Z. Säugetierkunde **65** (2000) 51–54
http://www.urbanfischer.de/journals/saeugetier

ZEITSCHRIFT FÜR SÄUGETIERKUNDE
INTERNATIONAL JOURNAL OF MAMMALIAN BIOLOGY

WISSENSCHAFTLICHE KURZMITTEILUNGEN

Variability in measurements of microchiropteran bats caused by different investigators

By A. Herr, N. I. Klomp, and Lindy F. Lumsden

Johnstone Centre, Charles Sturt University, Albury, NSW and Arthur Rylah Institute, Department of Natural Resources and Environment, Victoria, Australia

Receipt of Ms. 09. 12. 1998
Acceptance of Ms. 15. 09. 1999

Key words: Microchiroptera, bats, biometrics, measurement variablity

The forearm length is a standard measurement taken in studies of microchiropteran bats. It has been used in taxonomic revisions (e.g. Kitchener and Caputi 1985; Kitchener et al. 1986, 1987), for the differentiation of closely related bat species during field studies (e.g. Hall and Richards 1979; Reardon and Flavel 1991; Parnaby 1992; Queale 1997) and to investigate differences between populations of individual species (e.g. Kitchener and Caputi 1985; Tidemann 1986; Lumsden and Bennett 1995), in determining age and growth rates (e.g. Kunz and Anthony 1982; Anthony 1988), body condition (e.g. Ransome 1990; Herr 1998), and sexual dimorphism (e.g. Myers 1978; Best 1988; Jones and Kokurewicz 1994; Lumsden and Bennett 1995). In most ecological studies measurements are taken on live animals under field conditions, thereby increasing the potential for error. Errors could be due to variation in measurements taken by a single investigator or due to differences between investigators. Bilateral differences in the length of the forearm of individual bats are another source of variation. This study investigates the variability of forearm measurements of bats caused by different investigators as well as differences in left and right forearm lengths of individuals.

Measurements were taken on 31 little forest bats (*Vespadelus vulturnus*) and 13 Gould's wattled bats (*Chalinolobus gouldii*) caught in Chiltern State Forest, north-eastern Victoria (36°09′S 146°39′E) in February 1996. The sample included both males and females, adults and sub-adults. The authors (Investigators 1–3) used their own Vernier calipers to measure the forearm lengths of the bats under field conditions. Each measured the left and right forearm of each bat twice. Measurements were made to the nearest 0.1 mm. The data were recorded separately for each investigator by three additional people.

The results were analysed using one-way and two-way ANOVAs. All data were normally distributed with equal variances. Although there were several outliers in the data, ANOVAs conducted with and without these outliers were found not to influence the results significantly. To assess variability among investigators, their first measurements were compared, whilst treating the measurements of left and right forearms as independent values.

There were no significant differences among the mean measurements taken by the three investigators for either species (Tab. 1), with variation between investigators less than 0.5 mm. Using the first measurement of each forearm (all investigators combined),

0044-3468/00/65/01-051 $ 12.00/0

Table 1. Means and standard deviations of the first measurement made by three investigators (1, 2, 3) of each forearm of the 44 microchiropteran bats. All measurements in mm. Results of one-way ANOVAs are also presented.

Forearm	Investigator 1	Investigator 2	Investigator 3	F-ratio ANOVA	P
V. vulturnus (n = 31)					
Left forearm	27.8 ± 0.8	27.9 ± 0.7	28.1 ± 0.8	1.29	N.S.
Right forearm	28.0 ± 0.8	28.0 ± 0.8	28.1 ± 0.8	0.16	N.S.
Mean (both forearms)	27.9 ± 0.8	27.9 ± 0.7	28.1 ± 0.8	1.11	N.S.
C. gouldii (n = 13)					
Left forearm	45.5 ± 1.4	45.4 ± 1.4	45.8 ± 1.3	0.29	N.S.
Right forearm	45.7 ± 1.3	45.5 ± 1.4	45.9 ± 1.5	0.35	N.S.
Mean (both forearms)	45.6 ± 1.3	45.4 ± 1.4	45.8 ± 1.3	0.66	N.S.

Table 2. Mean absolute differences (in mm) between the first and second measurement of each forearm measured by the three investigators (measurements from both forearms have been combined).

