

# Evidence for energetic constraints affecting a small island Komodo dragon population

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## Abstract

Factors regulating population dynamics of insular Komodo dragon (*Varanus komodoensis*) populations are poorly understood. However, variation in prey density induced by anthropic or natural processes is suspected to be an important mediator of this species' population dynamics and subsequent persistence. In this study we documented changes that reflect energetic constraints to the Komodo dragon population on Gili Motang Island within Komodo National Park, Indonesia. Comparison of annual body size frequency distributions in 1994, 2002, 2003 and 2004 indicated a recent frequency shift towards proportionally more smaller and lighter dragons. Further the population's body mass and body condition has decreased by 40-50 % and 20-30% over this time. Currently, somatic growth rates for dragons on Gili Motang are 49.24% less than that of similar sized individuals on neighbouring Rinca Island. Catch per unit effort has decreased 63.56% from 0.57 dragons/trap day in 1994 to 0.25 dragons/trap day in 2004. In 2004, dragon density and abundance were estimated at  $5.1 \pm 0.6$  dragons /km<sup>2</sup> and  $53 \pm 6.2$  post hatchling individuals, respectively. Taken together, these results reflect a population that has been exposed to food resource limitations. At present it is difficult to calibrate the severity of such changes upon the population due to an absence of long term data. However, increased conservation attention including heightened terrestrial resource security coupled with long-term monitoring of dragons and their prey on this island should be instigated. If current patterns persist, further and possibly manipulative conservation measures may be needed to stop the potential extirpation of Komodo dragons and their prey on this small isolated island.

Key words: *Varanus komodoensis*; Komodo dragon; prey limitations; ecological consequences; island populations

## 1. Introduction

Komodo dragons (*Varanus komodoensis*) are large robust monitor lizards restricted to five islands in south-east Indonesia (Auffenberg, 1981; Ciofi and De Boer, 2004). Dragons are apex predators, and as adults their diet mainly comprises large ungulate prey, including Timor deer (*Cervus timorensis*), wild pigs (*Sus scrofa*) and to some extent water buffalo (*Bubalus bubalus*) (Auffenberg, 1981). Increasingly, temporal and spatial differences in the density of prey are being recognised as key regulators of ecological attributes that underpin variation among extant dragon populations (Jessop et al. 2005a-submitted; Jessop et al., 2004). For example, large differences in the density of ungulate prey among the four islands within Komodo National Park (KNP) were highly correlated with the maximum body size of the corresponding dragon population (Jessop et al. 2005a-submitted). The two small islands (< 15 km<sup>2</sup>) of Gili Motang and Nusa Kode possessed very low densities of large prey which were associated with a significant reduction in the maximal body size of dragons, resulting in dwarfed populations (Jessop et al. 2005a-submitted, Jessop et al. 2005b-submitted). In contrast, 5-8 fold higher ungulate densities are consistent with the much larger dragon body sizes measured on the big islands (> 230 km<sup>2</sup>) of Komodo and Rinca. However, besides body size, insular differences in prey density, and thus food availability to dragons, is also expected to influence many other vital processes that underpin population dynamics, including growth, mortality and fecundity (Jessop et al., 2004; Laurie & Brown, 1990). Conceivably, a pronounced reduction in density of large ungulate prey (or other prey) by anthropic or natural processes is one mechanism that could threaten the viability of insular dragon populations in KNP. In other reptiles, temporal differences in food availability, often induced by climatic phenomena, have had dramatic influences on vital rates and ultimately on population abundance (Laurie and Brown, 1990; Andrews, 1991; Wikelski et al., 1997; Shine and Madsen, 1997; Madsen and Shine, 2000).

Komodo dragon populations within KNP may have been and may currently be exposed to fluctuating, or more importantly, decreasing large prey densities through

anthropic or natural processes. For example, up until the year 2000 across the 5 major islands within KNP (Komodo, Rinca, Padar, Nusa Kode and Gili Motang), deer were illegally hunted (a practice that still occurs on the nearby Flores Island) (Ciofi and De Boer, 2004). Anecdotal accounts from park rangers suggest that repeated and systematic hunting were responsible for significant (but unquantified) mortality of Timor deer. For other predators, reduction in food resources due to anthropic processes (eg. hunting, modified fire regimes), often in concert with habitat fragmentation, can severely threaten their viability (Gittleman, 1989; Noss et al., 1996; Amar et al., 2003). Climatic processes, particularly annual rainfall patterns are extremely important in regulating the abundance of terrestrial prey populations (Coulson et al., 2000; Nicholas et al., 2003; Ogotu and Owen-Smith, 2003). Annual rainfall variation across the wet/dry tropics of Northern Australia (a biogeographical zone similar to KNP) greatly influences prey density and in turn the population dynamics of their reptile predators (Shine and Madsen, 1997; Madsen and Shine, 1999; Madsen and Shine, 2000). Thus similar patterns of annual rainfall in this unusually dry region of Indonesia (Monk et al., 1997) are expected to influence the population dynamics of prey and in turn dragons.

Could dragon populations within KNP be currently subject to an insufficient density of prey? Directly quantifying the effects of prey fluctuations on the population dynamics of Komodo dragon populations is not possible due to an absence of long-term monitoring. However, an alternative approach to assess this question, at least in part, could be achieved by analysing morphological changes (eg. body-mass, size and condition), comparative rates of growth and an index of population abundance collected for Komodo dragons on Gili Motang, a small island located on the southern border of KNP (figure 1). This island, is most suitable for this study, as unlike the other islands in KNP for which little base line population data exists, morphological and trapping data were collected from this Island in 1994 (in concert with genetic studies). These data are complimentary to that collected annually in 2002, 2003 and 2004 and thus provides an adequate time course over 8-10 years with which to compare the potential effects of decreased prey density on this Komodo dragon population. At present, Gili Motang contains the lowest density of Timor deer within KNP and, in addition, alternative large ungulate prey such as wild pigs and water buffalo are absent (Jessop et al. 2005b submitted). Immigration of prey onto this

island is also expected to be negligible due to its relative isolation enforced by strong oceanic currents.

