Information for users of the electronic Lucid identification key to the species of *Anolis* lizard

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"Difficult taxa are those for which none but the specialist can identify species with any confidence, and the specialist not without tremors of unease."

Williams et al. (1995:4)

I Matching-based Computer Keys

In 1995 Ernest Williams and collaborators published a landmark paper describing their "computer approach" to identification of *Anolis* lizards (anoles). This work employed the data management and programming tool Hypercard to produce an application that matched a set of character scores from an unknown specimen to scores for the same characters in Williams' vast database of *Anolis*. The resulting "*Anolis* Handlist" was a stark and wonderful departure from the standard dichotomous keys used by taxonomists and field biologists.

The advantages of such matching-type keys over their paper dichotomous brethren are myriad and obvious. In matching keys, accurate identification is not dependent on correct decisions on early couplets, as it is in dichotomous keys, and a set of similar and possible species rather than a single final verdict may be rendered. Furthermore, one may start the identification process by eliminating species according to a particular character thought to be telling, rather than necessarily starting at the first couplet of a dichotomous key. As pointed out by Williams et al. (1995), the process of using a matching key better mimics the thought sequence of a practicing taxonomist whereby a set of particular important characters are first checked based on overall gestalt of the specimen, and subtler traits are examined as necessary.

The Williams et al. approach was ahead of its time. Today such electronic matching-based keys are commonplace. The Lucid (Lucidcentral.org) platform has become a standard means to present such keys, probably due to its widespread availability, functionality, and ease of use. Dichotomous keys are still used and still useful, mainly as the only keys available to most workers for most taxa at most field sites. But "computer approaches" are becoming as accessible as cell phones, and paper dichotomous keys concomitantly are becoming obsolete. Hopefully our application of the Lucid platform to the case of *Anolis* will allow widespread use of the matching approach to these lizards.

The *Anolis* lizards were Williams' area of expertise and archetypal example of a "difficult" taxon. Clearly, individual anoles frequently cannot be identified without "tremors of unease." There has never been a comprehensive dichotomous key for these forms, taxonomic confusions abound, and many of the 398 species of *Anolis* appear similar in morphology. Regional tools such as Schwartz and Henderson (1991) and

Kohler (2008) are supremely valuable. But clearly, there is a need for a tool to enable easier identification of anoles. I hope that the presentation here of an identification key and, by implication, a species list, will encourage and facilitate research on anoles.

II Characters

Character data for every species of *Anolis* (n = 398; see species justification at stevenpoe.net) were taken from 1000s of preserved specimens (see Acknowledgments for museum list) and from observation of 273 species of *Anolis* in life during field work in 19 countries. Dewlap photos for 248 species of *Anolis* are included, mainly through the generosity of colleagues (see Acknowledgments). Consider contributing a dewlap photo for use in the key (kunayalae@yahoo.com).

I employ the following characters to identify *Anolis*. Characters are followed by the range of potential states. Characters are based mainly on Williams et al. (1995; see also Poe [2004]). Descriptions and images of characters and character states are available in the key.