Species	Investigator	N	Mean absolute difference	S. D.	Mean forearm	Mean difference (percentage of forearm)
V. vulturnus	1	62	0.23	0.31	27.9	0.8%
	2	62	0.09	0.09	27.9	0.3%
	3	62	0.16	0.19	28.1	0.6%
	Combined	186	0.16	0.22	28.0	0.6%
C. gouldii	1	26	0.31	0.31	45.6	0.7%
	2	26	0.15	0.16	45.4	0.3%
	3	26	0.15	0.12	45.8	0.3%
	Combined	78	0.20	0.23	45.6	0.4%

the 95% confidence intervals of forearm length were calculated to be ± 0.1 mm for *V. vulturnus* and ± 0.3 mm for *C. gouldii*. The mean absolute difference between measurements of individual bats taken by different investigators was 0.3 ± 0.3 mm for *V. vulturnus* and 0.4 ± 0.3 mm for *C. gouldii*.

The influence of the different investigators and the sides (left and right forearm) were compared using the first measurements of each forearm. There were no significant differences between the mean length of the left and right forearms, nor between the mean forearm length. However, in three of the 31 *V. vulturnus* measured, the right and left forearms were significantly different, with all six pairs of measurements outside the 95% confidence limit. In all cases the right forearm was larger than the left, with mean differences of 1.7 ± 0.5, 1.0 ± 0.3, and 0.7 ± 0.2 mm.

The mean absolute differences between first and second measurements of each forearm taken by the three investigators were compared. This mean difference is presented as a percentage of the forearm length for comparison between species (Tab. 2). The differences between repeated forearm measurements were proportionally higher for the smaller species *V. vulturnus* with 16.1% of the differences outside the 95% confidence interval, compared to 3.8% for *C. gouldii*. These differences were markedly higher for Investigator 1, with 25.0% of the differences between repeated measurements outside the 95% confidence interval, compared to 3.4% and 9.1% for Investigators 2 and 3, respectively.

Although there was no significant difference in the mean value of measurements taken by the three investigators, there was considerable variability between sets of repeated measurements, with variability of the measurements of one investigator being greater than the variability among the investigators. Measurement variability was not uniform among investigators. For example, Investigator 1 showed the greatest difference between the first and second measurements of *V. vulturnus* at 1.5 mm, while this difference was 0.4 mm for Investigator 2 and 1.0 mm for Investigator 3.

This study found that measurements taken by single investigators are more reliable than those collected by multiple investigators. This variability needs to be considered when measurements made by two or more investigators are compared. Further, researchers need to take their own inconsistencies into consideration when using morphometrics to identify closely-related species or to compare populations. Within south-eastern Australia, the lengths of the forearm of several pairs of sympatric bat species (e. g. *Scotorepens orion* and *S. balstoni*, *V. darlingtoni* and *V. pumilis*, and *Nyctophilus timoriensis* and *N. gouldi*) are used as a diagnostic character in taxonomic keys often relying on differences of 1 mm (Parnaby 1992). Such differentiation between species requires careful measuring, preferably with duplicate measurements.

Although differences in the lengths of left and right forearms of bats have been recognised previously (unpubl. data), this study has demonstrated that such differences often may be due to measurement errors. While there was no significant difference between the left and right forearms of the population, three individual *V. vulturnus* showed a significantly larger right forearm than left. Clearly, when repeated measurements are being used, for example, for growth studies, all measurements should be taken from the same side of the bat.

Variability of measurements caused by the use of different techniques among researchers could be reduced by the adoption of measuring standards. We suggest measuring to the end of the radius of the bat's right forearm. If the data are being recorded by a second person, the recorder should repeat the measurement back to the measurer, to reduce recording errors. It is further recommended that bat forearms are measured to the nearest 0.1 mm, but that statistical comparisons suggesting differences between means of less than 0.2 mm for the smaller species (proportionately greater for the larger species) are treated with some caution.

The precision of investigators can be verified by comparing duplicate measurements or by comparing forearm measurements obtained by different investigators (as described by Barrett et al. 1989). The 95% CIs of all first measurements reported in this study (± 0.1 mm and ± 0.3 mm) would suggest that duplicate measurements of the forearm of individual *V. vulturnus* and *C. gouldii* should be less than 0.2 mm and 0.6 mm, respectively.

To overcome variability between investigators, comparisons of measurements could be used to generate confidence intervals of means, although this would only be practical in a limited geographical region and would need to be repeated and checked at regular intervals (Rogers 1984; Barrett et al. 1989). Where such an approach is not possible, measurement variability should be determined and considered in statistical analyses of morphometrics.