What effects might be observed if prey and in particular deer density is sufficiently low to impose energetic constraints on the Gili Motang Komodo dragon population? Given that deer are primarily predated by large lizards- energetic constraints would be predicted to have the greatest effects for large individuals relative to other size classes within the population. To test this prediction we examined criteria that could provide evidence for energetic constraints (i.e. food based resource limitations) within the Gili Motang Komodo dragon population by comparing data collected in 1992, with that collected in 2002, 2003 and 2004. We assessed the following attributes- (a) *Increased specific mortality*: selective mortality on particular groups of dragons could be inferred by comparing frequency differences among the annual distributions of body-length and mass, and by measuring annual differences in the mean body size and body mass of the population. If selective mortality was operating, for example on large dragons, using these criteria, we could expect to record shifts in the body size distribution and decreased populations means in body-length and mass as large lizards became increasingly rare. (b) *Decreased body condition*: body condition residuals (mass/length) are widely used as an index of physiological condition in vertebrates, if food limitations have affected lizards then their body condition is expected to decrease. Further if food limitations are acting selectively because of reduction in a particular sized prey within this island population, relative changes in body condition should be greatest for the size classes of dragons most utilising that prey resource. To determine if there was evidence for different sized prey items constraining body condition we compared dragons divided into large and small categories (based on body length). (c) *Decreased Somatic growth rates*: growth rates will be influenced by food availability. If energetic constraints (i.e. prey limitations) are present, a decrease in the somatic growth rate in this population is expected. To examine for decreased growth rates we compared estimates of current growth rates between Gili Motang and neighbouring Rinca, a large Island that contains a population of dragons that are the most phylogeographically similar to Gili Motang (Ciofi et al., 1999). (d) *Population declines*: if food limitations were pervasive enough, mortality and disruption of vital processes could lead to a decline in population abundance in Komodo Dragons. As an indicator of potential population

decline we compared annual differences in catch per unit effort (CPUE) to ascertain if catch has changed across time. (e) *Population abundance estimate*: to ascertain a current estimate of dragon abundance on Gili Motang mark recapture data was analysed to provide an estimate of the current population size on Gili Motang.

Understanding processes, by way of ecological studies, that influence the population dynamics of insular komodo dragons are prerequisites for managing a potentially difficult species to conserve. Komodo dragons share many characteristics that make large predators, particularly carnivores, complicated to conserve (Purvis et al., 2000). These include a high tropic position and low population densities. Additionally their large body size, entails a life-history with delayed age to maturity, less than annual reproduction in females, and in turn slow rates of population growth that could limit recovery in the advent of a decline (Auffenberg, 1981; Jessop, unpublished data). This species also has a very restricted range and is endemic to five islands in south-east Indonesia that differ considerably in area ( $343 \text{ km}^2$  -  $10 \text{ km}^2$ ), reciprocal proximity, and biogeography (Monk et al., 1997; Pet and Yeager, 2000). Such a spatially fragmented distribution also entails that each island population may differ widely in ecology and genetic structure because of both biotic and abiotic factors affecting their evolutionary history (e.g. MacArthur and Wilson, 1967; Kaneshiro, 1995; Grant, 1998). Further, any inherent variation among islands could present differential population responses to both stochastic and deterministic threats (Frankham, 1998).

## **2. Materials and methods**

Gili Motang (Figure 1) is a small mountainous island ( $\approx 10.3 \text{ km}^2$ ), with three peaks (each  $\approx 280$ - $320$  m high) located in the south eastern corner of KNP. Dry deciduous monsoon forest covers 85% of the island and savannah grass land the remainder. Field work for this study consisted of four trapping sessions; first in 1994 as part of a population genetic study, and then again annually from 2002 through to 2004 during routine population monitoring within Komodo National Park. All trapping sessions occurred during the dry season (August). The primary study area on this island consisted of a triangular shaped wedge,  $2.1 \text{ km}^2$  in area, on the north-west side of the island. Outside this core study area a number of randomly positioned trapping sites

were used to verify that our trapping area provided a representative population sample. Komodo dragons were captured in 300 cm x 50 cm x 50 cm long box traps baited with goat meat ( $\approx 0.5$  kg). These traps are effective for capturing all size classes of monitor above yearlings, which are largely arboreal. Each year, we used set trapping locations positioned at a distance of between 200 m and 700 m from each other, depending on terrain and vegetation. Within the forested areas traps were positioned between 200-400 meters apart. Cages were positioned in shaded areas in order to avoid overheating of trapped individuals and were checked twice daily. Following capture, Komodo dragons were restrained with rope and their mouths taped shut. Several morphological characters, including head length, and snout to vent length (SVL) were measured using calipers and a fiberglass tape. Body mass was obtained using digital scales. After 1994, Komodo dragons were permanently marked using passive integrated transponders (Trovan ID100).

Body condition was assessed by using the residuals of the linear log-log regressions of SVL against body mass of all animals captured throughout the study. This condition index reduces the influence of changes in body shape during ontogeny (Wikelski and Trillmich, 1997). To further discriminate size related changes in body condition, dragons were categorised into large and small lizards using the SVL mid point of the 1994 data. Lizards below and above 85cm SVL were categorised as small and large lizards, respectively. To assess differences in island specific somatic growth rates a comparison in the annual growth (using head length as the axis of growth) between Gili Motang and Rinca Islands (see Jessop et al., 2005a, submitted for details on field protocols used to capture dragons on Rinca), were measured and only animals that overlapped in size (50-117cm SVL) between the two islands were considered for comparison.

