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Review of morphometric measurements used in anuran species descriptions and recommendations for a standardized approach

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Abstract

Standardization and repeatability is at the heart of all scientific research, yet very little literature exists to standardize morphometric measurements within vertebrate groups. This is particularly true for amphibians. Our study attempts to rectify this lack of methodological standardization for the measurement of morphological characters in anurans through an extensive literature survey of 136 species descriptions representing 45 currently recognized families of frogs. The survey revealed 42 morphological measurements represented in five percent or more of the literature reviewed. All measurements are listed by most commonly used name, acronym, and most precise definition, and we provide statistics summarizing the variation in measurement use and description from the surveyed literature. Of these 42 measurements, a subset of 16 were found in the top 75% of all surveyed descriptions and identified as a focal set of recommended measurements in an effort to standardize the morphometric measurements that describe anuran species diversity. Illustrations of these 16 measurements are provided as a visual reference for standardizing their measurement.

Key words: accuracy, character, consistency, definition, frog, methods, morphology, standards, synonym

Introduction

Morphometric measurements of herpetological organisms are necessary for species delineation, phylogenetic analyses, and even our understanding of evolutionary change in an organism's physical characteristics, yet there is little consistency of physical measurements and descriptions across, or even within, taxa (Dubois 2010; Wiens 2001). Terminology used by many researchers may seem obvious or self-explanatory, however, there are many instances when characteristics vary markedly in the literature and require explanation (Harvey *et al*. 2000). Despite the importance of the proper application of specialized terms and definitions in morphological studies of amphibian and reptile species, there are few publications that address this issue.

Recently a publication on *Anolis* taxonomy became the first to analyze the use of characters (both measurements and counts) in current species description publications (Köhler 2014). Köhler (2014) found a high degree of variation across surveyed *Anolis* literature regarding the choice, definition, and use of characters that were deemed important and how they were used and defined in each study. This publication also discussed the lack of detail and standardization in descriptions of species of the genus (Köhler 2014). Two decades prior to Köhler's study, in a publication on a computer-based application using morphological characters in the identification of *Anolis* species, Williams (1994) recognized 37 useful *Anolis* characters that could be well defined and incorporated into computer software. Both Williams (1994) and Köhler (2014) addressed issues in standardization of morphological terms, such as the use of equivocal terms and definitions for characters, and whether working definitions of each character are included in the published methods.

Two editions of the Dictionary of Herpetology provide sample terms for the study of herpetology, including those used to describe morphometric characters (Peters 1964; Lillywhite 2008). Lillywhite's (2008) newest edition provides guidelines for the application of terms relevant to herpetology. The author offers the definitions of herpetological terms, including the earliest or most relevant use of the word, current and obsolete usages, and

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synonyms and misnomers (Lillywhite 2008). Although intended for beginners in herpetology, and as a basic reference text, both editions are relevant to any usage and application of terms, and illustrate the importance of standardization and consensus of terminology (Peters 1964; Lillywhite 2008). There are also a handful of herpetological or amphibian-based texts that discuss a variety of anatomical features of anurans (e.g. Duellman & Trueb 1994; Vitt & Caldwell 2013), although there are no recommendations for specific characters over others.

Although these published works have provided sound reference tools, the taxonomic breadth of focused suggestions for practices in descriptive work remains quite focused. To date, a two-fold problem exists in in the absence of consensus or standardization in the measurement and description of morphological characters among frogs. First, there is no authoritative text that recommends or standardizes characters for use in species description publications. Second, and more importantly, publications describing new diversity or revising taxonomy are highly variable in a number of critical aspects: (1) the amount of information provided about morphological measurements, (2) the selection of morphological measurements incorporated into the descriptive study, and (3) the methods used to measure morphological characters. Lack of consistency in the above could lead to an over- or under-representation of new species, particularly if the measurements involved are diagnostic.

A definition of a phenotypic character should state its attributes and distinguish it from other characters based on observable differences, such as measurements (Rodrigues 1986). These characters, when selected as the diagnostic features of a species, can serve as a definition for inclusion in a group of similar organisms (Rowe 1987). Standardization is not only important for the selection of terms for features of an organism, but is also necessary for proper use of these features and characters in diagnosis. Several papers have addressed the definition and application of the word "character" and how it relates to descriptive and taxonomic studies (Ghiselin 1984; Colless 1985; Rodrigues 1986). Ghiselin (1984) focused on the equivocation of biological terms, or the use of a term with multiple meanings as if there were only one meaning. He defines "character" in taxonomy as a specific part of an organism and "character state" as an attribute or quality of the character. It is not enough, therefore, to simply label a feature of an organism as a character because the nature of the word character in its application of biology is ambiguous. A character or morphometric measurement must be explicitly defined as including specific features of an organism and referring to a specific context.

