



**Fowlers Gap**  
Arid Zone Research Station

# 1 Research Reports – 2002

## ***Wildlife Tourism with Rangeland Kangaroos: Product development and implementation***

**Investigators:** David Croft  
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The objectives of the project are:

1. to research product designs for access ways, viewing platforms, interpretative materials and accommodation to create and support a high quality experience in wildlife tourism with kangaroos
2. to test market the products to clientele derived from education groups (Study Abroad), alumni and a local operator at Fowlers Gap and to trial some products with Sturt National Park visitors,
3. to assess patterns of usage and visitor satisfaction with the products,
4. to assess and apply remedial action to any adverse impact on wildlife or habitat through the tourism enterprise created around the products,
5. to create a model for wildlife tourism enterprises on public and 'private' lands in the rangelands
6. to promote the products to stakeholders from the National Parks and Wildlife Service, pastoral leaseholders, local and national tourism operators from the development site at UNSW arid zone field station, Fowlers Gap.

The project has completed most of the milestones for the third and final year with a lag of around a quarter for some activities as a consequence of delays in facility construction due to floods in 2000 and severe drought in 2002. Developments at Fowlers Gap have remained on schedule except for the construction of a campground. A basic campground was due for completion in December 2002 to service 'campers' attending the 'Year of the Outback' conference at Fowlers Gap. However, severe drought through 2002 saw drying up of water at the site in mid-year delaying any program to construct an ablutions block. Fowlers Gap staff were fully extended in stock management (early shearing, culling of sheep flock for sale, feeding of breeding stock) and water management (relocation of water sources, rotation of stock in paddocks) through the second half of 2002. Thus construction of ablutions and campsites was held over until 2003 for possible opening in mid year when large groups are booked into the Station.

A significant and expanding specialty market for Broken Hill and the surrounding region is art tourism, especially artists seeking to produce works in Outback landscapes. We have continued to develop opportunities for this on Fowlers Gap and elsewhere with Dr Idris Murphy from the College of Fine Arts (UNSW), graduate colleagues in Broken Hill and New South Global at UNSW. We will introduce an 'artists-in-residence' program in 2003 to stimulate knowledge about the site. Thus part of the development of a strategy for tourism in the rangelands has been nature-based 'art' tourism. Artists require studio space and so we have been planning options at Fowlers Gap that could be applied more generally in the region. A major

development proposal has been put to UNSW for 2003 to develop a multi-purpose space for art and interpretation and to embed this within a small botanic garden. A grant application for the latter will be made to the Bushcare division of the Natural Heritage Trust in early 2003. The botanic garden has been strongly endorsed by local graziers who see interpretation and knowledge about botanic resources as essential to promoting understanding of sustainable land use in the pastoral context. The Bushcare coordinator for the Far West region has indicated support for the proposal.

The Mt Wood complex at Sturt National Park comprises the historic homestead with major elements built in the 1880s, early and mid-1900s; the stone shearer's quarters; the shearing shed; an outdoor pastoral museum and a bush campground. This complex is being used as a test site for adaptive re-use of pastoral infrastructure for nature-based tourism with NSW National Parks and Wildlife Service. The complex has been opened to guests through 2002 and continues to receive funding through NPWS for restoration to meet OH&S standards. An exit survey of guests has been developed and a usable sample will be gathered through 2003. An interpretive walkway around the complex has been developed and will be opened shortly for the 2003 tourism season (commences around Easter). A program of conservation volunteers has been developed and has seen two French and six German students and several Australians through a typically 6-week course in 2002. The volunteers have been involved in a project on the role of ephemeral creeks in biodiversity conservation (pitfall trapping of small mammals, reptiles and ground invertebrates) and have gathered information on raptor distribution in the Park as part of a monthly survey and species lists for avifauna to assist in interpreting the fauna to guests. Computer facilities have been upgraded to provide distributed access to the broadband satellite hub at the complex to enable internet access to conservation volunteers and guests.

A presentation on 'kangaroos in tourism' was made at the Broken Hill development roundtable in July 2002. The presentation was attended by Broken Hill tourism operators, councillors, pastoralists and the interested public. A tourism strategy for the region as proposed in this project was outlined and received significant support from operators and councillors. A presentation was also made to an academic audience at the 'Year of the Outback' conference on 'Animal function in arid environments' held at Fowlers Gap Dec 13-16, 2002. This group of around 50 delegates exercised the infrastructure and services we have developed in this project and returned very favourable comment. We received a report from Professor Duncan Mitchell of the University of Witwatersrand in South Africa on the development of private nature conservancies including a property he had inherited. An outcome of this meeting is a proposal to develop through a fellowship at Fowlers Gap linkages with post-doctoral researchers in South Africa, Namibia (especially the Desert Research Foundation of Namibia) and Botswana with interests in nature-based tourism as a conservation mechanism in arid lands.

### **Publications:**

Wilson, S., Scott, N. and Croft, D. (2002). Wild partnerships. *Animals Today* **10(3)**: 12-14.