To provide an index of population decline, catch per unit effort (CPUE) was calculated by dividing the total annual catch by the number of effective trapping days (number of trap sites multiplied by the number of effective field days). The Jolly Seber method was used to determine an estimate of population size ( $N$ ) within the study area from 2002-2004. This estimate was then used to calculate density based on the animals caught across 28 trapping sites within the core study area. In addition, to compensate for the movement of individuals outside the core area, a boundary strip

was included around the trapping area to estimate the effective size of the area trapped (Krebs, 1999). Once the boundary area was included the effective trapping area represented 3.5 km<sup>2</sup> (35 % of the island area). To calculate an estimate of total island population size, the area of the entire island was divided by the effective trapping area and then multiplied by the number of Komodo dragons captured within the effective trapping area.

Data are graphically presented as frequency histograms, the mean and the standard error of the mean (SEM). Bootstrapping techniques (Manly 1997) based on 1000 samples were used to provide pseudo-data sets for analyzing statistical differences between frequency distributions of SVL and mass. Estimating differences between annual frequency distributions on bootstrapped data was calculated by using the Kolmogorov-Smirnov test (K-S test). To analyze data with respect to temporal changes in the population mean for measurements of SVL, body mass and body condition we compared raw data using parametric ANOVA. To determine differences in somatic growth rate between Gili Motang and Rinca Island, data were analyzed using T-tests. Data that failed to meet the assumptions of normality and equal variance for parametric tests were log transformed. Regression and ANOVA was used to test for significant differences in catch per unit effort over time

### **3. Results**

#### *3.1. Temporal differences in the annual frequency distributions of SVL and body mass.*

Frequency distributions of SVL and body mass data are presented in figure 2. To compare distributional differences across the four sampling periods we used bootstrapped data in pairwise comparisons between 1994 and data collected in 2002, 2003 and 2004. In all cases the 1994 distribution of SVL and body mass data was significantly different from 2002 (1994 vs 2002: SVL- K-S test;  $D = 0.75, p < 0.001$ ; Mass- K-S test;  $D = 0.94, p < 0.001$ ), 2003 (1994 vs 2003: SVL- K-S test;  $D = 0.91, p < 0.001$ ; Mass- K-S test;  $D = 0.97, p < 0.001$ ) and 2004 (1994 vs 2004: SVL- K-S test;  $D = 0.69, p < 0.001$ ; Mass- K-S test;  $D = 0.85, p < 0.001$ ). These statistical

differences indicated a progressive distributional shift in SVL and body mass within the population over time. In particular the population shifted from relatively more heavier and longer Komodo dragons in 1994 to predominantly lighter and shorter Komodo dragons in 2002, 2003 and 2004 (figure 1). Despite the general absence of the largest lizards over the period 2002-2004 relative to 1994, in 2004, the longest lizard was captured (SVL of 117.5cm). This individual, however, appeared in exceptionally poor condition and weighed 24.5 kg, resulting in a negative departure of 9.6kg from the logistic regression equation ( $\text{mass} = 50.15/(1 + 482.55*\exp(-0.5677*SVL))$ ) predicting the relationship between mass and SVL for the Gili Motang population based on the 1994 data.

### *3.2. Differences in SVL, Body Mass and Body Condition*

The mean SVL of individuals in the population decreased across the four annual samples, from  $85.52 \pm 5.70$  cm in 1994, to  $77.68 \pm 2.46$ ,  $72.14 \pm 3.11$  and  $76.18 \pm 4.65$  cm in 2002, 2003 and 2004, respectively (figure 3), however this was not significant ( $F_{3,63} = 1.83$ ;  $p = 0.18$ ). Although these changes in SVL approached significance when the largest individual captured both in 2004 and across the study was not included in the analysis ( $F_{3,62} = 2.31$ ;  $p = 0.08$ ). The mean body weight of the population significantly decreased over time ( $F_{3,63} = 4.40$ ,  $p < 0.01$ ) from  $15.17 \pm 3.13$  kg in 1994, to  $8.59 \pm 0.93$ ,  $6.36 \pm 1.58$  and  $8.98 \pm 2.95$  in 2002, 2003 and 2004, respectively (figure 3). Post-hoc tests indicated that the mean weight of Komodo dragons in 1994 were significantly different from those measured annually from 2002-2004, which formed a homogenous subset. These results follow the frequency shifts in the body size, in that a decreased mean body mass was attributed to a decrease in the largest and heaviest lizards in the population.

The mean body condition residual of the population significantly decreased (two-way ANOVA:  $F_{3,63} = 5.80$ ,  $p < 0.001$ ), from  $0.061 \pm 0.015$  in 1994, to  $-0.005 \pm 0.013$ ,  $-0.014 \pm 0.009$  and  $-0.019 \pm 0.016$  in 2002, 2003 and 2004, respectively (figure 4). Post-hoc tests indicated that the mean body condition of Komodo dragons in 1994 were significantly different from those measured annually from 2002-2004, which again formed a homogenous subset. Further there was a significant interaction between year and size (two-way ANOVA:  $F_{3,63} = 3.90$ ,  $p = 0.013$ ) with respect to

differences in body condition indicating that a lizard's body size contributed to the extent of its body condition change over time. In particular this indicated in some years (2002 and 2004) large lizards (>85 cm SVL) lost more condition compared to small lizards (< 85 cm SVL).

### *3.3. Comparison of Somatic Growth Rates*

The somatic growth rates measured for similar sized Komodo dragons (SVL 50-117 cm) inhabiting Gili Motang and Rinca were significantly different ( $t_{1,28} = 2.680$ ,  $p = 0.012$ ). Komodo dragons on Gili Motang exhibited a growth rate of  $0.514 \pm 0.086$  cm/yr, 49.54% less than the  $1.019 \pm 0.192$  cm/yr growth recorded on Rinca Island (figure 4).