Having well-defined terminology for morphological measurements does not preclude the possibility for errors in measurement based on other factors, such as shrinkage due to ethanol preservation and measurement bias. One particular study by Lee (1982) on the effects of preservation on anuran morphology addresses the importance of measurement precision, and how ambiguity in the definition of characters affects precision and the ability to draw conclusions from measurements. Lee (1982) demonstrates that when morphometric characters are not defined as clearly recognizable anatomical features, measurements tend to be more distorted and variable. In addition, the study found that inter-observer interpretation and definition of a character affects precision in measurements (Lee 1982). Although Lee's (1982) study focuses primarily on specimen shrinkage as a result of preservation, it touches on measurement bias and error, which can also cause problems in the definition and application of morphometric traits. Measurement error can be quantified as the proportion of the total variance in within-individual measurement due to different measurers (Yezerinac *et al*. 1992). Measurement errors have been documented in both external and internal characters in a variety of taxa and have indirectly affected research such as condition indices, heritability of traits, and differentiation among similar species, and differentiation among similar species (Yezerinac *et al*. 1992; Blackwell *et al*. 2006; Goodenough *et al*. 2010; Viscardi *et al*. 2010; Roitberg *et al*. 2011). Measurement errors are further exacerbated when there is a lack of clear and consistent definitions for morphometric characters.

With the variability and ambiguity of herpetological terminology and morphological measurements in mind, we propose a new approach for standardizing the selection and description of anuran morphometric measurements for taxonomic and descriptive studies. We reviewed data on anuran morphometric measurements from published species descriptions and generated a list of the most commonly measured traits with their names, acronyms, and definitions. This list should serve as a basis for descriptions of anuran morphometric traits for future diagnostic, morphometric, and natural history studies; other characters that define taxa should be added to this central core list on an as-needed basis. This paper also highlights the current problems with lack of standardization and definitions of morphometric measurements used in anuran species descriptions.

Methods

Our survey of published anuran species descriptions and taxonomic reviews included 136 articles (References Section). We are aware of the dynamic and perpetually changing nature of organismal classification, and therefore, focused our survey efforts more on current research to explore how terms and characters have been used in recent practice. Although we reviewed publications from as early as 1960, the majority of the articles surveyed were published from 2000–2014 (81.6% of articles). Additionally, we wanted our data to be as taxonomically inclusive as possible, with the final dataset representing 45 of the 57 currently recognized anuran families (Frost 2015). Representative studies involving the following families were not included in the final dataset: Alsodidae, Ascaphidae, Batrachylidae, Ceratophryidae, Conrauidae, Heleophrynidae, Limnodynastidae, Nasikabatrachidae, Odontobatrachidae, Rhinodermatidae, Rhinophrynidae, and Scaphiopodidae. Species descriptions citing these families were not readily available during our literature review, possibly for one or several of the following reasons: i) a family may have not required recent taxonomic revision; ii) a family may be monotypic; or iii) a family may have low species-level diversity, and therefore, few formal species descriptions. We accessed articles primarily through Web of Science databases or through the University of Oklahoma Library Services interlibrary loan department.

We focused our review of collected literature only on parts of the article that would divulge morphometric measurements including the abstract, materials and methods, and results sections, plus associated tables, and recorded the list of measured morphological measurement that were relevant to the particular taxon or taxa of focus. For each study, we also recorded the family of the focal species, and the names and acronyms for each measurement listed along with definitions, when provided. From this dataset, a primary name and definition were chosen for each morphometric measurement, based on frequency in the literature, the greatest precision for measurement, and the least likelihood of interpretation error. Each article was put into one of four categories, based on the measurement definitions provided: (1) all definitions provided within the text, (2) some of the definitions provided, (3) no definitions provided in any form, and (4) definitions provided only via a citation for another article. This allowed us to understand how frequently the surveyed literature provided measurement definitions that other researchers could then use and interpret.

The full list of morphometric measurements cited in the literature were sorted from highest to lowest in terms of the number of citations and the number of anuran families associated with each measurement. This allowed us to describe a set of 16 measurements that were incorporated into 25% or more of the articles reviewed, representing a strong baseline for measurements to compare across anuran taxa. Based on the results of our literature review, we provide illustrations of the 16 most cited measurements to show how they should be measured on a representative organism.

Results

The surveyed literature included publications from a total of 39 journals, with the majority of articles published in *Zootaxa* (27.2%) and *Herpetologica* (16.9%; Fig. 1). The final morphometric measurement dataset included 116 disparate measurements that were relevant to the description of at least one species of frog. Of the 136 surveyed articles, 22 listed definitions or fully explained every measurement (16.2%), 60 (44.1%) listed definitions for only some of the measurements, and 30 (22.1%) listed no definitions. An additional 24 articles (17.6%) cited another source as the basis for the measurement used in the new species description (comprising 32 additional sources), but did not provide any definitions of their own.