Acknowledgements

We are grateful to Andre Da Silva, Julie-Anne Harty, and John Silins for their assistance in the field. We also like to thank Catherine Caddle, Andrew Bennett, Graeme Gillespie, and Alecia Bellgrove for their critical review. This work was conducted under DCNR permit RP-96-192.

References

ANTHONY, E. L. P. (1988): Age determination in bats. In: Ecological and Behavioural Methods for the Study of Bats. Ed. By T. H. KUNZ. Washington D.C.: Smithsonian Institution Press. Pp. 47–58.

BARRETT, R. T.; PETERZ, M.; FURNESS, R. W.; DURINCK, J. (1989): The variability of biometric measurements. Ringing and Migration **10**, 13–16.

BEST, T. L. (1988): Morphological variation in the Spotted Bat *Euderma maculatum*. Am. Midl. Nat. **119**, 244–252.

HALL, L. S.; RICHARDS, G. C. (1979): Bats of Eastern Australia. Brisbane: Queensland Museum Booklet 12.

HERR, A. (1998): Aspects of the ecology of insectivorous forest-dwelling bats (Microchiroptera) in the western slopes of the Australian alps. PhD thesis, Charles Sturt University. URL: http://batcall.csu.edu.au/~aherr/thesis/thesis.pdf.

JONES, G.; KOKUREWICZ, T. (1994): Sex and age variation in echolocation calls and flight morphology of Daubenton's bat *Myotis daubentonii*. Mammalia **58**, 41–50.

KITCHENER, D. J.; CAPUTI, N. (1985): Systematic revision of Australian *Scoteanax* and *Scotorepens* (Chiroptera: Vespertilionidae), with remarks on relationships to other *Nycticeiini*. Rec. Western Australian Mus. **12**, 85–146.

KITCHENER, D. J.; CAPUTI, N.; JONES, B. (1986): Revision of Australo-Papuan *Pipistrellus* and of *Falsistrellus* (Microchiroptera: Vespertilionidae). Rec. Western Australian Mus. **12**, 435–495.

KITCHENER, D. J.; JONES, B.; CAPUTI, N. (1987): Revision of Australian *Eptesicus* (Microchiroptera: Vespertilionidae). Rec. Western Australian Mus. **13**, 427–500.

KUNZ, T. H.; ANTHONY, E. L. P. (1982): Age estimation and post-natal growth in the bat *Myotis lucifugus*. J. Mammalogy **63**, 23–32.

LUMSDEN, L. F.; BENNETT, A. F. (1995): Bats of a semi-arid environment in south-eastern Australia: biogeography, ecology and conservation. Wildl. Res. **22**, 217–240.

MYERS, P. (1978): Sexual dimorphism in size of vespertilionid bats. Am. Nat. **112**, 701–711.

PARNABY, H. (1992): An interim guide to identification of insectivorous bats of south-eastern Australia. Sydney: Technical Reports of the Australian Museum No. 8.

QUEALE, L. F. (1997): Field identification of female Little Brown Bats *Vespadelus* spp. (Chiroptera: Vespertilionidae) in South Australia. Rec. South Australian Mus. **30**, 29–33.

RANSOME, R. (1990): The Natural History of Hibernating Bats. London: Christopher Helm.

REARDON, T. B.; FLAVEL, S. C. (1991): A Guide to the Bats of South Australia. rev. ed. Adelaide: South Australian Museum in association with the Field Naturalists' Society of South Australia (Inc.).

ROGERS, K. G. (1984): Bar-tailed Godwit morphometrics. Victorian Wader Study Group Bulletin **8**, 23–25.

TIDEMANN, C. R. (1986): Morphological variation in Australian and island populations of Gould's Wattled Bat, *Chalinolobus gouldii* (Gray) (Chiroptera: Vespertilionidae). Australian J. Zool. **34**, 503–514.

Authors' addresses: ALEXANDER HERR and NICHOLAS I. KLOMP, Johnstone Centre, Charles Sturt University, PO Box 789, Albury, NSW 2640.; LINDY F. LUMSDEN, Arthur Rylah Institute, Department of Natural Resources and Environment, PO Box 137, Heidelberg, Victoria 3084, Australia, (e-mail: jcentre@life.csu.au/jcentre)