## ***Conservation of arid zone biodiversity in the sheep grazing piosphere***

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This project was commenced in 2002 and addresses many of the deficiencies of past studies of grazing intensity by stock in large rangeland paddocks by employing new GPS-tracking technology. The technology provides 5-10 m accuracy with 8-16 fixes per day per annum. This provides precise location of telemetered subjects across the diel cycle without disturbance by observers, heavy labour investment in conventional tracking or attempts to integrate movement patterns from dung deposition and measurement with attendant sampling biases. The project will quantify the zone of attenuating grazing impact on plant communities by both continuous and subsequent stratified sampling of the cover of functional plant groups, measurement of structure and diversity of perennial species across landscape units in radial transects from the watering points. The assessment of the fauna will be strategic with a focus on kangaroos that potentially contribute to grazing effects, threatened small mammals that may suffer from them, bird communities that are sensitive to variation in foliage height diversity, and insects, especially ants and termites, that respond to small-scale disturbance. Sampling will be continuous (kangaroos, birds) or stratified (small mammals and insects). Observations will be made in contiguous paddocks of Mitchell grass and chenopod shrubland with either a central or peripheral watering point.

The aims are:

- Define the usage by sheep of paddocks with different configurations of watering points using precise GPS-tracking technology
- Define the zone of attenuating impact on vegetation (piosphere) from the watering point along radial transects
- Determine the relationship between sheep grazing within a paddock and the piosphere
- Determine the effect of the piosphere on the distribution of kangaroos, small mammals of conservation concern, the structure of bird communities, and predominantly social insect diversity and abundance
- Assess the conservation benefit of water point configurations that encourage even or uneven grazing.

The principal benefits of fulfilling these aims are:

- Accurate definition of the zone of grazing intensity around watering points by sheep to direct further management for production in an ecologically sustainable framework
- Identification of any conservation benefits accruing from embedding lightly grazed zones in a matrix of pastoral land use
- Determination if 'reserved' areas incur unintended costs through harbourage of pests (e.g. invasive native species) or competitors (kangaroos, feral herbivores) as perceived (rightly or wrongly) by pastoral land managers

Results from 2002 are atypical given the severity of the drought but did prove the GPS technology with sheep. The study will be repeated under better rainfall conditions.

***The role of functional muscle structure in our understanding of the characteristics of hopping in kangaroos.***

**Investigators:** Terry Dawson, Brock Mifsud and Matt Raad  
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The energetic capacity of red kangaroos (*Macropus rufus*) has been studied in relation to the work capabilities of their muscles. To understand the unusual characteristics of hopping (it is a very cost effective mode of travel) we need to know where the work is actually being done during locomotion. Our work has previously shown that kangaroos have a high energetic capacity, i.e. are mammalian 'athletes' but we do not understand the mechanism by which kangaroos increase the efficiency of hopping. From samples collected at Fowlers Gap, we examined the distribution of muscle mass in red kangaroos and the volume of mitochondria in those muscles. Mitochondria are the organelles fundamental to energy production in the body. The combination of mitochondrial volume and muscle mass demonstrated that most (as would be expected) work capacity was in the upper leg and hip region. Approximately 70% of the total muscular capacity for work in the body was in this region. The surprise was in the work potential of the muscles of the back and tail. We had considered these to be largely involved in elastic recoil but the density of mitochondria in these regions was the highest in the body musculature. We are continuing our studies into the mechanics of these regions.

***Canopy interception losses in dryland shrubs: investigating a little-known component of the water balance***

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In water-scarce environments such as those of the Australian arid and semi-arid zones, the fate of rainwater is of heightened ecological significance (Dunkerley 2002; Dunkerley and Brown 2002). The spatial distribution of water arriving at the soil surface also influences key processes including the production of raindrop-impact seals and crusts at the soil surface (these are a primary influence on soil water uptake rates), and the generation of surface runoff. Though foliar cover is often less than 30%, the trapping of rainfall on leaves and branches has several potentially important consequences. These include protection of the soil beneath the canopy from all or part of the erosive energy of rain, which in the open is typically  $0.1 - 0.4 \text{ W m}^{-2}$ . Partly as a consequence of this, sand grains splashed from the surrounding unprotected soils that happen to land beneath the canopy of a shrub are likely to remain sheltered there, and so slowly build up the small mound that is often seen beneath saltbush and bluebush shrubs at Fowlers Gap. This light-textured body of sediment is very porous

and permeable to water, and this probably aids plants in trapping water that drips through their canopy or that trickles down stem and branches.

However, the canopy also retains some water on wet leaves and branches. The amount that can be held is termed the *canopy storage capacity*. Water held in this store is lost to the plant as the foliage dries out following the cessation of rain. Thicker canopies better-protect the soil beneath from splash, but also potentially cost the plant more in water lost to evaporation. A thicker canopy can hold the entirety of the rain delivered in a small storm, only overflowing in larger events. Because of this, days when water reaches the roots of a plant are only a subset of annual rain days. Surprisingly little is known of this process of *canopy interception loss* in Australian dryland plants.