Of the 116 measurements, 42 (36.8%) were present in five percent or more of the surveyed publications (Table 1). The remaining 74 (63.2%) measurements were included at low frequencies in published studies over the last half-century (Appendix 1). Interestingly, 45 of these 74 measurements (60.8%) were used in only one of the surveyed articles (Appendix 1). Forty-two (56.8%) of the low-frequency measurements were also completely without definition. Among the 42 most frequently cited measurements, the number of names used for a single measurement ranged from one (Snout–urostyle Length) to 25 (Eye–nostril Distance; Table 1). Within these 42 measurements, all had at least one definition per measurement with a range from one (Snout–urostyle Length) to nine (Foot Length; Table 1). The number of articles citing a given focal morphological measurement ranged from

TABLE 1. Summary of the 42 morphometric measurements referenced in five percent or more of the sampled articles, providing the name of the measurement, its primary acronym and primary definition, and the total number of names, definition, citations, and representative families per measurement. Entries with a "—" indicate measurements that lack an acronym or definition in the literature.

Primary Name	Primary Acronym	Primary Definition	Total # Names (Definitions)	Total # Citations	Total # Families	Fig. 3 Code
Head width	HW	At the widest point; angle at the jaws	11 (8)	130	42	A
Snout–vent length	SVL	Direct line distance from tip of snout to posterior margin of vent	7 (3)	129	39	B
Tibia length	TL	Distance from the outer surface of the flexed knee to the heel/tibiotarsal inflection	14 (3)	123	42	C
Interorbital distance	IOD	The shortest distance between the anterior corners of the orbits	23 (4)	118	37	D
Head length	HL	From the posterior of the jaws to the tip of the snout	5 (6)	115	36	E
Eye diameter	ED	Horizontally from the anterior to posterior corner of the eye	11 (5)	113	40	F
Internarial distance	IND	Shortest distance between the inner margins of the nostrils	11 (4)	105	37	G
Eye–nostril distance	EN	From anterior corner of the eye to the posterior margin of the nostril	25 (3)	96	35	H
Foot length	FL	From the base of the inner metatarsal tubercle to the tip of Toe IV	4 (9)	91	31	I
Tympanum diameter	TD	Greatest horizontal width of the tympanum	6 (2)	70	28	J
Thigh length	THL	Distance from the vent to the knee	13 (7)	66	29	K
Snout length	SL	Distance from the tip of the snout to the anterior corner of the eye	7 (3)	63	28	L
Hand length	HAL	From the base of the outer palmar tubercle to the tip of Finger IV	8 (4)	58	22	M
Forearm length	FLL	From the flexed elbow to the base of the outer palmar tubercle	10 (6)	48	23	N
Upper eyelid width	UEW	Greatest width of the upper eyelid margins, measured perpendicular to the anterior-posterior axis	4 (7)	47	22	O
Finger IV disk width	Fin4DW	The widest horizontal diameter of Finger IV	14 (4)	39	16	P
Finger IV length	Fin4L	From the proximal edge of the palmar tubercle to the tip of Finger IV	8 (5)	27	15	
Eye–tympanum distance	ETD	From the anterior margin of the tympanum to the posterior corner of the eye	13 (2)	27	11	
Toe IV length	Toe4L	From the metatarsal tubercle to the tip of Toe IV	9 (6)	26	14	
Snout–nostril length	NS	Distance from the center of the external nares to the tip of the snout	15 (2)	26	17	
Toe IV disk width	Toe4DW	The greatest horizontal distance between the edges of Toe IV disk	12 (2)	25	12	

……*continued on the next page*

TABLE 1. (Continued)

Primary Name	Primary Acronym	Primary Definition	Total # Names (Definitions)	Total # Citations	Total # Families	Fig. 3 Code
Tarsus length	TSL	From the tibiotarsal articulation to the base of the inner metatarsal tubercle	6 (3)	24	13	
Finger II length	Fin2L	From the proximal margin of the palmar tubercle to the tip of the Finger II	7 (4)	23	13	
Inner metatarsal tubercle length	IMT	The greatest length of the inner metatarsal tubercle	5 (3)	22	13	
Mandible to eye distance	MBE	Distance from posterior corner of mandible to posterior corner of eye	15 (4)	19	7	
Upper arm length	UAL	From the body to the elbow	3 (3)	18	10	
Horizontal tympanic annulus diameter	TAD	Horizontal diameter of the tympanum including the annulus	5 (2)	12	5	
Mandible–nostril distance	MN	From the posterior corner of the mandible to the nostril	9 (1)	11	8	
Finger II disk width	Fin2DW	Measure at the widest point on the Finger II disk	6 (1)	11	3	
Parotid length or parotid width	PW or PL	The greatest distance between the parotid glands	7 (4)	11	1	
Finger III length	Fin3L	From the proximal edge of the palmar tubercle to the tip of the Finger III	6 (4)	11	11	
Hind–limb length	HLL	Measured from vent to tip of Toe IV	2 (4)	10	9	
Lower arm length	LAL	Distance from the elbow to the tip of Finger IV	5 (2)	10	7	
Body width	BW	The greatest width of the body	3 (3)	9	7	
Widths of penultimate phalanges of Toe IV	PpToe4	Measure at midpoint of penultimate phalange of the Toe IV	5 (2)	9	2	
Widths of penultimate phalanges of Finger IV	PpFin4	Measure at midpoint of penultimate phalange of the Finger IV	6 (2)	9	2	
Toe V length	Toe5L	From the metatarsal tubercle to the tip of Toe V	5 (4)	9	8	
Toe I length	Toe1L	From the metatarsal tubercle to the tip of Toe I	5 (3)	9	9	
Snout–urostyle length	SUL	From the tip of the snout to the posterior end of the urostyle	1 (1)	8	6	
Finger IV width	Fin4W	Measure at the widest point on Finger IV	2 (3)	8	7	
Toe III length	Toe3L	From the metatarsal tubercle to the tip of Toe III	6 (2)	8	8	
Finger V length	Fin5L	From the proximal margin of the palmar tubercle to the tip of Finger V	5 (3)	7	7	

