Notes on reproduction of Jackson's chameleon *Chamaeleo jacksonii* (Squamata, Chamaeleonidae), from Hawaii

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ABSTRACT - Histological examination of gonads from invasive *Chamaeleo jacksonii* collected in Oahu, Hawaii revealed both male and female populations were reproductively active in December and February. Litter sizes of 12.2 ± 4.4 SD (range 7-21) are within limits reported for *C. jacksonii* in previous studies. Linear regression analysis revealed a significant positive relationship between *C. jacksonii* female body size and clutch size. The smallest reproductively mature females measured 94 mm SVL. Adult males were significantly larger than females. The smallest reproductively mature *C. jacksonii* male from Hawaii measured 70 mm SVL as opposed to 90 mm in Kenya (Lin & Nelson, 1981). This indicates Hawaiian *C. jacksonii* males join the breeding population at an earlier age compared to those in native populations and this may suggest that *C. jacksonii* has a higher reproductive potential in Hawaii compared with Kenya.

JACKSON'S chameleon *Chamaeleo jacksonii* Boulenger is native to Kenya and Tanzania, Africa (Tilbury, 2010). It was established in Oahu, Hawaii in the 1970s from released pet-trade animals (McKeown, 1996) and is also established in California (McKeown, 1997). The subspecies established in Hawaii is reported as *C. jacksonii xanthologus* (McKeown, 1991) but we have also been informed that all three subspecies of *C. jacksonii* were deliberately released in Hawaii (G. Howard, pers. comm.). Reproduction has been studied in a wild population of *C. jacksonii* from Kenya which exhibited a seasonal reproductive cycle with minimum reproductive activity from January to March; average litter size was 21.7 (Lin & Nelson, 1981). The purpose of this note is to report information on reproduction in the alien population of *C. jacksonii* from Hawaii. Information on reproductive characteristics of invasive species is important in assessing their rate of spread, possible ecological impact and for assessing the feasibility of potential management programs to ensure the survival of native species. Furthermore, it is little known to what extent reproductive parameters of invasive species are modified in their invaded environments or how long might be required to achieve such modification.

METHODS

A sample of 88 *C. jacksonii* consisting of 30 adult males (mean snout-vent length [SVL] = 98.1 mm ± 16.8 SD, range 70-140 mm), 19 adult females (mean SVL = 107.1 mm ± 11.5 SD, range 90-130 mm) and 39 juveniles (mean SVL = 48.9 mm ± 11.1 SD, range 25-67 mm) deposited in the Bernice P. Bishop Museum (BPBM), Honolulu, Hawaii, USA and The University of Michigan, Museum of Zoology (UMMZ), Ann Arbor, Michigan, USA was examined (Appendix). Chameleons were collected from Honolulu, Oahu, Hawaii during February 2000 (BPBM) and December 2002 (UMMZ).

The left gonad was removed from each specimen and embedded in paraffin. Histological sections were cut at 5µm and stained by haematoxylin followed by eosin counterstain (Presnell & Schreibman, 1997). Enlarged follicles > 4 mm length and oviductal eggs or embryos were counted. An unpaired t-test was used to compare *C. jacksonii* male and female mean body sizes (SVL); the relationship between clutch/litter size and female SVL was examined by linear regression

using Instat (vers. 3.0b, Graphpad Software, San Diego, CA).

RESULTS

Adult males of *C. jacksonii* were significantly larger than females (unpaired t-test, df = 47, t = 2.0, P = 0. 047). Two stages were observed in the testicular cycle (Table 1): (1) spermiogenesis, in which the lumina of the seminiferous tubules were lined by clusters of sperm or metamorphosing spermatids; and (2) recrudescence, in which there was a proliferation of primary spermatocytes in preparation for the next period of sperm production.

Month	N	Spermiogenesis	Recrudescence
December	15	14	1
February	15	15	0

Table 1. Stages in monthly testicular cycle from December and February in 30 *C. jacksonii* from Oahu, Hawaii.

Regression (inactivity in which the seminiferous tubules are reduced in size and spermatogonia and Sertoli cells predominate) was typically seen in subadult males. The smallest male that exhibited spermiogenesis (UMMZ 236284) measured 70 mm SVL and was collected on 3 December 2002. Testes of males smaller than 70 mm SVL were either in regression or early recrudescence (with a small number of primary spermatocytes present).