### *3.4. Catch per Unit Effort and Population Abundance Estimate*

Between 1994 and 2004, catch per unit effort (CPUE) declined from 0.571 Komodo dragons / trap day to 0.254 Komodo dragons / trap day, or a 63.6% decline in catch (figure 5). This decline was significant over time (CPUE =  $64.2 - (0.0319 * \text{year})$ ;  $R^2 = 0.994$ ,  $F_{1,3} = 306.77$ ,  $p = 0.003$ ). Twelve Komodo dragons were caught in 1994, 22 in 2002, 18 in 2003 and 16 in 2004. Recapture rates were 50 % ( $n = 9$ ) in 2003 and 50 % ( $n = 8$ ) in 2004. Mark recapture data collected in 2002-2004 produced a density estimate of  $5.1 \pm 0.6$  Komodo dragons / km<sup>2</sup> within the effective trapping area. When extrapolated to the entire island the population abundance of the island was estimated as  $53 \pm 6.2$  Komodo dragons.

## **4. Discussion**

Between 1994 and 2004, the Gili Motang Komodo dragon population has undergone multiple changes indicative of energetic constraints (i.e. insufficient food) presumably reflecting prey limitations. Evidence from frequency changes in the length and body mass distributions over time indicated that there has been a recent trend for the population to lose its largest and heaviest individuals. Further the mean body-mass of the population has significantly declined by 43.46 - 55.21% in recent years (2002-

2004) from that measured in 1994. These two results imply that food limitations may have preferentially impacted, via selective mortality, the largest individuals within this small island population. These changes are indicative of an insufficient abundance of large ungulate prey. Currently the density of deer on Gili Motang, the only species of large prey, is the lowest among the four island populations within KNP. Even compared to Nusa Kode, an island of similar area which also contains a small population of Komodo dragons, the deer density on Gili Motang is  $\approx 50\%$  less (Jessop et al. 2005b submitted). A decrease in large prey could selectively increase mortality in large Komodo dragons because their capacity to access a broader range of smaller prey is either unavailable to them due to ontogenetic changes in body size and foraging behaviour. Thus in the absence of deer, large dragons are presumably unable to procure sufficient prey to meet energetic requirements and thus increase mortality through starvation. In addition, because absolute energetic requirements scale with body size (Schmidt-Nielsen 1984), larger dragons would require greater absolute energetic requirements to survive on this small isolated island relative to smaller individuals. Thus in food limited populations mortality is likely to be higher for particular categories of animals. In other vertebrates, environmental stress inducing food limitations has been found to select for increased male mortality, due to males often having a larger body size, lower fat reserves and greater nutritional and energetic requirements (Flood, 1970, Laurie, 1990). While we did not record the sex of the Gili Motang dragons (as this requires genetic or surgical sexing methods), the largest individuals in varanid lizard populations are typically males (Green and King, 1999), suggesting selective mortality on large male adults may be also operating in this island population.

Other components of the populations also experienced changes related to the suspected decrease in prey. In particular, decreased body condition in small lizards (Figure 4) in recent years suggested that the current population were also experiencing to some extent energetic constraints. Somatic growth rates of Komodo dragons on Gili Motang are nearly half those of similar sized dragons measured on neighboring Rinca Island. Again these results imply that across Gili Motang, while large prey are very low, other prey items may have also decreased in abundance and further imposed energetic constraints that have led to a reduction in growth. At present we can not assign causality to the mechanisms by which prey may have declined on this island.

However it seems probable that both anthropic (i.e deer hunting- C. Ciofi personal observation) and/or natural fluctuations in rainfall may have decreased prey on Gili Motang. Measuring the dynamics (i.e. abundance) of several key small prey resources (eg. geckos, rats, bird and turtle eggs) in concert with current studies on deer is crucial for understanding the link between the population dynamics of Komodo dragons and their prey on this small island.

Ultimately, energetic constraints on a population can lead to increased mortality, reduced recruitment and emigration and ultimately decreased abundance (Laurie and Brown, 1990; Shine and Madsen, 1997; Preen and Marsh, 1995). There is some evidence that this has occurred on Gili Motang with recent measures of CPUE (a proxy of population abundance) decreased by up to 63.5 % compared to 1994. It is unlikely that emigration has played any role in this decrease, as mark-recapture data (after 3 years) has recorded very few long distance intra- and only one inter- island movements elsewhere in KNP (Jessop, unpublished data). Thus the reduction in CPUE is likely to arise primarily as a result of mortality. Energetic constraints could also reduce recruitment by decreasing annual rates of fecundity. For example, in periods of low prey availability, female dragons may lengthen their interbreeding interval to less than annual, as the time for accrual of sufficient stored energy for breeding is delayed (Jessop et al., 2004).

#### *4.1. Management and Conservation Considerations*

Do managers of KNP currently need to intervene and manipulate conditions to enhance the Gili Motang Komodo dragon population? One difficulty in answering this question is that without prior knowledge of the population dynamics on this island it is impossible to gauge. Simply, we do not know if our current results (i.e. decreased CPUE and a single estimate of population abundance) are indicative of a temporary downward oscillation or a progressive decline in population abundance. Also given its small area and approximately 10000 years of isolation from other insular populations, population densities on Gili Motang are likely to have always been less (based on biogeographic theory) than the larger islands where densities of ungulate prey are significantly greater. Further stochastic and deterministic processes could be expected to promote variation in Komodo dragon and their prey's

abundance over time as seen in other tropical reptiles. Thus a lack of long term data and the expected potential for a very different dynamic on this small island due to biogeography makes it difficult to calibrate the current risk of extirpation for this population.

However, as the current population abundance on Gili Motang is estimated at  $53 \pm 6.2$  post-hatchling it falls below several theoretical thresholds used to flag extinction proneness. In particular demographic and environmental stochasticity and the loss of genetic variability are key factors underpinning extinction in small populations (Frankham, 1998). Demographic stochasticity is usually the major stochastic component threatening population viability when the population size is on the order of 100 individuals or smaller (Lande 1993). Small populations are predicted to have considerable long-term consequences on the genetic viability of populations due to the combined effects of reduced population size and increased isolation leading to reduced genetic variance (Frankham 1998, Young & Clarke 2000, Frankham et al. 2002). Thus the inherent mechanisms promoting extirpation of dragons (and presumably large prey such as deer) on Gili Motang may well be in place.