A medium-term experiment established at Fowlers Gap in 2002 seeks to derive new measures of canopy interception loss in two common varieties of small shrub, *Maireana pyramidata* and *Cassia eremophila*. About 20 individuals of each species were equipped with a new kind of sub-canopy device designed to provide multi-year data on the water falling through the canopy. At nearby sites, tipping-bucket raingauges and a set of identical recording devices (but with no canopy protection) were set out to provide calibration data. In essence, the devices employ a small block of non-toxic, water-soluble material, whose initial weight is recorded. Blocks in the open lose material in solution in all rain events, and thus slowly become lighter, while those sheltered by canopies only lose weight when the canopy interception store overflows. The devices in the open provide a calibration in  $\text{mg mm}^{-1}$  that can be used to interpret the weight loss of the sub-canopy tablets in terms of the depth of water passing below the canopy. Given that some water may fall through gaps in the canopy in storms of any size, in a process termed *free throughfall* (Dunkerley 2000), up to five devices were installed beneath each shrub, with the mean weight loss being used in subsequent analyses.

The method outlined is very cheap to apply. This was a design goal when its development was undertaken, since the diversity of plant forms and ages means that in many ecosystems, many individuals have to be monitored before a canopy loss figure for an ecosystem can be derived. It also allows for some redundancy in the array of sensors. This means that the loss of a few devices (perhaps caused by stock) can easily be tolerated. The devices use no power, and need simply to be extracted, weighed, and re-inserted at any convenient opportunity (monthly, annually, etc). This can be done at the shrub using a small battery-powered balance. Results to date (more being needed owing to drought conditions!) show a very strong linear relation between weight loss and rain reaching the sensors (see Dunkerley 2002(b)). During preliminary trials in Melbourne, the devices have operated successfully through a total rainfall of  $> 250$  mm, which is about two average years at Fowlers Gap.

### **Publications:**

Dunkerley DL 2000. Measuring interception loss and canopy storage capacity in dryland vegetation: a brief review and evaluation of available research strategies. *Hydrological Processes* 14: 669-678.

- Dunkerley DL 2002(a). Infiltration rates and soil moisture in a groved mulga community near Alice Springs, arid central Australia: evidence for complex internal rainwater redistribution in a runoff-runon landscape. *Journal of Arid Environments* 51: 199-219.
- Dunkerley DL 2002(b). Canopy interception losses in dryland plant communities: why are they important, and how can we measure them? Paper delivered at Tenth Conference of the Australian and New Zealand Geomorphology Group, Kalgoorlie WA, 30 September – 4 October 2002. Conference Abstracts page 17.
- Dunkerley DL and Brown KJ 2002. Oblique vegetation banding in the Australian arid zone: implications for theories of pattern evolution and maintenance. *Journal of Arid Environments* 51: 163-181.

### ***An evaluation of factors leading to kangaroo-vehicle collisions in the arid zone of Australia***

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Kangaroo vehicle collisions are a frequent event on Australian highways. Despite high resulting economic costs as well as animal welfare issues, little research has been done to investigate the impact of road mortality on kangaroo populations, to find out where and why accidents occur and how the collisions can be mitigated. During this 6-month study data on species, sex and age of kangaroos killed on the road were collected on a 21.2 km section of sealed outback highway in far western NSW. The spatial and temporal distribution of road-killed kangaroos were investigated in relation to the cover and quality of road side vegetation, road characteristics, density of kangaroos along the road and climatic variables.

A total of 125 kangaroos were found killed on the road. Grey Kangaroos were under represented in the road kill sample as compared to their proportion in the source population. No bias towards either sex was found. The age structure of road killed kangaroos was similar to age structures found in other kangaroo populations. Road kills mainly occurred in plain open country. In road sections with curves or stock races road kill frequencies were higher than expected. Road kill locations had significantly higher pasture cover, relative greenness and height than locations where no road kills occurred. Hence road side vegetation was another factor that potentially influenced the spatial distribution of road kills. The road created an edge effect, as pasture cover and relative greenness in the first meter interval on the road side were significantly higher than in meter intervals further away. There was some evidence that road side vegetation attracted kangaroos to the road to graze. The temporal distribution of road kills was highly correlated with night time traffic. The probability of a kangaroo-vehicle collision increased exponentially with traffic volume. With an average traffic volume of 53 vehicles per day the probability of a least one road kill was 35 %. The results are discussed in relation to risk factors inducing road kill and the potential to mitigate against them.

## ***Energy requirements of juvenile red kangaroos (*Macropus rufus*) beyond pouch exit: the cost of growth***

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Using animals from Fowlers Gap Arid Zone Research Station we quantified the energy requirements for maintenance and growth of juvenile red kangaroos (*Macropus rufus*) at two ages: the young-at-foot (YAF) stage, when young had permanently left the mother's pouch but were still sucking, and shortly after they were weaned. When fed high-quality chopped lucerne hay, YAF kangaroos (body mass  $6.4 \pm 0.2$  kg) and weaned red kangaroos (body mass  $10.9 \pm 0.3$  kg) had digestible energy intakes ( $\text{kJ kg}^{-0.75} \text{ d}^{-1}$ ) of  $641 \pm 27$  kJ and  $677 \pm 26$  kJ  $\text{kg}^{-0.75} \text{ d}^{-1}$ , respectively, significantly higher than the  $385 \pm 37$  kJ  $\text{kg}^{-0.75} \text{ d}^{-1}$  ingested by fully mature, non-lactating females (body mass  $25.8 \pm 1.6$  kg). On a good quality diet, juvenile red kangaroos aged from permanent-pouch-exit until after weaning (ca. 220 – 400 d) had average growth rates of  $55 \text{ g body mass d}^{-1}$  and total daily energy requirements that were 1.7 – 1.8 times those of mature, non-reproductive females. However, YAF and weaned red kangaroos had maintenance energy requirements (i.e. energy intake needed to maintain a body mass change of zero) that were not significantly higher than those of mature, non-lactating females, the values ranging between 384 and 390 kJ digestible energy  $\text{kg}^{-0.75} \text{ d}^{-1}$ . Therefore, the energetic cost of growth was the major reason for the higher energy requirements of juveniles relative to non-lactating, mature females. Importantly, the MER of mature female red kangaroos was 84% of that previously reported for similarly sized, but still growing, male red kangaroos and our results are important for assessing the competitive grazing impacts of red kangaroos, both intra- and inter-specifically, in Australia's arid rangelands.

