it does not require that the inflection contour join the dominant frequency contour at a sharp (nearly 90°) angle (Figure 2).

Straight or underslurred. A call is “straight or underslurred” if either of these terms describes the dominant frequency contour. Thus only overslurred calls do not meet this criterion. The presence of a tail can sometimes cause a call to appear overslurred, even when the dominant frequency contour is not. Therefore, if a tail is present, it should be ignored when this trait is assessed. Additionally, some calls may be slightly upslurred overall (frequency rises over the duration of the call). As long as the dominant frequency contour is not overslurred, these calls should still be classified as straight or underslurred, regardless of their overall angle or orientation on the spectrogram.

As for the “weet” call, each characteristic is more common in the Solitary Sandpiper than in the Spotted. Again, features were correlated (correlation probabilities between 70 and 90%), and the two species’ calls overlap in these features. On the basis of all four criteria being met simultaneously, of the 2789 “short” calls analyzed, 49.5% were classified correctly, 2.8% were classified incorrectly, and 47.7% were left unclassified. Percentages of calls with each feature are listed in Table 3. The confidence level for the pooled data was 95%, meaning that if a call was classified, there was a 95% likelihood that the classification was correct.

Brewer’s and Clay-colored Sparrows vs. White-crowned Sparrow

After pooling the calls of the Brewer’s and Clay-colored Sparrows, between which we found no consistent difference, we identified three features of the calls’ spectrograms that might distinguish them from those of the White-crowned Sparrow: falling contour, horizontal, and rising contour (Figure 3).

Falling contour. A call meets this criterion if the dominant frequency contour is preceded by a contrasting, sharply angled downslur. This downslur often but not always joins the dominant frequency contour at a 90° angle. Note that this feature is not the gentle downslur common in White-crowned Sparrow calls—the inflection contour is steep and forms an angle between 45° and 90° where it transitions to the dominant frequency contour.

Horizontal. We defined calls as “horizontal” if the dominant frequency contour is monotone, not slurred. If there is a voice break or other frequency

TABLE 3 Incidence of Features of the “Short” Call of the Solitary and Spotted Sandpipers

Feature	Solitary	Spotted
Foot	92.4%	14.9%
Vertical	83.5%	25.7%
Straight or underslur	88.0%	72.3%
Tail	81.0%	63.4%

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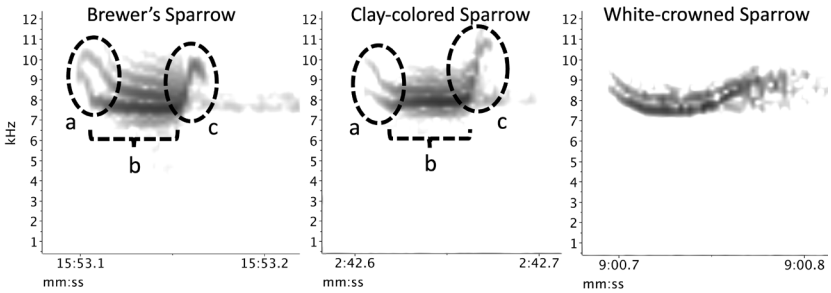


FIGURE 3. Three features distinguishing calls of Brewer's / Clay-colored and White-crowned Sparrows: (a) initial "falling contour," (b) dominant frequency contour "horizontal," and (c) final "rising contour."

modulation at the beginning or end of a "horizontal" call, it must form an angle with the dominant frequency contour. This is in contrast to the dominant frequency contour gradually merging with a frequency modulation at the start or end of the call. This is important to note, as White-crowned Sparrow calls are often underslurred, and in some cases the central, lower-frequency portion of the note may appear flat (White-crowned Sparrow call in Figure 3). In these cases, there is no obvious, contrasting frequency modulation that forms an angle with the dominant frequency contour, so the dominant frequency contour is not "horizontal."

Rising contour. A call has a "rising contour" if the dominant frequency contour is followed by a contrasting and sharply angled upslur. Again, it should be noted that this is not the gentle upslur of an underslurred White-crowned Sparrow call—the ascent is steep, and, as with a "falling contour," the angle at the end of the dominant frequency contour is approximately 45° to 90° .