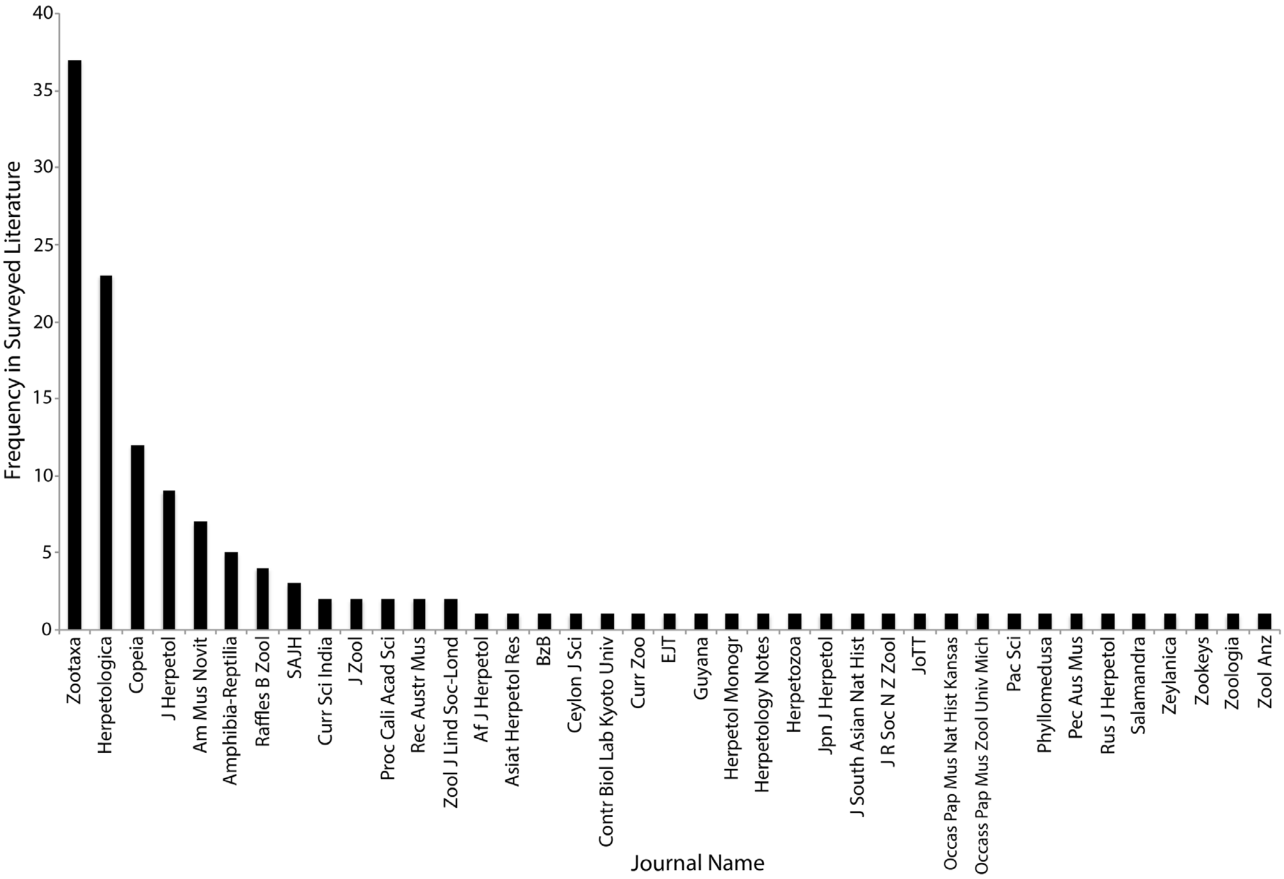

FIGURE 1. A histogram showing frequency of published articles by journal name. Where possible, journal names are labeled using standard abbreviations.