Hence, given this general extinction proneness of small island populations we suggest to the managers of KNP that they prepare initiatives that firstly increase conservation by increasing resource security of this population and concurrently enable robust long term monitoring to be established. With respect to increased resource security and monitoring, it is extremely important that there are regular terrestrial patrols on this island to ensure increased resource security on this island. At present, due to its isolation and limited resources, Komodo National Park is unable to provide adequate terrestrial resource security for Gili Motang. This is especially relevant given that Komodo National Park exhibits multi-use resource zonation across terrestrial and marine environments. Areas of high conservation value that warrant highest preservation are demarcated as core zone, of which Gili Motang is part. However without proper enforcement of Gili Motang, such zonation has little conservation value. Long term monitoring to provide estimates of Komodo dragon abundance and their prey is necessary to make informed decisions particularly with respect to initiating recovery and threat abatement management. Quantifying, estimates of prey

density and to ultimately understand how volatility in prey species influences the demography of this small island isolated Komodo dragon population is crucial.

If despite increased terrestrial resource security, subsequent monitoring indicates a further reduction in the abundance of Komodo dragons alongside their prey, recovery options that promote population growth for both dragons and deer could be carefully considered. Such options might include supplemental feeding and translocation of dragons and/or deer. Moderate supplemental feeding to provision existing individuals on this island could ensure that immature animals reach maturity and that breeding adults provide recruitment.

However, careful design of any supplemental feeding protocol would be needed to limit alteration of hunting and social behaviours, artefacts that were observed on Komodo Island when dragons were previously fed goats to enable easy viewing for tourists. Translocation could be considered but such programs can be difficult to obtain success (Wolf et al., 1996; Nelson et al., 2002, but see Madsen et al., 1990), especially in the current absence of adequate ecological and population information for Komodo dragons. For example, translocating dragons to Gili Motang could be detrimental, if this population has already undergone adaptive divergence due to isolation, and thus introductions could introduce genes that were maladaptive in this small island environment (Storfer, 1999). Alternatively if there is little adaptive divergence between populations then translocations could provide a powerful tool to recover this population in the advent of a serious decline as additional genetic variance could facilitate population recovery (Madsen et al., 1999). With respect to prey augmentation, it might initially be suspected that if predation pressure is reduced on deer due to the current reduction in the number of large Komodo dragons, population growth of the Gili Motang deer population would increase. Again natural recovery could still be limited or fail if the current deer abundance (and other prey species) is critically low and limited by stochastic influences disrupting demographic and genetic processes maintaining population growth. In this situation it could be necessary to increase the deer population on Gili Motang to provide an adequate long term prey base.

#### 4.2. Conclusions

Komodo National Park represents a vital refuge for the endemic monitor lizard, the Komodo dragon (*Varanus komodoensis*). Even so these island reserves, and in particular the small island of Gili Motang, are likely to be susceptible to natural and anthropic disturbances influencing the viability of Komodo dragon populations. Given the very low prey density on Gili Motang, the effects of prey limitations on Komodo dragons may be most acute for this population compared to other island populations, at least within KNP. Other factors specific to Gili Motang may also intensify the effects of prey limitations relative to other island dragon populations. For example, population genetics data (Ciofi, et al. 2002) indicates that Komodo dragons on Gili Motang show the lowest degree of genetic diversity among all extant populations. Similarly, genetic drift, the resulting increase in inbreeding and consequent additional decrease in genetic variation can render a small population like Gili Motang more vulnerable to natural or anthropically induced changes of habitat, prey availability or other ecological factors (Lande, 1988; Frankham, 1998; Eldridge et al., 1999). We have suggested management options that could be instigated to specifically address the Gili Motang population and promote long term conservation, but we caution implementation of any manipulative options should rely as much as possible on insights gleaned from robust data collected from continued monitoring.