## ***Year of the Outback Conference: Animal Function in Arid Environments***

**Reporter:** Terry Dawson  
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A highly successful and enjoyable regional meeting of the Australian Mammal Society was held in conjunction with Fowlers Gap Arid Zone Research Station. The meeting was held over three days in early December, a time when the impact of the drought was still very evident. Approximately 50 researchers, including two international visitors and representatives from all states attended; 17 graduate students made vigorous contributions. The conference broadly examined the environmental physiology of animals in the arid zone. The main focus was "How are animals able to make a living in such an extreme and unpredictable environment?" Several keynote speakers reviewed major topic areas. It is anticipated that the proceedings of the conference will be published in *Australian Mammalogy*, the journal of the Australian Mammal Society. The conference attracted considerable media attention with articles by James Woodford appearing in *The Sydney Morning Herald*. Stories that attracted special attention concerned the great increase in camel numbers in arid Australia and the unusual biology of emus.

The abstracts for the majority of papers follow.

## **GONADAL AND ENDOCRINE CORRELATES OF BREEDING FLEXIBILITY IN ARID-ZONE WHITE-PLUMED HONEYEATERS**

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In the Australian arid zone, conditions conducive to breeding vary spatially and temporally. Because of this unpredictability, birds residing in the arid zone would benefit by having the ability to link breeding readiness to proximate cues rather than to those representing long-term average conditions, such as photoperiod. The White-plumed Honeyeater *Lichenostomus penicillatus*, is a widely distributed resident in Australian riparian habitats that is known to breed throughout the year across much of its extensive range. Our studies of populations near Fowlers Gap demonstrate the absence of testicular regression in adult males. Repeated laparotomies on individuals show that, although small changes in testis size occur, these do not follow a seasonal pattern. Plasma testosterone levels in males are typically low (<1.0 ng/ml), with a very damped annual cycle. To determine whether males undergo seasonal changes in the sensitivity of the downstream targets to GnRH-I, we challenged free-living male honeyeaters with intrajugular injections of chicken-GNRH or saline (control) at 5 times during a year. Blood samples were collected after the dose to assess plasma levels of luteinizing hormone (LH, at 5 min) and testosterone (T, at 15 min). Blood samples for background LH and T levels were also collected from untreated males immediately after capture during each of the sampling periods. Males challenged with cGNRH-I had higher plasma LH levels compared with both the Saline and Background groups at all sampling times, but there were no differences between months. The results of this experiment taken with field measures of hormone levels and testes size support the contention that these, and possibly other Australian passerines, support their flexible breeding strategy through year-round activity of the hypothalamic-pituitary-gonadal axis.

## **ENERGETIC CONSIDERATIONS OF MOULT/BREEDING OVERLAP IN ARID-ZONE BIRDS**

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Feathers are essential for many vital functions of birds and must be renewed annually. The moult process places an energetic and nutritional burden on birds, consequently most species restrict moult to times when thermoregulatory costs are minimal and when breeding has been completed. In fact, species living in highly seasonal environments have endocrine feedback mechanisms that prevent overlap of moult and breeding activities. For species living in habitats with unpredictable resource abundance, moult remains highly scheduled, but breeding may occur whenever resources are sufficient, often resulting in moult/breeding overlap. This raises several questions: 1) do species exhibiting moult/breeding overlap differ from species showing moult/breeding segregation in terms of energy costs of these activities, 2) if not, do they suffer greater stress during overlap of these activities, and 3) do they differ in sensitivity to hormonal signalling? Our studies of White-plumed Honeyeaters reveal no difference between the basal metabolic rates of White-plumed Honeyeaters and those of seasonal breeders, but the honeyeater clutch sizes are significantly smaller. Based on studies of another sedentary species, we believe the moult costs of White-plumed Honeyeaters are less costly than measured in migratory, seasonal breeders. Consistent with this possibility, there was no difference in stress responsivity (pattern of glucocorticoid secretion under stress) or blood parasite load in non-breeding, non-moulting birds compared to those breeding while moulting. Finally, moult rate was far less sensitive to testosterone in male White-plumed Honeyeaters than in males of seasonally breeding species.