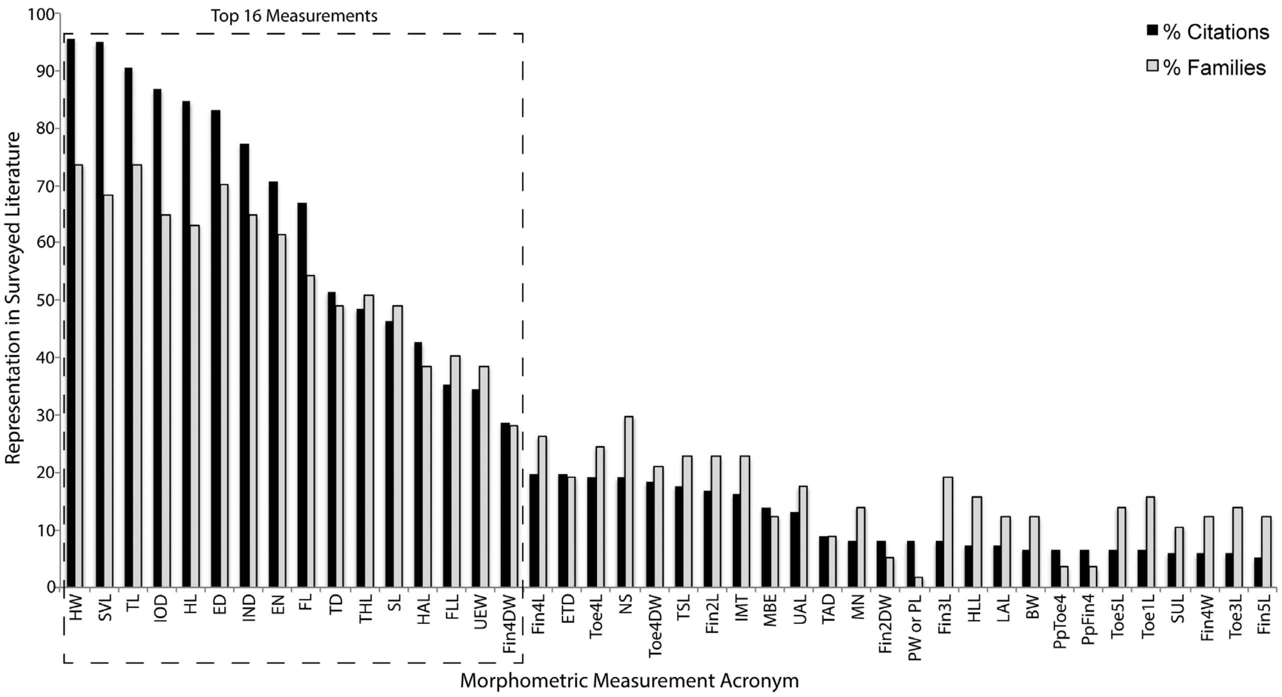

FIGURE 2. A visual representation of the 42 morphometric measurements that were represented in the top 95% of citations and families surveyed, as represented by percentage of the total. The top 16 measurements represented in 75% of the literature are highlighted by a box with a dotted outline.