1 Location [Mexico: Pacific versant, West of Isthmus of Tehuantepec; Pacific versant, East of Isthmus of Tehuantepec; Caribbean versant including Yucatan/ Belize/ Guatemala/ Honduras: Mainland; Utila; Roatan; Guanaja/ Nicaragua: Mainland; Great Corn Island/ El Salvador/ Costa Rica: Mainland; Pacific slope lowlands; Caribbean slope lowlands; Cocos Island/ Panama: West of canal; East of canal/ Colombia: Western Andes to Pacific; Magdalena River Valley; Eastern Andes to Amazonia; North of Andes, including Santa Marta mountains; Gorgona Island; Malpelo Island/ Ecuador: Western Andes to Pacific; Eastern Andes to Amazonia/ Peru: Western Andes to Pacific; Eastern Andes to Amazonia; Bolivia/ Paraguay/ Brazil/ French Guiana/ Suriname/ Venezuela/ Caribbean Islands: Bermuda; Bahamas; Turks & Caicos; Cayman Islands (Grand Cayman, Cayman Brac, Little Cayman); Cuba (Isla de la Juventud, West--Pinar del Rio, La Habana, Artemisa, Central--Mayabeque, Matanzas, Villa Clara, Cienfuegos, Sancti Spiritus, Ciego de Avila, Camaguey, Las Tunas, East--Granma, Holguin, Santiago, Guantanamo); Jamaica; Puerto Rico (mainland); Mona; Desecheo; Vieques; Culebra; Hispaniola; Haiti (mainland); Navassa; Gonave; Les Cayemites; Vache; Tortue; Dominican Republic (mainland); Saona; Beata; Alta Velo; Vieques; Culebra; St. Croix; Carrot Rock; St. Thomas; St. John; Jost van Dyke; Tortola; Virgin Gorda; Anegada; Swan Islands; Sombrero; Anguilla; St. Martin; Saba; St. Eustatius; St. Christopher; St. Kitts; Nevis; Redondo; Barbuda; Antigua; Montserrat; Guadeloupe islands (Grande/Basse Terre, Desirade, Marie Galante, Petit Terre, Terre de Haut, Kahounne, Fajou); Dominica; Martinique; St. Lucia; St. Vincent; Grenadines; Grenada; Bequia; Mustique; Canouan; Mayreau; Union; Petit St. Vincent; Petit Martinique; Carriacou; Ronde; Grenada; Barbados; Trinidad; Tobago; Islands North of Venezuela (Los Testigos; Margarita; Blanquilla; Tortuga; Orchila; Los Roques; Las Aves; Bonaire; Curacao; Aruba); San Andres; Providencia]

2 Elevation in meters [0 – 3000]. For each species, elevational ranges were determined by first examining Vertnet (i.e., museum) records. Records with elevation data were accepted as valid unless there was some reason to doubt them (e.g., an

unbelievably high elevation; a likely misidentification; etc.). Some (not all) records lacking elevation data were georeferenced for elevation using Google Earth. These records were augmented by personal observation (i.e., my field notes) and examination of secondary literature (e.g., Schwartz and Henderson 1991). Lower elevational limits were rounded down to nearest 50 meters, upper elevational limits were rounded up to nearest 50 meters. For example, a species known from a single locality of elevation 1672 meters was listed as being found from 1650-1700 meters. For small islands where anoles have been found islandwide (e.g., St. Croix, Malpelo Island), the maximum elevation of the island was used. Additionally, elevations were taken and localities were georeferenced for elevation from original species descriptions.

3 Snout to vent length (SVL, body length) in millimeters [0 - 200]

4 Number of scales across the snout between the second canthals [0 - 30]

5 Number of postmental scales [2-12]

6 Number of scale rows between subocular and supralabial scales [0, 1 or more]

7 Nasal area [circumnasal contacts rostral, circumnasal contacts 1st supralabial, circumnasal + 1 scale to rostral, circumnasal + 2 scales to rostral, circumnasal + 3 scales to rostral, elongate anterior nasal contacts rostral]

8 Minimum number of scales between supraorbital semicircles [0, 1, 2, 3, 4, 5]

9 Number of loreal scales [1-14, 15-29, 30+]

10 Number of elongate superciliary scales [0, 1, 2, 3, 4]

11 Size of interparietal vs. ear [ip < ear, ip = ear, ip > ear]

12 Number of rows of abruptly enlarged middorsal body scales [0-2, 5-15]

13 Number of abruptly enlarged sublabial scales [0, 1, 2]

14 Middorsal caudal scale rows [single, double]

15 Ventral scales [keeled, smooth]

16 Dorsal body color [brown, green, gray/white, blue]

17 Pattern on flanks [solid, lateral longitudinal stripe, short broad stripe over shoulder, bands, ocelli/spots, lichenous]