## **FORAGING BEHAVIOUR OF RED KANGAROOS – FROM PATCH TO LANDSCAPE.**

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Red kangaroo populations may grow on the ‘ephemeral bounty’ of grasses and forbs but survive on mainly perennial grasses in run-on patches. We explore, through a controlled experiment in captivity, the foraging behaviour of small through large size classes when presented with grass swards of different heights. We examine how red kangaroos meet the challenges of increased vertical complexity of forage and reduced visual acuity at night. We describe their responses to and effects on foraging resources in small 0.4 ha plots in the field. Finally we compare usage of landscape units in habitat descending from foot-slopes to flood-out plains. The results are discussed in relation to whether sheep grazing has created ‘marsupial lawns’ favouring an increased abundance of large kangaroos.

## **ARE RED KANGAROOS THE KINGS OF THE OUTBACK? WHAT ABOUT THE BIG BIRD, THE EMU**

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Over many years our group at UNSW have shown that red kangaroos are superior mammals when it comes to living in harsh arid environments. Their capabilities are equal to or superior to those of most large, arid adapted mammals found through the world. They have excellent water conservation mechanisms, especially urine concentrating abilities. They can withstand extremely high environmental temperatures. Additionally, they can extract sufficient energy and nitrogen from poor quality fibrous vegetation. Because of our mammal centred viewpoint we often overlook the abilities of birds and, in this case the emu. The emu has very different physiological characteristics (probably dinosaur derived) to those of mammals. For example, they only concentrate their urine to a fraction of that of the red kangaroos, yet their water losses are not much different from those of the kangaroos. Overall, the emu does things in a very different way to the kangaroos but it is the emu that is able to wander around foraging during the hottest part of summer days in the arid zone. The kangaroos on the other hand are restricted to the shade of trees and bushes in these circumstances. So then who are the kings of the outback?

## **RESOURCE TRACKING AND EXPLOITATION IN AUSTRALIAN DESERT RODENTS: A REVIEW.**

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Food and water resources are commonly limiting in desert environments but for rodents in arid Australia the high spatial and temporal variability in resource availability presents an additional challenge. Free water often becomes available only after local or regional rainfall, while pulses of food often follow 1-6 months later. In this review, we firstly describe the ability of Australian desert rodents to track and exploit ephemeral resources. We then compare the responses of Australian rodents with those of rodents from other world deserts, and show that they differ in at least six major ways. Thus, in comparison with their counterparts elsewhere, Australian desert rodents:

- 1) are more mobile, more likely to occupy shifting home ranges and to move long distances (>10km) to obtain resources;
- 2) are primarily omnivorous rather than granivorous, herbivorous or insectivorous;
- 3) do not appear to show strong preferences for particular types of food within major food groups (e.g. different species of seeds, types or sizes of invertebrates);
- 4) very seldom cache food and do not construct food stores;
- 5) are able to reproduce at any time of year when resources are available; and
- 6) appear poorly attuned while foraging to risk of predation from either terrestrial or volant predators.

These differences can be interpreted as selective responses by rodents in arid Australia to an environment where the supply of food is temporally and spatially uncertain, in contrast to the seasonally more predictable environments that prevail in arid regions elsewhere.

## **HOW MANY FERAL CAMELS ARE THERE?**

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Between August and October 2001 we conducted a broadscale aerial survey to ascertain the abundance of feral camels in the southern third of the Northern Territory (NT). The survey indicated that there were a minimum of 52,329±4,760 (SE) feral camels at an average density of 0.20±0.02 camels/sq.km. Assuming that only one in four camels were seen, the actual population was probably about 209,316±19,040 camels (0.81±0.08 camels/sq.km). The highest densities of camels were recorded in the south-western part of the area surveyed. The feral camel population in the NT increased by about 210% between 1993 and 2001, a rate of increase of about 10% per annum. On the basis of early survey work which showed that the Northern Territory supported about 27% of Australia's camels, the national population may be as high as 775,000 animals. In the absence of management intervention, the rate of growth of the camel population is unlikely to diminish in the foreseeable future. The environmental impacts of camels and options for their management will be discussed.

## **THE ROLE OF TORPOR IN ARID ZONE MAMMALS**

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Approximately half of the Australian continent is arid, receives less than 300mm of rain/year, and is characterised by low primary production, limited supply of food and high daily fluctuations of ambient temperature ( $T_a$ ). Despite these adverse conditions the diversity of small mammals in the Australian arid zone is high, although their abundance is generally low. The most successful groups of small arid zone mammals are the dasyurid marsupials (~47% of all Australian species), native rodents (~37%), and insectivorous bats (~22%). A probable reason for the success of the insectivorous dasyurids and bats, which must cope with strong fluctuations in food availability, is their extensive use of torpor for energy and water conservation. Torpor is characterised by substantial reductions of body temperature ( $T_b$ ) and metabolic rate (MR), but also water loss and other physiological processes. Arid zone dasyurids like dunnarts (*Sminthopsis* spp.), planigales (*Planigale* spp.), fat-tailed antechinus (*Pseudantechinus macdonnellensis*) and mulgaras (*Dasycercus cristicauda*) use daily torpor extensively, some even during the reproductive season when most mammals maintain strict homeothermy. Dasyurids reduce  $T_b$  from about 35 °C during normothermia to about 15 °C during torpor and MR to about 30% of basal MR; mass loss, and thus water loss, is related to the duration of torpor bouts. Dasyurids usually commence torpor at night or in the early morning and arouse around midday or in the afternoon. Recent evidence shows that desert dasyurids bask in the sun during rewarming from torpor and thereby can minimise energetic cost of arousal to a fraction of that required for active arousal. Arid zone bats are also likely to use torpor extensively, but few species specifically from the arid zone have been studied. Nevertheless, species with a wide distribution range including arid areas like long-eared bats,