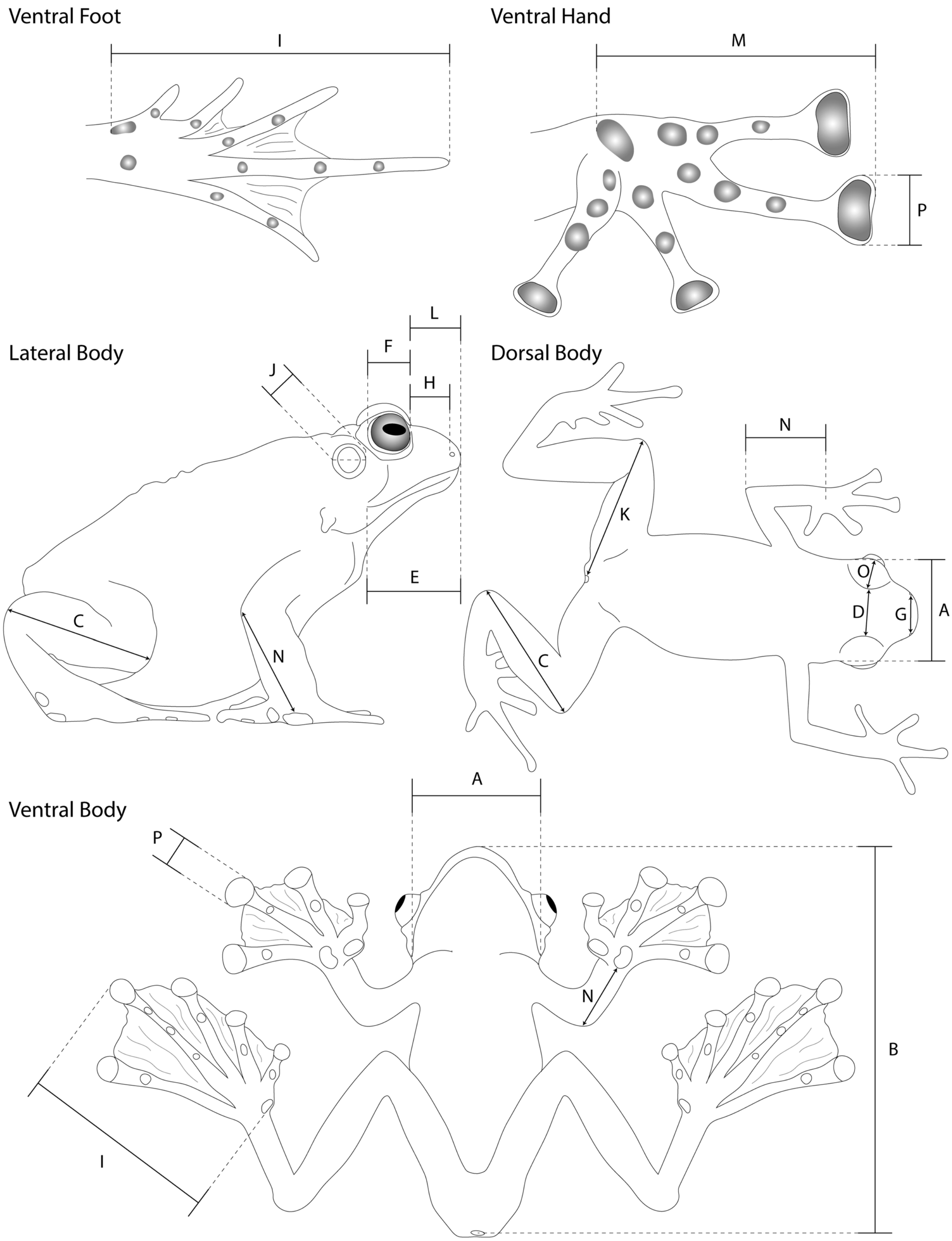

FIGURE 3. An illustration showing physical location on an anuran for the 16 morphometric measurements that were represented in the top 75% of citations and families surveyed. Each measurement is represented by a code on the figure; A: Head width; B: Snout–vent length; C: Tibia length; D: Interorbital distance; E: Head length; F: Eye diameter; G: Internarial distance; H: Eye–nostril distance; I: Foot length; J: Tympanum diameter; K: Thigh length; L: Snout length; M: Hand length; N: Forearm length; O: Upper eyelid width; P: Finger IV disk width.

seven (Finger V Length) to 130 (Head Width; Table 1). The number of families represented by each measurement ranged from one (Parotid Width or Length) to 42 (Head Width; Table 1). We provided the range, mean, and standard deviation for total number of definitions, representative families, and citations from the 42 measurements combined (Table 2). An analysis of all 42 measurements by percentage representation in the literature and families can be seen in Figure 2; which also highlights the 16 most represented measurements.

TABLE 2. Summary statistics of the 42 morphometric measurements referenced in five percent or more of the sampled articles. Range, mean, and standard deviation values represented for each parameter.

Parameter	Range	Mean	Standard Deviation
Total number of citations	7–130	42.6	40.8
Total number of families	2–42	17.4	12.6
Total number with definitions	1–70	16.0	17.4
Number of definitions per character	1–9	3.7	1.8

The top 16 most used morphometric measurements from the sampled literature were, in order from most cited to least cited (% of citations; % of families): Head Width (95.6; 73.7), Snout–vent Length (94.9; 68.4), Tibia Length (90.4; 73.7), Interorbital Distance (86.8; 64.9), Head Length (84.6; 63.2), Eye Diameter (83.1; 70.2), Internarial Distance (77.2; 64.9), Eye-nostril Distance (70.6; 61.4), Foot length (66.9; 54.4), Tympanum Diameter (51.5; 49.1), Thigh Length (48.5; 50.9), Snout Length (46.3; 49.1), Hand Length (42.7; 38.6), Forearm Length (35.3; 40.4), Upper Eyelid Width (34.6; 38.6), and Finger IV Disk Width (28.7; 28.1; Fig. 1). These measurements were found in more than 25% of the surveyed articles and families and are represented visually to increase measurement precision (Fig. 3). We follow Alberch and Gale (1985) in recognizing fingers as homologous to vertebrate digits II–V.

Discussion

Systematic studies of anuran diversity employ a specialized vocabulary for phenotypic characters, for which the definition and context of use can change the interpretation and accessibility of reported character states. This results in a lack of consensus on which morphometric measurements are most important in diagnosing species and how they should be defined and measured (Bisby & Nicholls 1977; Altig 2007). The issue is not only that morphometric measurements do not have discrete definitions, but also that there is an apparent lack of consistency in the level of descriptive detail about measurements that can be observed throughout taxonomic literature. In other words, the quality and detail with which researchers determine what morphological traits are important and how they are measured vary greatly among the surveyed articles.