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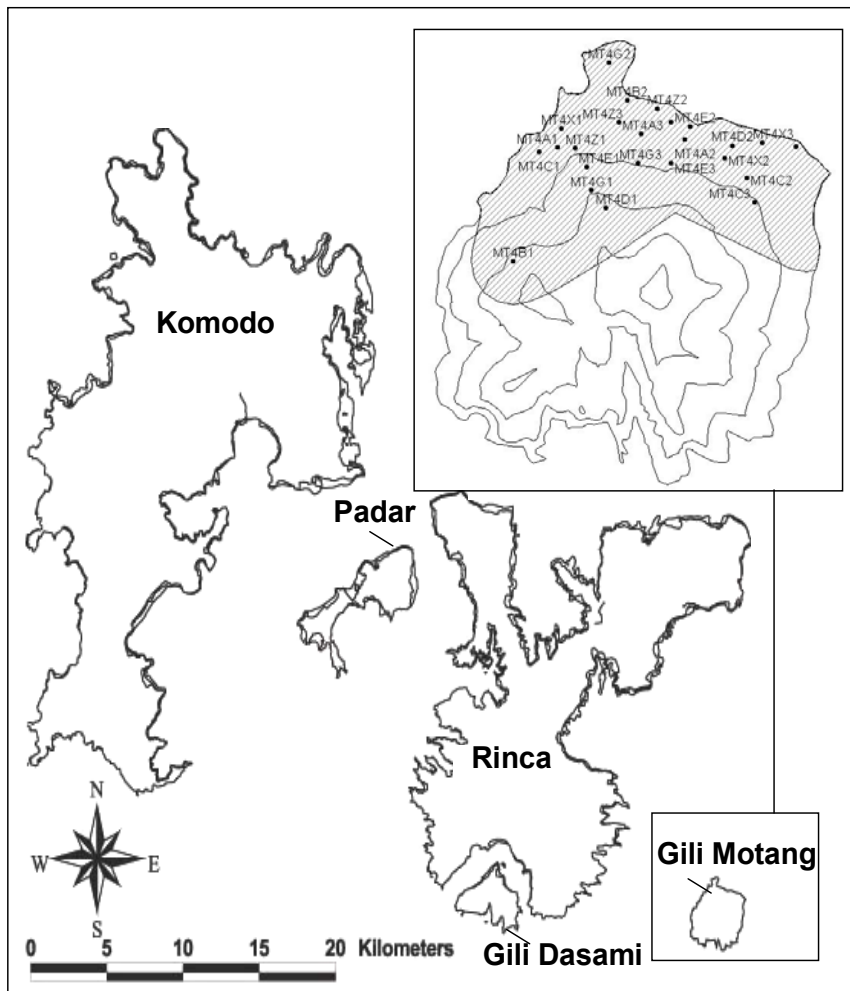
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