*Nyctophilus geoffroyi*, enter brief torpor for part of the day in summer and prolonged torpor for up to 2 weeks in winter. Torpid *Nyctophilus* spp. and broad-nosed bats, *Scotorepens balstoni*, can reduce  $T_b$  to a minimum of 2-3 °C and MR to 2% of basal MR; mass loss, and consequently water loss, are minimal during torpor. In contrast to dasyurids and bats, no reliable information is available on torpor in native Australian rodents, perhaps because little work with respect to torpor has been conducted in Australia. Daily torpor in small rodents is common on other continents and it is possible that Australian rodents also use it, although they are mainly granivorous. Thus, it appears that the success of small insectivorous mammals in the Australian arid zone is partially due to their use of torpor, which allows them to survive and reproduce despite limited food and water supply.

## **CYCLIC GMP SYSTEMS IN BODY FLUID REGULATION OF *NOTOMYS ALEXIS***

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The Spinifex Hopping-mouse, *Notomys alexis*, is a desert rodent that inhabits central and western Australia. *Notomys* has adapted a suite of behavioural and physiological mechanisms that enable them to survive in arid environments when water is limited. One critical adaptation is their ability to produce highly concentrated urine (measured as high as 9400 mOsm; the highest recorded among mammals). In *Notomys*, the loop of Henle in the kidney descends deep into the medulla, thereby increasing the medullary concentration gradient. In addition, the colon of *Notomys* has a greater absorptive area than that of non-desert rodents that allows increased reabsorption of water, thereby facilitating the production of small quantities of very dry faeces.

In mammals, the natriuretic and guanylin peptides regulate renal and intestinal fluid and electrolyte transport by binding to and activating guanylyl cyclase (GC) receptors to stimulate production of the intracellular second messenger guanosine 3':5'-cyclic monophosphate (cGMP). Increases in production of cGMP in the kidney and intestine leads to the excretion of water and salt. However, the role of the natriuretic and guanylin peptides in fluid homeostasis in desert species is yet to be clarified. Under laboratory conditions, *Notomys* can survive for extended periods without access to free water whilst maintaining plasma volume and osmolarity. Because signalling molecules that generate cGMP promote the excretion of water, it was hypothesised that natriuretic and guanylin peptide synthesis would be down regulated in water-deprived *Notomys* to reduce the loss of water in the urine and faeces. The aim of this study was to investigate the mRNA expression of atrial natriuretic peptide (ANP), C-type natriuretic peptide (CNP), guanylin, uroguanylin and the GC receptors (type A, B and C) in the kidney, and proximal and distal colon of *Notomys* during a period of water deprivation.

Using a semi-quantitative multiplex PCR technique, the expression of the natriuretic and guanylin peptides and the GC receptor mRNAs were determined in the kidney, while guanylin peptides and GC-C mRNA expression were also determined in the proximal and distal colon of control (access to water) and water-deprived (7 days) *Notomys*. In the kidney, ANP and GC-A mRNA levels were increased in water-deprived mice, while CNP and GC-B mRNA levels were decreased. Water deprivation increased guanylin and uroguanylin mRNA expression in the distal colon, but remained unchanged in the kidney and proximal colon. The expression of GC-C mRNA increased in the proximal colon but not the distal colon. This study shows that water deprivation differentially affects the cGMP system, and that system is not uniformly down-regulated to conserve water.

## **DIFFERENTIAL RESPONSES BY SYMPATRIC MACROPOD TAXA TO SEVERE DROUGHT.**

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The responses to severe drought by yellow-footed rock-wallabies *Petrogale xanthopus* and euros or common wallaroos *Macropus robustus* have been compared. The wallaby population remains fairly static, with deaths mainly from juveniles, while euros die in significant numbers, especially the larger [and presumably older] animals. Nearly 30% of those dying are large males. It is hypothesised that the smaller females are better able to survive severe drought thus providing the necessary residual breeding base for when conditions improve.

## **METABOLISM: INSIGHT FROM ARID ZONE REPTILES**

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The metabolic rate of animals varies both with body size and whether it is an endotherm or ectotherm. Considerable insight into metabolism has come from the comparative study of arid zone reptiles with mammals. These reptiles have the same preferred body temperature as mammals (i.e. ~37°C) but have a metabolic rate that is ~14% of that of a similar sized mammal. The reptiles we have studied are (i) the central-netted dragon *Amphibolurus nuchalis*, (ii) the bearded dragon *Pogona vitticeps* and (iii) shingle-back *Trachydosaurus rugosus*. These reptiles have smaller organs/tissues and less mitochondria (the site of oxygen consumption in cells) than do mammals. Their cell membranes are less leakier to ions than are mammalian cells and therefore they expend less energy in maintaining their intracellular environment. Their mitochondrial membranes are also less leaky to protons than are the mitochondrial membranes of mammals. The membranes of these reptiles tend to contain monounsaturated lipids whilst those from mammals have lipids that are predominantly polyunsaturated. These differences in membrane lipid composition are related to the differences in membrane functional properties. These findings from arid-zone reptiles have been instrumental in the development of the "membrane pacemaker" theory of metabolism. This approach has recently been used to examine the long-known but little understood relationship between metabolic rate and body size in mammals with considerable success.

