SPECIES IDENTIFICATION AND BODY SIZE ESTIMATION OF AMPHIBIANS IN WASHINGTON STATE BASED ON FOOT MORPHOLOGY

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Introduction

Species identification based on their dismembered or partly digested parts represents a basic part of dietary studies on organisms. While attempting to identify amphibian limbs obtained from river otter (*Lontra canadensis*) GI tracts, we found few data to allow identification of amphibians from their limbs. We were also interested in estimating body size of the individual amphibians eaten based on the size of limb remnants.

For these reasons, we began to develop systematic data with two foci:

• Development of a key to amphibians of Washington State based on foot morphology

• Development of regressions designed to estimate body size based on single, easily measurable features of amphibian feet

Our objective here is to present two preliminary aspects of this work:

• A preliminary version of the dichotomous key to the feet of all 27 amphibian species in Washington State

• A regression for the relationship between toe length and body size for the northwestern salamander (*Ambystoma gracile*)

Methods

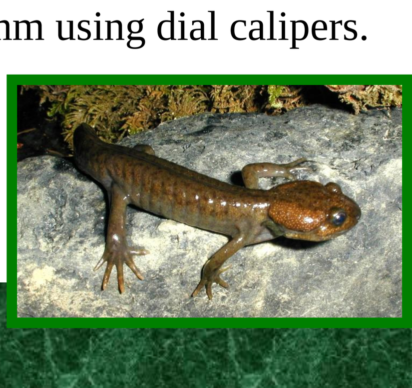
Foot Morphology Key

We extracted data on amphibian foot morphology for the 27 species of amphibians known to occur in Washington State from published literature. We verified those data by examining museum specimens from the University of Washington Burke Museum and the University of Puget Sound Slater Museum, photographs of amphibian feet from several sources, and to a lesser degree, live animals. We also examined specimens and photographs for characteristics of amphibian feet not addressed in the literature Collectively, we used these data to develop a verification table for all features of foot morphology that might be useful to distinguish either different groups or species of amphibians. Using this table, we constructed a preliminary (beta) version of a dichotomous key based on foot morphology.

Foot Feature-Body Size Regressions

In order to develop useful foot feature-body size regressions, we had to select a feature of foot morphology that could be measured with minimal ambiguity, and had a large enough dimension that would be potentially effective to distinguish body sizes over some range. These criteria led us to using the length of the longest digit on any foot as the variable on which body size could be most reliably regressed.

Northwestern salamander *(Ambystoma gracile)* was one of the two species we identified from dismembered feet from river otter stomachs, so we developed a regression for this species first. In the absence of developmental aberration or injury, the longest digit on northwestern salamanders is digit 3, regardless of whether front or hind feet are involved. Hence, we measured the length of digit 3 on the left front and hind feet, and body size as snout-vent length (SVL). We measured digit 3 from the tip of the digit to its right base with the digit extended looking at the animal from below. With the body in a straightened position, we measured SVL from the end of the snout to the anterior end of the cloacal slit. We arbitrarily measured the left side; if developmental aberration or injury existed to the third digits on that side, the right side was measured. Hence, digit symmetry between right and left sides was assumed. Measurements were taken to the nearest 0.1 mm using dial calipers.



We used 283 northwestern salamanders collected during an old-growth study on the west slope of the Cascade Range in Washington State during 1984 and 1985 (Aubry and Hall 1991). This sample was ideal for this analysis because it could populate a regression over almost the full range of known northwestern salamander post-metamorphic body sizes. Exploratory data revealed that the digit-SVL relationships were linear, so we used a general linear model (GLM). We generated two GLM regressions based on these data, one for the relationship between the length of digit 3 on the front feet and SVL, and the other for the relationship between length of digit 3 on the hind feet and SVL. As body sizes predicted from these regressions are estimates, we also wanted to understand the variation around these estimates based on the actual variation among individual northwestern salamanders. For this reason, we calculated prediction intervals around the body sizes estimated from the regression (Dowdy and Wearden 1991). Specifically, for any particular third digit length, we can calculate a prediction interval around individual body size estimates, in this case based on SVL.