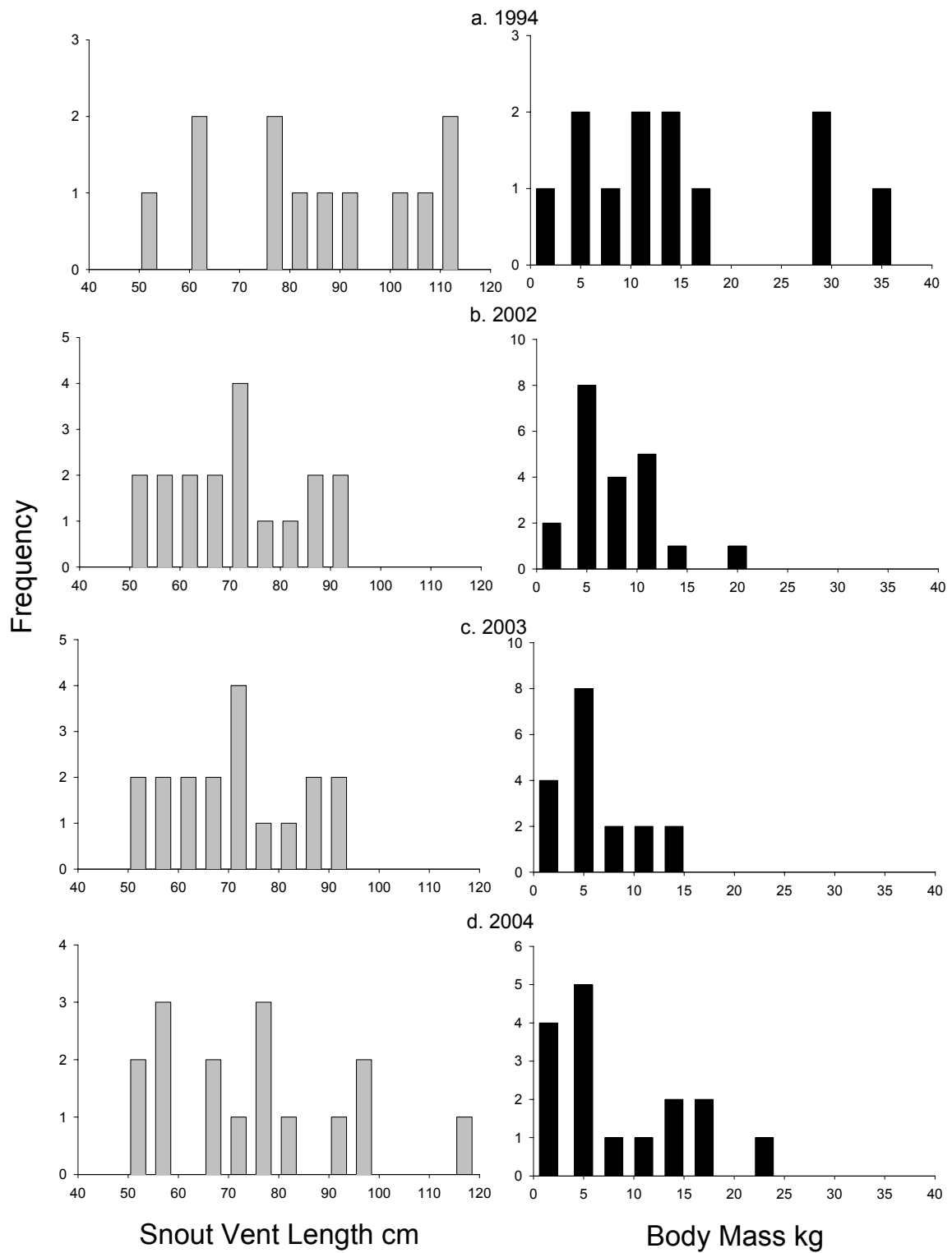
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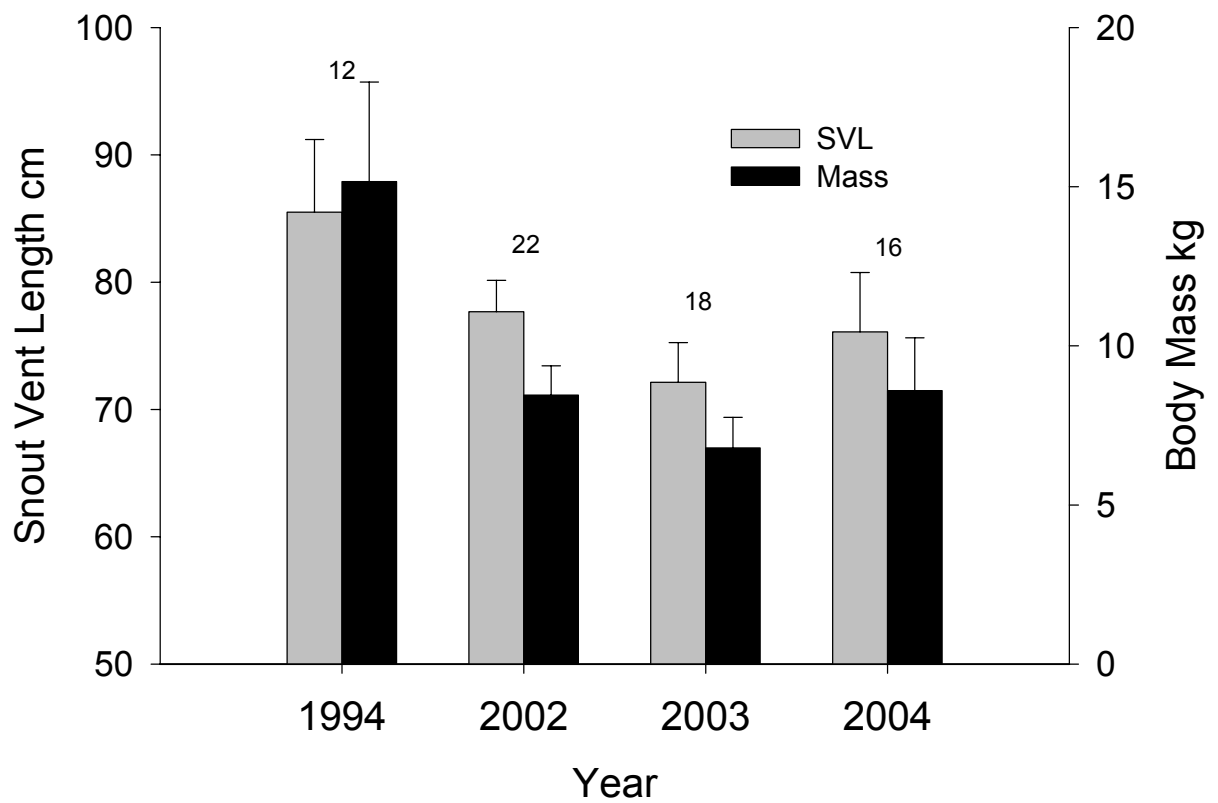
## Figures