## **SPERM PRODUCTION IN THE MALE ECHIDNA: IS IT ADAPTED FOR LIFE IN AN ARID ENVIRONMENT?**

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The Short-beaked echidna survives well in an arid environment so that it is pertinent to question whether sperm production is adapted to cope with this environment. We have shown that sperm production in echidna exhibits unique mammalian characteristics. These include the kinetics and duration of a cycle of the seminiferous epithelium (13.8 d for the echidna), the location of the acrosome and presence of a cytoplasmic droplet on spermatozoa, and the duration of sperm transport through the epididymis (14 d). Also, the epididymis is differentiated into distinct segments, the proximal region being structurally and functionally similar to the "initial segment" that is unique to the mammalian epididymis. Nevertheless, the male reproductive tract of monotremes is generally considered to be in the primitive condition for mammals with the testes being located intra-abdominally between the kidneys and the excurrent ducts also being located intra-abdominally. The condition contrasts with that of scrotal mammals and even other testicond mammals. The latter all exhibit varying degrees of development of a sperm storage region of the epididymis displaced from the testis towards the body surface. Consequently, it is considered that the echidna epididymis exhibits no characteristics that can be considered as an adaptation to cope with an arid environment. However, echidna are adapted to improve the competition between males to achieve paternity (sperm competition). They have relatively large testes for their body size, and sperm form into bundles of 20-30 sperm as they pass through the epididymis. This bundle formation is unique among mammals. The sperm are bound together by specific proteins secreted by the cauda epididymidis and several bundles associate with one another to enhance forward movement. The bundles persist for more than an hour after sperm are released into physiological media, but eventually sperm dissociate.

## **THERMOREGULATION AND TORPOR IN THE TAWNY FROGMOUTH (*PODARGUS STRIGOIDES*)**

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Many small mammals are able to avoid the high energetic costs associated with thermoregulation by entering torpor, a physiological state characterised by a substantial reduction of body temperature ( $T_b$ ) and metabolic rate. However, only a few small birds (<80 g) were known to possess this ability and it widely assumed that birds evade energetic bottlenecks chiefly by long distant migration. Nevertheless, not all bird species are migratory and those eating insects or nectar are likely to be subjected to temporary food shortage. Since the large tawny frogmouth, *Podargus strigoides* (Podargidae: Caprimuligiformes; ~500 g) is sedentary and preys mainly on ground active invertebrates, we investigated whether this species employs torpor. The study was conducted on the New England Tablelands at an altitude of about 1000m, but frogmouths are widely distributed including the arid areas of Australia. During 1997 and 1999 we equipped a total of eight free-ranging frogmouths with external temperature-sensitive radio-transmitters attached to a harness (long range) to measure skin temperature ( $T_{skin}$ ). In addition, core  $T_b$  was measured in three of these birds with an intraperitoneal transmitter (short range).  $T_{skin}$  was closely correlated with  $T_b$ , although  $T_{skin}$  was usually several degrees lower than  $T_b$ . Transmitter signals and ambient temperature ( $T_a$ ) were continuously recorded by data loggers (up to 9 months) and roost locations were determined daily in the early morning. During the three coldest months of the year (June-August), shallow torpor with  $T_b$  as low as 29.1°C occurred frequently, but torpor was not observed during spring and summer. Torpor occurred mainly during the night and less frequently in the morning. Frogmouth entered night torpor on cold nights ( $T_a < 7^\circ\text{C}$ ) after a short activity period around dusk. Night torpor lasted on average for about 7 h and birds always aroused before sunrise to either commence a second short foraging period or to fly directly to a day roost tree. Frogmouths occasionally entered a second shorter torpor bout at dawn. As frogmouth selected north-facing branches as day roosts, passive heating by the sun might have caused or contributed to arousal from dawn torpor. We conclude that even some large birds use torpor when detrimental weather conditions would increase thermoregulatory costs and reduce food availability, a situation that is likely to occur also in arid zones inhabited by tawny frogmouths.

## **MITOCHONDRIA AND MUSCLES DURING COLD ACCLIMATION IN *SMINTHOPSIS CRASSICAUDATA*.**

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The effects of cold acclimation on the mitochondrial characteristics in muscles, as well as on the mass of organs and muscles, were examined in the fat-tailed dunnart, *Sminthopsis crassicaudata*. The heart was the only muscle in which changes in mass and mitochondrial characteristics were observed between warm and cold acclimated *S. crassicaudata*. In the cold acclimated (CA) *S. crassicaudata*, hearts were 13.5% heavier; 14.2% greater in mitochondrial volume density,  $V_v(mt,f)$ ; 26.6% greater in total mitochondrial volume,  $V_v(mt,m)$ ; and 17.3% greater in inner mitochondrial surface density compared to warm animals. In CA dunnarts, the mean percentage mass of the liver increased by 16% compared to warm acclimated (WA) dunnarts. In addition, the digestive tract of CA *S. crassicaudata* was 37% heavier than those of WA animals. At least part of this difference was due to the 13% difference in mean gut length between the two groups. These results suggest that CA dunnarts have higher basal metabolic rates compared to WA dunnarts, and that the skeletal muscles are not sites of increased heat production by either shivering or regulatory non-shivering thermogenesis (regulatory NST). Although it is conceivable that regulatory NST occurred in sites other than in the skeletal muscles for the maintenance of body temperatures in the CA animals, this appears unlikely since skeletal muscles are already the largest organ group in the body that could possibly facilitate regulatory NST. Since dunnarts have high metabolic capacities, the maintenance of body temperatures in the CA

animals may have been due to shivering alone, without increases in either mitochondria or in the surface densities of the mitochondrial cristae.