18 Nuchal lyre [absent, present]

19 Dorsal head interorbital bar [absent, present]

20 Tail [banded, solid]

21 Male dewlap [absent, small: extends posteriorly to axillae, large: extends posteriorly past axillae to chest]

22 Female dewlap [absent, small: extends posteriorly to axillae, large: extends posteriorly past axillae to chest]

23 Scales on dewlap [in rows of single scales, in rows of multiple scales, scattered]

24 Male dewlap color [yellow, orange, red, white, pink, blue, green, brown, peach, purple]

25 Toepads [enlarged laterally and distinct from claw, narrow and continuous with claw]

26 Axillary pocket [absent or shallow, deep and narrow]

27 Scales in supraocular disc [some enlarged and gradually decreasing in size, 2-4 abruptly enlarged, approximately equal in size]

28 Color of iris [brown, yellow, blue or grey, green, red]

29 Length of tail [approximately equal to SVL, 1.5 x SVL, 2 x SVL, greater than 2.5 x SVL].

30 Lateral scales [homogeneous, heterogeneous]

31 Anterior extent of adpressed hindlimb [to ear or posterior to ear, between ear and eye, to eye, between eye and tip of snout, past snout]

32 Number of expanded toe lamellae (as counted in Wiliams et al. [1995]) [6-50]

33 Number of supralabial scales between rostral and center of eye [4 - 12]

III Using the key

The key is designed to identify species of *Anolis* lizard ("anoles"). For a given unknown lizard, one may narrow the possibilities to *Anolis* by noting the combined presence of two traits: expanded scales beneath the digits ("toepads," present in almost all species of *Anolis*) and an extensible flap of skin under the head ("dewlap," present in almost all males and some females of *Anolis*).

The Lucid key to *Anolis* is accessible at *stevenpoe.net* (current password is 'EEW'). Once accessed, pertinent data may be entered into the character boxes (Fig. 1). As data are entered, incompatible species are eliminated and potential species are shown in the upper right panel. At any time, the user can click on the photo link next to a species name to see images of that species.

Useful commands.—The reader should access the Lucid Help screens to explore the full functionality of the anole key. However, in recognition that many if not most workers would prefer to just use the key rather than learn all the ins and outs of it, I here note some of the commands that my group has found to be most useful.

The **View->Image thumbnails** command should be enabled at all times. This command allows immediate thumbnail viewing of potential species.

Entities -> Sorting mode -> Ranked should be used to examine potential species that may have been eliminated by failing to match for single or a few characters. In some cases, a 'next-best' species may be a better identification than a 100% match, for example if a character state was assessed incorrectly, an aberrant specimen is in hand, or a range extension has been discovered.

Features -> Find Best will highlight the character that will best discriminate among the remaining species choices. For example, suppose you score an individual