Results

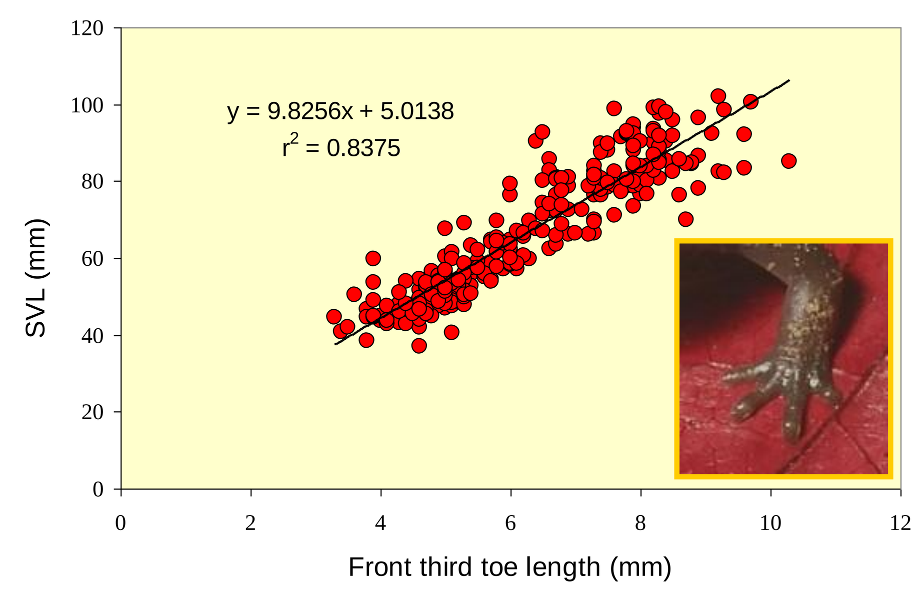
Foot Morphology Key to Washington Amphibians (beta version)