According to our results, the majority of articles surveyed provide morphometric measurement definitions for only a subset of the measurements used, followed by articles with no definitions provided, articles with definitions provided via another source, and lastly, articles with full definitions provided in-text. In other words, it is uncommon for researchers to provide detailed information on the measurements that they use to delineate new species. This is concerning for the field and underscores a barrier to more standardized approaches for descriptive anuran research. For the articles that cite another source for their definition, it is necessary that the cited study provide complete morphometric measurement information and definitions. Too often this critical information was also missing from these cited publications; the article would instead reference yet another previously published work. This lack of clarity in morphometric measurements of diagnostic characters can also lead to incorrect cladistics analyses (Dubois 2010; Wiens 2001).

A key observation made in this survey is that the field of anuran systematics is experiencing a rapid growth of taxonomic descriptions, yet is accompanied by a disproportionately slower increase in authoritative studies cited, and often absent or poorly described methodological guidelines for subsequent researchers to use. For example, the character Tympanum Diameter (TD) was defined as such in the surveyed literature: (1) diameter of tympanum, (2) greatest diameter of tympanum, (3) horizontal diameter of tympanum, (4) horizontal width of tympanum (5) maximum tympanum diameter (Grant *et al*. 2007; Onn *et al*. 2009; Mo *et al*. 2010; Ohler *et al*. 2011; Rowley *et al*.

2014). Thus, Tympanum Diameter is an ambiguous character because its features and contexts are not explicit. The definition should instead be standardized as the greatest horizontal width of the tympanum, which includes the annulus, if present (Table 1), which would then provide the researcher with the unambiguous information on how to interpret and measure the character Tympanum Diameter. There can be no consistency in measurements if the same term can mean several different things depending on who is measuring and how they define it, which can lead to an inability to compare morphometric measurements across broad anuran taxa.

Our survey of anuran species descriptions revealed 16 key morphometric measurements that were represented in 75% of the surveyed articles. Through our analysis of the literature and the data obtained, we were able to reach consensus on a primary name, acronym, and definition for each of those 16 measurements, which we suggest should be the minimum used for all new anuran species descriptions. These traits were separated from a larger compiled list of 42 other measurements that may only be important for certain families and should still be considered in anuran species description and diagnosis, as needed. While our efforts attempted to generalize measurements that could be used for all 57 anuran families, there may be additional ones that are unique to only one family or genus, that were not included in our analysis (i.e. Tail Length in Ascaphidae). These special characters should not be excluded from a descriptive paper, but merely added on to a standardized baseline list of characters. One additional piece of information noted during our research was the relative lack of Sex as an identifiable character trait to include in new species descriptions (24.3% of literature surveyed; 29.8% of anuran families). Since many anuran families show sexual dimorphism (Vitt & Caldwell 2013), Sex of the type specimens should be listed, in addition to all other measured characters.

This research is not meant to provide an exhaustive list of all possible morphometric measurements that should be used in species diagnosis, but an attempt to standardize the most common measurements used in the literature today. We recommend that the measurements, acronyms, and definitions described herein be considered for use in the description and diagnosis of anuran species. In addition, we suggest that future researchers should provide the definitions to all measurements and characters used or cite another reference that does so, in order to provide maximum clarity for all anuran morphometric measurements. A cornerstone of the scientific method is the repeatability of relevant measurements (Wiens 2001). Although the outlined steps towards standardizing taxonomic terminology and definitions are seemingly simple, they have the potential to result in significant improvements in the precision and accessibility of anuran systematics.

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APPENDIX 1. Summary of the 74 morphometric measurements referenced in less than five percent of the sampled articles, providing the name of the measurement, its primary acronym and primary definition, and the total number of citations and representative families. Entries with a "—" indicate measurements that lack an acronym or definition in the literature.