Each feature was more frequent in the Brewer's/Clay-colored Sparrow complex than in the White-crowned Sparrow, but the consistency with which each of these appears in one species or complex varied (Table 4). Again, features were correlated, with correlation probabilities ranging from 30 to 50%. The best-performing schema was the most conservative, classifying calls with all three features as Brewer's or Clay-colored, those with none of these features as the White-crowned, and leaving the rest unclassified. Of the 1454 sparrow calls analyzed, this schema correctly classified 66.2% correctly, 1.5% incorrectly, and left 32.3% unclassified. The confidence level for the pooled data under this schema was 98%, meaning that if an identification is made, there was a 98% chance that it was correct.

DISCUSSION

Audio recordings of flight calls allow us to identify and count birds that migrate at night, but because some birds cannot be reliably distinguished by their flight calls, or the criteria for distinguishing them have not yet been discovered, this method cannot be applied consistently. Therefore, we attempted to make progress on this front by finding new criteria that distinguish two sets of species with similar flight calls by using features visible

TABLE 4 Incidence of Features of Flight Calls of the Brewer's/Clay-colored and White-crowned Sparrows

Feature	Brewer's/ Clay-colored	White-crowned
Horizontal	83.9%	29.5%
Falling contour	31.6%	1.8%
Rising contour	76.7%	18.7%

in audiospectrograms of those calls: the Solitary vs. Spotted Sandpipers and Brewer's/Clay-colored Sparrows vs. White-crowned Sparrow. Using only features represented graphically, we were able to identify up to 60% of calls that would have been otherwise unidentifiable, with very low error rates (between 0.5% and 3%). These results should allow for acoustic analysts to make more species identifications, though we acknowledge that even with these tools, a large portion of calls will remain unclassified.

Our success in finding criteria to increase the resolution of identification for these species will improve the ability of researchers and community scientists within their ranges to assess the migrants passing through their area. For us in Montana and throughout the Intermountain West, these distinctions will help illuminate migratory patterns in an area where research and data have been deficient by comparison to many areas of the United States. For example, the Spotted Sandpiper breeds commonly throughout our region (Reed et al. 2020), while the Solitary Sandpiper typically only passes through during migration (Davis 1961). We have just 42 observations of this species in the county where we conduct most of our research (<https://FieldGuide.mt.gov/speciesDetail.aspx?elcode=ABNNF01070>). In Montana, the Solitary Sandpiper's breeding range is much more limited, and the status of the population is poorly known. Indeed, we currently lack any information on the timing and magnitude of Solitary Sandpiper migration in the Intermountain West; the only data on the schedule of its migration inland come from farther east (B. Harrington, in Moskoff 2020). And though the Spotted Sandpiper breeds widely across Canada and south to the middle United States, its migratory patterns are also poorly understood (Reed et al. 2020). Differentiating the calls of these two species could provide benefits to our understanding of both.

The scarcity of visually verified recordings limited our analyses to those comparisons for which samples were large enough to reveal patterns (we did not attempt any comparison of a species with fewer than 10 calls available). We excluded many comparisons of interest because we could not obtain an adequate sample of calls. In our region, we would like to improve means of distinguishing the calls of the Song Sparrow (*Melospiza melodia*) and Fox Sparrow (*Passerella iliaca*) and those of species in the "double-banded upsweep" complex, such as the Tennessee Warbler (*Leiothlypis peregrina*), Nashville Warbler (*L. ruficapilla*), Orange-crowned Warbler (*L. celata*), Townsend's Warbler (*Setophaga townsendi*), Ovenbird (*Seiurus aurocapilla*), and Vesper Sparrow (*Pooecetes gramineus*). Calls of the Yellow-billed and Black-billed Cuckoos (*Coccyzus americanus* and *C. erythrophthalmus*) are usually distinct, but where call variants overlap, a definitive identification

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is extremely difficult. If any criteria distinguish the calls of subspecies of Wilson's Warbler (*Cardellina pusilla pileolata* vs. *C. p. chryseola*) and Brewer's Sparrow (*Spizella breweri breweri* vs. *S. b. taverneri*), their application would improve understanding of their population status and life history (Paxton et al. 2013, Rotenberry et al. 2020).

We call on recordists to target these species also, and ideally upload recordings to a public archive. Anyone might then follow the methods we have presented to discover and test criteria evident in spectrograms for differentiating problem species. In other regions where more species have been recorded, researchers might find recordings in public archives already sufficient to apply our methods. Finally, this method need not be limited to flight calls but could be applied to any difficult-to-distinguish sounds, avian or otherwise. We hope additional efforts toward recording and archiving visually verified flight calls will reveal criteria for distinguishing additional species.

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