**Figure 1.** Map of Gili Motang (framed in box) in relation to other major islands in Komodo National Park. Inset details locations of trapping sites used in this study



**Figure 2.** A comparison of frequency distributions in mass of the Gili Motang Komodo dragon population sampled in 1994, 2002, 2003 and 2004.



**Figure 3.** A comparison of mean snout vent length and body mass (a) and mean body condition (b) of the Gili Motang Komodo dragon population sampled in 1994, 2002, 2003 and 2004. Error bars represent the standard error of the mean and numbers refer to sample size.

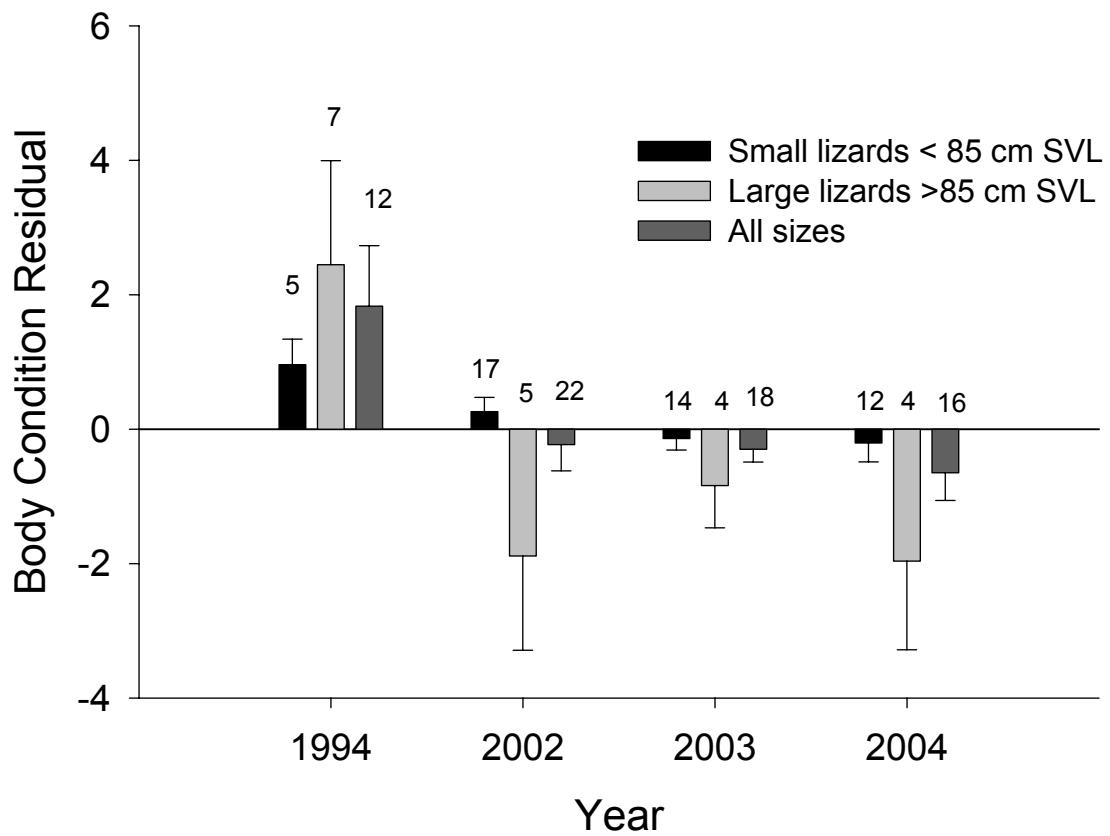
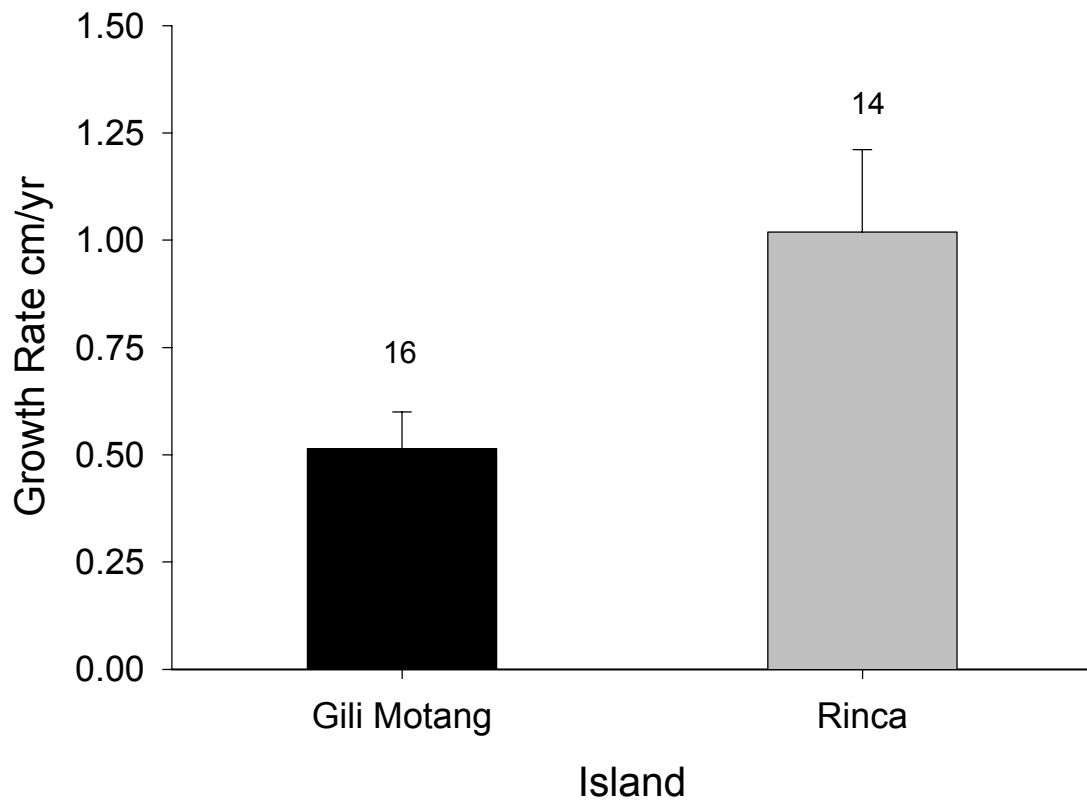
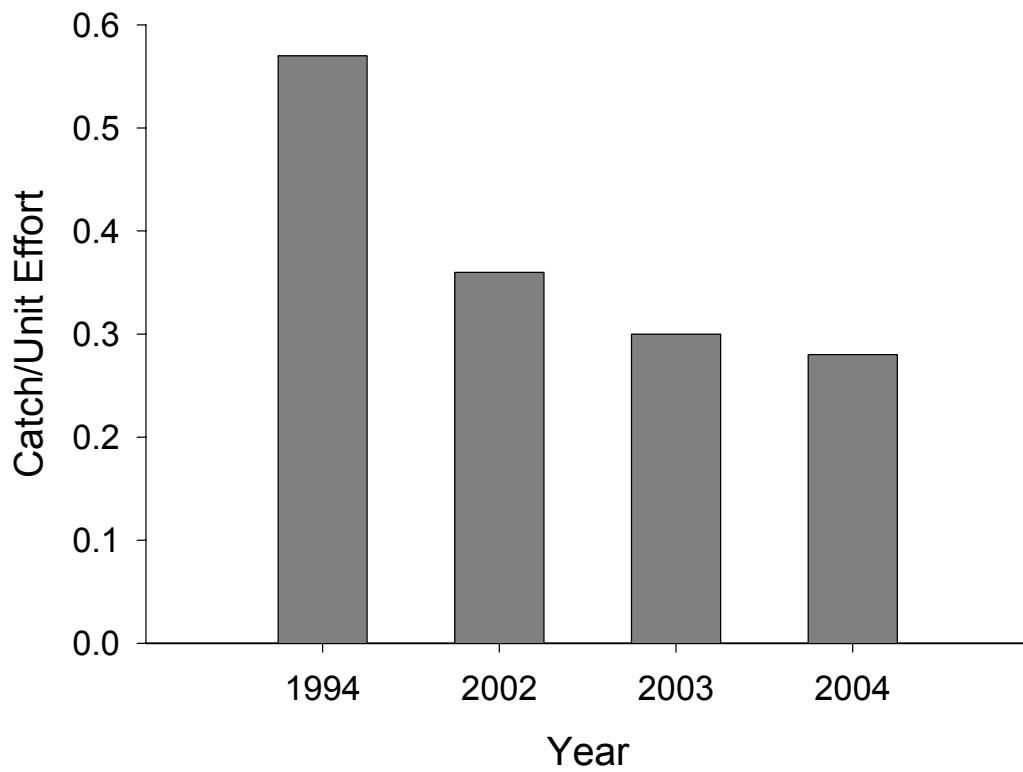


Figure 4. A comparison of the mean body condition of the Gili Motang Komodo dragon population sampled in 1994, 2002, 2003 and 2004. The data is represented by three categories- (1) large dragons (> 85 cm SVL), (2) small dragons (<85 cm SVL) and (3) these 2 categories combined for all sizes within the population. Error bars represent the standard error of the mean and the numbers above refer to sample size.



**Figure 5.** A comparison between somatic growth rates (based on head length) of Komodo dragons sampled on Gili Motang and the neighbouring large island of Rinca. Comparison between island populations was standardised to include only those individuals that overlapped in size. Error bars represent the standard error of the mean and the numbers above refer to sample size.



**Figure 6.** The annual catch per unit effort for Komodo dragons captured on Gili Motang during trapping sessions conducted in 1994, 2002, 2003 and 2004.