Primary Name	Primary Acronym	Primary Definition	Total # Names (Definitions)	Total # Citations
Length of Finger II	THBL	From the edge of the palmar tubercle to the tip of Finger II	6	4
Length of Toe II	Toe2L	—	6	6
Head depth	HD	Greatest transverse depth of the head, taken posterior of the orbital region	5	4
Tibia width	TW	Maximum width of tibia along its length	5	4
Nostril diameter	ND	Measured along the long axis of the nostril, including the bordering flap and papilla	5	2
Femoral gland width or femoral gland length	—	—	4	2
Axilla–groin distance	AGD	Distance between posterior edge of forelimb at its insertion to the body to anterior edge of the hind limb at its insertion to the body	4	4
Forearm width	FAW	Greatest width of the forearm	4	3
Distance from heel to tip of Toe IV	TFOL	—	3	2
Nostril–lip distance	NLD	—	3	2
Inner palmar tubercle length	IPTL	Maximum length of the inner palmar tubercle	3	3
Inner toe length	ITL	—	3	2
Outer metatarsal tubercle length	OMT	Greatest length of outer metatarsal tubercle	3	2
Snout width	—	—	3	2
Tympanum–nostril distance	TND	Distance between the anterior-most point of the inner margin of the inner rim of the tympanum and the nostril	3	1
Diameter of Toe III disk	Toe3DW	—	2	1
Distance from distal edge of metatarsal tubercle to maximum incurvation of web between Toe IV and V	MTFF	Toes being spread	2	2
Distance from distal edge of metatarsal tubercle to maximum incurvation of web between Toe III and IV	MTTF	Toes being spread	2	2
Distance from maximum incurvation of web between Toe IV and V to tip of Toe IV	FFTF	Toes being spread	2	2
Distance from maximum incurvation of web between Toe III and IV to tip of Toe IV	TFTF	Toes being spread	2	2
Outer palmar tubercle length	OPTL	Maximum length of the outer palmar tubercle, measured parallel along forearm axis	2	2
Palm width	—	Distance across the palm at the distal edges of the two metacarpal tubercles	2	1
Sacrum width	SW	—	2	1

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APPENDIX 1. (Continued)

Primary Name	Primary Acronym	Primary Definition	Total # Names (Definitions)	Total # Citations
Thigh width	—	Maximum width across thigh (femur)	2	1
Diameter of Finger III disc	D	—	2	2
Width of upper arm	—	Width of center of the upper arm (humerus)	2	1
Distance between head and tip of the toe	FOL	—	2	2
Toe web extensions	T1W-T5W	—	2	2
Width of Toe I disk	Toe1DW	—	2	2
With of Toe IV	Toe4W	Measured at the base of the disc	2	2
Body mass	BM	—	2	1
Choana width	—	Maximum width of the choana	1	1
Eye area	EA	By measuring horizontal distance between bony orbital borders of eye to estimate radius (r) and by applying equation πr^2 to get an estimate of area	1	1
Fascicular length	—	Maximum length of the longest axis of the dentigerous fascicule	1	1
Interfascicular distance	—	Shortest distance between dentigerous fascicules	1	1
Greatest length of inner carpal tubercle	ICT	—	1	1
Greatest length of outer carpal tubercle	OCT	—	1	1
Length of inner metacarpal tubercle	IMC	Greatest length of inner metacarpal tubercle	1	1
Length of outer metacarpal tubercle	OMC	Greatest length of outer metacarpal tubercle	1	1
Height of lingual papilla	LPH	—	1	1
Knee-knee distance	KK	With both thighs extended at a 90 degree angle from the body forming a straight line between both femurs	1	1
Subocular tentacle length	—	From the base to the tip of the free tentacle	1	1
Width of lingual papilla	LPW	—	1	1
Fringe length on the outer margin of Toe V	TFL	Measured from the middle of the proximal subarticular tubercle of Toe V to the end of the fringe	1	1
Length of the medial flange on the inner metatarsal tubercle	FGL	—	1	1
Tympanum area	TA	—	1	1
Metatarsus length	—	—	1	1
Minimal distance between inner edges of femoral glands on opposite thighs	FGD	—	1	1

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APPENDIX 1. (Continued)

Primary Name	Primary Acronym	Primary Definition	Total # Names (Definitions)	Total # Citations
Odontoid length	OPL	—	1	1
Digital length	—	Measured from the proximal edge of the most proximal subarticular tubercle to the distal tip	1	1
Toe length	TL	Distance between posterior margin of most proximal subarticular tubercle or crease of articulation and tip of disk	1	1
Toe disk length	TPL	—	1	1
Toe disk width	TPW	—	1	1
Nares measurements	—	Taken from the center of the nares	1	1
Number of spines on lateral mdii	—	—	1	1
Number of spines on medial mdii	—	—	1	1
Number of spines on medial mdiii	—	—	1	1
Number of lateral line plaques	—	Number of transverse plaques between the eye and vent	1	1
Number of tubercles under Finger IV	F4T	—	1	1
Orbita	O	—	1	1
Size and Shape of Subdigital tubercles	-—	—	1	1
Vent to tibiotarsal articulation	—	—	1	1
Width of disk of Finger V	Fin5DW	—	1	1
Width of disk of Second Toe	Toe2DW	—	1	1
Width of disk of Fifth Toe	Toe5DW	—	1	1
Total hind limb Length	LEG	From vent to tip of fourth toe with leg fully extended and being held vertically to median body plane	1	1
Width of Finger II	Fin2W	—	1	1
Width of Finger III	Fin3W	—	1	1
Width of Finger IV	Fin4W	—	1	1
Width of Toe I	Toe1W	—	1	1
Width of Toe II	Toe2W	—	1	1
Width of Toe III	Toe3W	—	1	1
Width of Toe V	Toe5W	—	1	1
Distance from anterior margin of nostril to tip of rostrum	NR	—	1	1