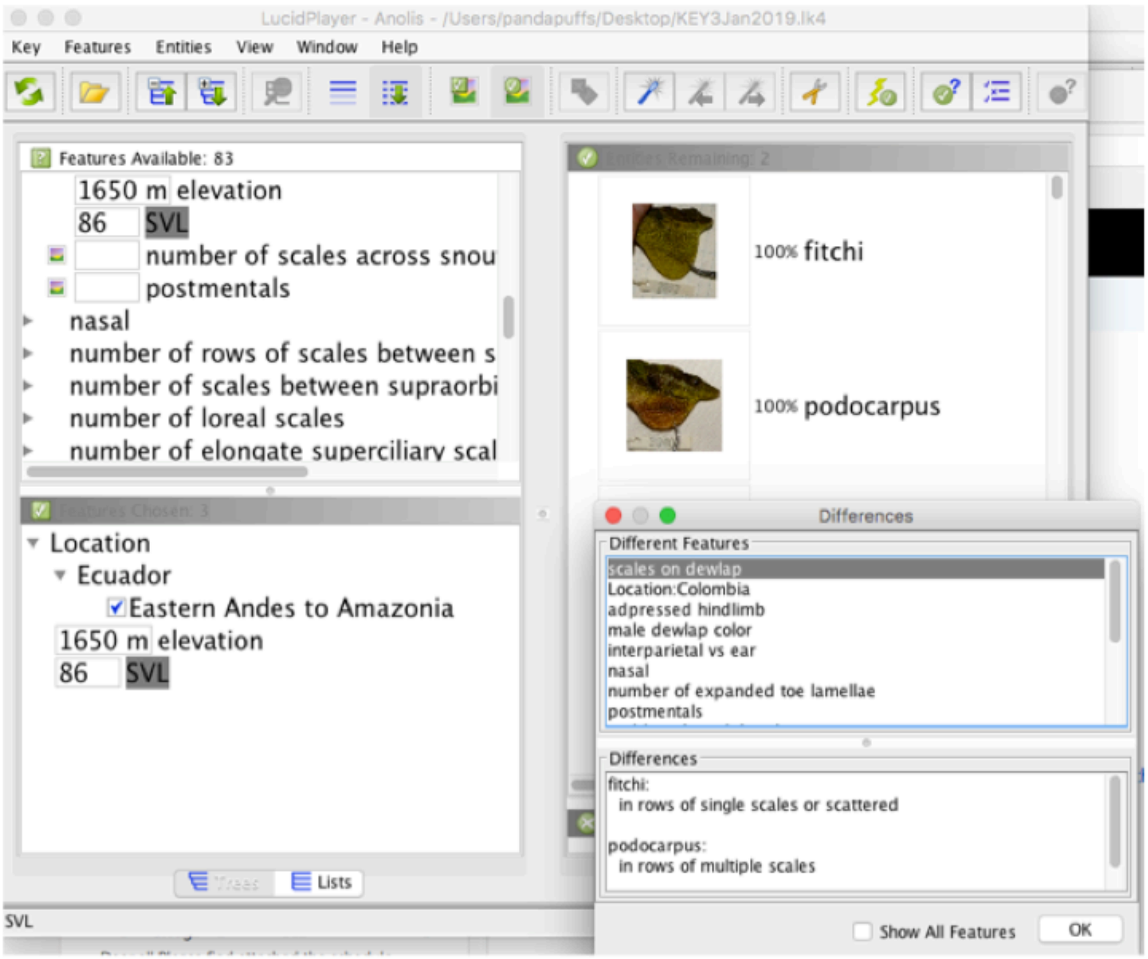

Figure 1. If you tell the key you have found an anole at 1650 meters elevation in the Eastern Andes of Ecuador with a body length of 90 millimeters, the key identifies *Anolis fitchi* and *A. podocarpus* as the most likely species. The "Differences" function suggests these two species may be distinguished by dewlap scalation.

from the Pacific versant of Mexico west of the Isthmus of Tehuantepec as possessing smooth ventral scales. This scoring reduces the number of candidate species to five. The **Find Best** function would direct you next to examine hindlimb length to further narrow your choices among these five. Similarly but less efficiently, the **Calculate Differences (Entities -> Differences…)** button can be used to examine how to differentiate candidate species. It gives a character list that may be accessed for information on each trait in each considered species.

Useful characters.—A naïve anole collector may enter whatever data is obvious to her or him. However, the key is more efficient if more telling characters are entered first. Here we review some of the more and less discriminating characters in the key.

The *male dewlap* is the single best character for identifying anoles. The approximate color pattern and size of the dewlap are usually invariant within species, and particular dewlap color patterns frequently are unique, or at least not shared by more than a few species in a region. The male dewlap formed the basis for my lab's earlier attempts at photo keys to some local anole faunas (e.g., Poe 2016), and figures prominently in useful guides that include anoles (e.g., Savage 2002; Kohler 2008). In many cases, the combination of locality and male dewlap color (as entered into the key, or simply examined in photos of candidate species) will be sufficient to identify a species in hand in the field. Of course, this option is not available for preserved specimens or many females.