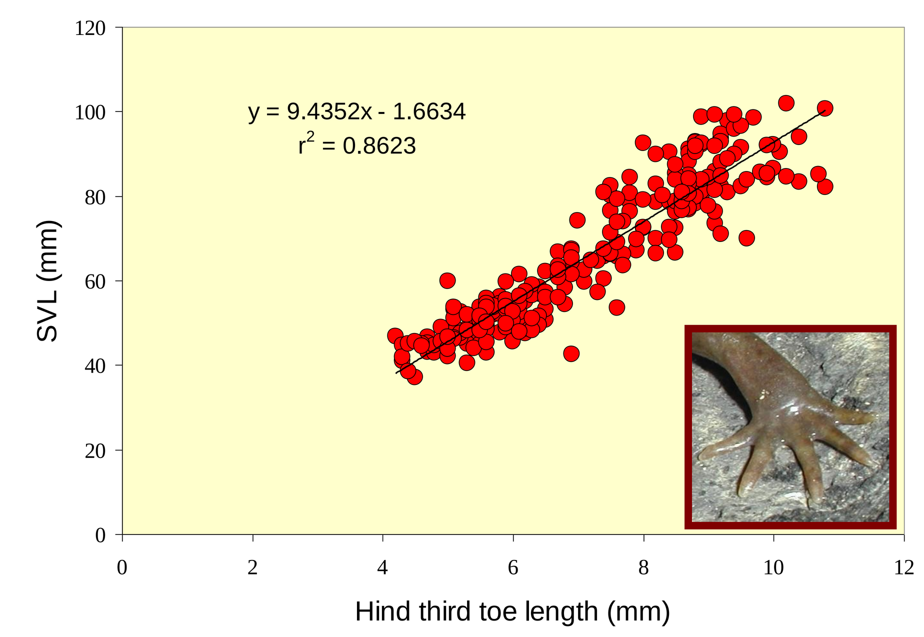
1. Four digits on limb, representing a front foot……………………………2
 Five digits on limb, representing a hind foot……………………………5
2. Digit 2 is shorter than digit 1………………..true frogs (*Rana*) and true toads (*Bufo*)
 Digit 2 longer than finger 1……………………………………………3
3. Digit 2 ≤75 percent of length of digit 3…………………………………4
 Digit 2 >75 percent of length of digit 3…….salamanders (Caudata) [to be completed]
4. Digits with expanded tips, possessing toe disks; in particular digits 3 and 4 (i.e., width of toe tip usually at least 1.4 times the width of the middle of the first phalange; an intercalary cartilage present that makes the toe tip appear to have a buckle in side view ……………………..Pacific chorus frog (*Pseudacris regilla*)
 Digits without expanded tips, toe disks or intercalary cartilage…………………………tailed frogs (*Ascaphus*)
5. Digits obviously webbed; digits highly asymmetric in length, length of digit 4 at least twice the length of digit 1……………………………………6
 Digits unwebbed or not clearly webbed; digits of relatively equal length, length of digit 4 considerably less than the twice the length of digit 1…………………15
6. Digits 4 and/or 5 broader or more flattened than digits 1, 2, and 3…………………………tailed frogs (*Ascaphus*)
 Digits 4 and 5 similar to digits 1, 2, and 3, but not broader or more flattened………..7
7. Digits with expanded tips, possessing toe disks; in particular digits 3, 4 and 5 (i.e., width of toe tip usually at least 1.2 times the width of the middle of the first phalange; an intercalary cartilage present that makes the toe tip appear to have a buckle in side view…………………………Pacific chorus frog (*Pseudacris regilla*)
 Digits without expanded tips, toe disks or intercalary cartilages……………………8
8. Cornified cutting, typically black or dark brown, subplantar tubercles……………...9
 Tubercles present, but not cornified……………………………………...11
9. One cornified cutting black or dark brown subplantar tubercles, tip of digit 1 also often cornified light brown or black…….Great Basin spadefoot (*Spea intermontana*)
 Two cornified cutting subplantar tubercles, may be black or dark brown…………...10
10. Distal end of digit 4 unwebbed…………………………western toad (*Bufo boreas*)
 Distal end of digit 4 webbed……………………..woodhouse toad (*Bufo woodhousii*)
11. Digits essentially fully webbed, webbing reaching toe tips or nearly so……………12
 Digits clearly not fully webbed, webbing on either side of digit 4 reduced or incised to at least level of first subarticular tubercle……………………………..14
12. Digits 1, 2, and 3 largely unpigmented dorsally, unlike dorsally pigmented digits 4 and 5……………………bullfrog (*Rana catesbeiana*), green frog (*Rana clamitans*)
 All digits more or less similarly pigmented dorsally……………………………...13
13. One single prominent, elongated tubercle on the inner metatarsal ……………………………………Columbia spotted frog (*Rana luteiventris*)
 One single prominent, elongated tubercle on the inner metatarsal and a less prominent outer tubercle……………………………Oregon spotted frog (*Rana pretiosa*)
14. Digits 4 and 5 have well defined large dark spots dorsally……………………………………northern leopard frog (*Rana pipiens*)
 Digits 4 and 5 lacking clearly defined dark spots, may have light diffuse spots………………….northern red-legged frog (*Rana aurora*), cascade frog (*Rana cascadae*)
15. Tips of all 5 digits cornified, 2 large plantar tubercles………Cope's giant salamander (*Dicamptodon copei*), Pacific giant salamander (*Dicamptodon tenebrosus*)
 Tips of all 5 digits not cornified ……………………………………………16
16. Digit 4 is equal to or longer than the sole of the foot……………………………………long-toed salamander (*Ambystoma macrodactylum*)
 Digit 4 is not equal to or longer than the sole of foot……………………………17
17. Digits are significantly wider at the base and taper to the tip…………………………18
 Digits are not significantly wider at the base than the tips, more symmetrical...…...19
18. Tips of digits are tapered to a point, skin not covered with tubercles, may have keratinized tips……………………………...tiger salamander (*Ambystoma tigrinum*)
 Tips of digits taper to rounded end, skin covered with tubercles, distinctly brown on top of foot, and yellow or orange beneath.…rough-skinned newt (*Taricha granulosa*)
19. Digit 1 is less than two-thirds the length of digit 2…………………………………20
 Digit 1 is more than two-thirds the length of digit 2……………………………northwestern salamander (*Ambystoma gracile*)
20. Digit 1 is more than one third the length of digit 2……………………………………torrent salamanders (*Rhyacotriton*)
 Digit 1 is less than one third the length of digit 2……………………………...21
21. Some webbing of digits even if limited…………………………………...…..22
 No visible webbing of digits……………………..ensatina (*Ensatina eschscholtzii*)
22. Digit 5 has only 1 phalange …..…...Larch Mountain salamander (*Plethodon larselli*)
 Digit 5 has 2 phalanges ……………………………………...Van Dyke's salamander (*Plethodon vandykei*), Dunn's salamander (*Plethodon dunni*), western red-backed salamander(*Plethdon vehiculum*)

This key will be refined so that every species can ultimately be individually broken out. Refinement remaining addresses partitioning the terrestrial salamanders and ranid frogs for the hind limbs, and most of the front limb portion of the key.

Digit length-SVL Regressions for Northwestern Salamanders

Below we present two sample regressions, one for the longest toe on each of the front and hind feet of post-metamorphic northwestern salamanders. Both regressions are moderately noisy, making the prediction intervals for body size for any particular digit length vary over a range of approximately 15-20 mm. However, the hind digit regression has a slightly higher coefficient of determination (r^2), likely due to its slightly larger overall dimension. Hence, where a choice is available, one should choose the hind third toe for measurement.





These results are preliminary. When completed, the key will be refined as described above. We also plan to complete digit length-SVL regressions for all 27 species of amphibians in Washington.

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