Three stages were observed in the ovarian cycle (Table 2): (1) quiescent, with no yolk deposition; (2) enlarged ovarian follicles (> 5 mm length); (3) oviductal eggs or embryos. The smallest reproductively mature females (UMMZ 236287, 236289) both measured 94 mm SVL and contained 7 and 9 oviductal eggs respectively. They were collected 3 December 2002. Mean clutch/embryo size (N = 14) was 12.2 ± 4.4 SD, range 7-21. The relationship between female body size (SVL) and clutch/embryo size for 14 *C. jacksonii* was significant and is expressed by the linear regression equation Y = -16.08 + 0.260X, r = 0.65, p = 0.011.

DISCUSSION

Chamaeleo jacksonii exhibited seasonal reproduction in Kenya with 'post-reproductive quiescence' extending from January to March (Lin & Nelson, 1981). We are unable to comment on seasonality in *C. jacksonii* from Hawaii as our samples were from only December and February. However, we did find both sexes to be reproductively active in February (Tables 1, 2), the period of quiescence in the species' native range.

Usually one, but occasionally two litters of *C. jacksonii* are produced each year (Tilbury, 2010). Gestation is about six to nine months (Dorval, 2006). The number of neonates produced by *C. jacksonii* is variable in different publications: 6-57 (Lin & Nelson, 1981) or 7-28 (Spawls et al., 2002) in Kenya; 8-52 (Lilley, 1984) or 10-50 (Dorval, 2006) in captivity; and 5-50 in Hawaii (McKeown, 1996). Our range of 7-21 neonates from Oahu, Hawaii falls within the wide range of previously reported clutch sizes. However, our maximum litter size of 21 is markedly smaller than the 50 reported by McKeown (1996) and may be the result of our small sample size of 19 females from only two months, February and December. It is unstated what the sample size was for the earlier determination of clutch size range from Hawaii (McKeown, 1996). Despite this result it is clear that the reproductive potential of *C. jacksonii* in Hawaii is quite high, consistent with the rapid expansion and high densities seen in that archipelago (FK, unpubl. data).

Lin & Nelson (1981) reported a minimum SVL of 90 mm for mature males from Kenya. Our minimum size for male maturity in *C. jacksonii* from Oahu, Hawaii is considerably smaller at 70 mm SVL. This suggests either that Hawaiian *C. jacksonii* males join the breeding population at an earlier age as compared to those in native populations or that Hawaiian specimens grow at a slower rate than seen in native populations. The former might indicate that male *C. jacksonii* have a higher reproductive potential in Hawaii than in their

Month	N	Quiescent	Enlarged follicles >5 mm	Oviductal Eggs or Embryos
December	5	1	3	1
February	14	4	2	8

Table 2. Stages in monthly ovarian cycle from December and February in 19 *C. jacksonii* from Oahu, Hawaii.

native Kenya; the latter explanation would lead to no obvious difference in reproductive potential between the two. Without comparative analysis of growth rates it is currently impossible to distinguish between these two possibilities. However, the fact that the Hawaiian specimens were obtained from much lower elevations (100-500 m) than the samples from their native range (1667-1881 m elevation) (Lin & Nelson, 1981) suggests that the former explanation is more likely.

ACKNOWLEDGEMENTS

We thank Carla Kishinami (BPBM) and Greg Schneider (UMMZ) for facilitating our loans of *C. jacksonii*, and Domingo Cravalho, Tom Kraus and George Phovas for collecting assistance. This is contribution 2011-005 from the Hawaii Biological Survey at the Bishop Museum.

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APPENDIX

Chamaeleo jacksonii from Oahu, Hawaii examined for the present study.

BPBM 14000, 14003-14007, 14010, 14011, 14013-14022, 14024-14028.

UMMZ 236284, 236285, 236287-236289, 236292-236295, 236299, 236301, 236306, 236307, 236309, 236311-236313, 236322, 236327, 236336, 236342, 236357, 236369, 236373-236395, 236397-236403, 236405-236411, 236412, 236413, 236415, 236416, 236419, 236537.