Among non-dewlap characters, *body size* (SVL) is useful if a large anole has been found. Because juveniles of large species are similarly sized to adults of small species, body size is less useful for identifying small species. *Ventral keeling* is a traditionally important character in anoles that is frequently invariant within species, although in a few forms—for example, *schiedii* group *Anolis*—keeling may be difficult to see. Green body color and distinctive uncommon traits such as blue eyes, greatly enlarged middorsal scales, or a lateral body stripe will eliminate species characterized by common anole traits such as brown body color, brown eyes, uniform dorsal scales, and solid body pattern. Such traits are useful for narrowing down the potential identifications to a few candidate species.

The key may be useful in two situations. First, identification of a live individual in the field should be possible by noting a few characters of locality, dewlap, and color pattern. Second, identification of preserved museum specimens should be greatly facilitated by use of this key. In this latter function, it may be necessary to input several characters in order to narrow down the species possibilities. I have used this key mainly to identify difficult preserved specimens, for example the type specimen of *Anolis utowanae* (Poe 2014).

In closing, I note some caveats that restrict the functionality of this key, especially in its early versions. First, although great effort has been expended to include all known and personally collected data for anoles, a few species remain poorly scored in the key. Some species (e.g., *Anolis laevis, A. incredulus, A. vicarius*) are known from a single individual. In some of these cases, I have had the opportunity to examine the single type specimen and score traits but in others specimen examination has not been possible and I have had to depend on whatever information was presented in the pertinent type description. Regardless, information on a single individual obviously does not encompass the variation in a species. In these cases I have been faithful to the information available--that is, I usually have not interpolated unknown information even if such information seems obvious (e.g. *A. incredulus* seems certain to grow beyond its listed maximum SVL of 34 mm; see below).

The repercussions of poorly scored species are not consistent but rather are related to the kinds of scorings that were possible for a given species. Species are likely to be oversuggested as potential matches if they contain "?"s—unknown conditions—for many traits. This state of affairs may obtain if, for example, I was unable to examine specimens of a species that was originally described based on few traits. Conversely, if the key's information for a species includes several point estimates rather than ranges, that species may not be inferred as a best match even if an individual of that species is in hand. For example, assume you find a green anole of SVL 42 mm in eastern Cuba at an elevation of 1500 meters. Based on this information, the individual could be the second known specimen of *A. incredulus*—a small, green, high-elevation form. But *A. incredulus* will not be an optimal match based on the entered traits of locality, color, body size, and elevation, because its listed maximum SVL (34 mm) reflects the type specimen, which is a juvenile, and its listed elevation range is narrow (1850-1900 meters), as it is based on the only known site where this species has been found (Pico Cuba).

Future versions of the key will include solutions to the issues of poorly scored species (e.g., detailed treatment of known localities for each species, highlighting poorly-known species, a "similar species" section for each species, etc.). But for now users must simply be aware that poorly known forms are potentially problematic. The **Find Best** function, examination of type descriptions (see stevenpoe.net), especial focus on locality, and entering a range of values beyond those observed (e.g., if a species to be identified has been found at 1650 meters, enter values from 1500 and 1800 meters to check for species matches at slightly lower and higher elevations) should be helpful in these cases.

Second, the key still is lacking dewlap photos for over 100 species. As mentioned above, the male dewlap is the most important trait for identification of anoles. I expect that each future version of the key will contain more dewlap photos, and eventually, hopefully, every species will be documented with a male dewlap photo.

Finally, in spite of my best efforts over 10 years of work on this key, there undoubtedly are many errors in scoring for many species. I certainly have missed some reported invasions, failed to measure an especially large specimen of some species, and neglected to record a comprehensive range of trait values for many species, among other failings. My fervent hope is that colleagues will join me in vetting this key via its use in the field and in museum collections. The current version of the key will not assure accurate identification of all specimens of anoles. But hopefully this key is a starting point that may achieve some utility as a preliminary guide to anoles. Future versions, with the help of colleagues, may eventually serve as an authoritative guide to anole identification.

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