## **FACTORS AFFECTING ROADKILL ON THE SILVER CITY HIGHWAY IN FAR WESTERN NSW**

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Kangaroo vehicle collisions are a frequent event on Australian highways. Despite high resulting economic costs as well as animal welfare issues, little research has been done to investigate the impact of road mortality on kangaroo populations, to find out where and why accidents occur and how the collisions can be mitigated. During this 6-month study data on species, sex and age of kangaroos killed on the road were collected on a 21.2 km section of sealed outback highway in far western NSW. The spatial and temporal distribution of road-killed kangaroos were investigated in relation to the cover and quality of road side vegetation, road characteristics, density of kangaroos along the road and climatic variables.

A total of 125 kangaroos were found killed on the road. Grey Kangaroos were under represented in the road kill sample as compared to their proportion in the source population. No bias towards either sex was found. The age structure of road killed kangaroos was similar to age structures found in other kangaroo populations. Road kills mainly occurred in plain open country. In road sections with curves or stock races road kill frequencies were higher than expected. Road kill locations had significantly higher pasture cover, relative greenness and height than locations where no road kills occurred. Hence road side vegetation was another factor that potentially influenced the spatial distribution of road kills. The road created an edge effect, as pasture cover and relative greenness in the first meter interval on the road side were significantly higher than in meter intervals further away. There was some evidence that road side vegetation attracted kangaroos to the road to graze. The temporal distribution of road kills was highly correlated with night time traffic. The probability of a kangaroo-vehicle collision increased exponentially with traffic volume. With an average traffic volume of 53 vehicles per day the probability of a least one road kill was 35 %. The results are discussed in relation to risk factors inducing road kill and the potential to mitigate against them.

## **FOOD AND WATER REQUIREMENTS OF THE BRIDLED NAILTAIL WALLABY**

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Once considered to be common, the endangered bridled nailtail wallaby (*Onychogalea fraenata*) currently occupies less than 5% of its former range. The only known wild population occurs on and around Taunton National Park (Scientific) in central Queensland. Recent monitoring suggests a population size of <1,000. In the mid 1990s, in accordance with the species' Recovery Plan, the Queensland Government translocated a population of free-ranging bridled nailtail wallabies to Idalia National Park – a location on the extreme western limit of the species historical distribution.

Suitable and sufficient forage is an element of significant importance affecting the persistence of fauna populations within habitats. A primary objective of this project is to determine whether adequate forage and water resources are available at both Taunton NP and Idalia NP to support an increasing abundance of bridled nailtail wallabies. To achieve this, a detailed examination of their diet, an evaluation of forage availability and quality, and an assessment of their water requirements will be undertaken.

To determine the plant species consumed, microhistological analysis of faecal pellets will be used. This technique relies on identifying epidermal fragments of plant species in faecal pellets and comparing them against a reference collection of the epidermal structures of plants available for consumption. In conjunction with this, botanical species diversity and yield will be measured within occupied habitats, and the moisture, energy and nutritional value of dominating forage species determined.

Water requirements will be measured by means of isotopically labelled water. The washout rate of injected tritiated water will be used to determine the amount of water they process through their bodies each day. Animals which are less dependant on water display lower water flux rates. This can be indicative of adaptations – both physiological and behavioural – specific to mechanisms associated with water conservation that enable species to persist in arid environments.

Accordingly, this project will provide greater understanding of the extent to which the bridled nailtail wallaby is arid-adapted, and will offer some insight into their ability to persist in a semi-arid environment, such as Idalia National Park.

## **CAROTID BLOOD AND BRAIN TEMPERATURES OF FREE RANGING WESTERN GREY KANGAROOS (*MACROPUS FULIGINOSUS*)**

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Using implanted temperature loggers we measured temperature in the carotid artery in five (4 male, 1 female) western grey kangaroos every five minutes for between 39 and 74 days while the animals lived undisturbed at the Harry Waring Marsupial Reserve south of Perth.

Dry bulb temperature during the study ranged from an average minimum of (mean  $\pm$  SD)  $11 \pm 3^\circ\text{C}$  to maximum of  $24 \pm 5^\circ\text{C}$ . There were two days where maximum dry bulb temperature exceeded  $35^\circ\text{C}$  and a further 12 where it exceeded  $30^\circ\text{C}$ . Black globe temperature measured in the southern shade of a grass tree, ranged from an average minimum of  $10 \pm 4^\circ\text{C}$  to an average maximum of  $30 \pm 6^\circ\text{C}$ . There were 9 days where maximum shade globe temperature exceeded  $40^\circ\text{C}$ .

The animals were febrile for about 10 days following surgery but temperature rhythms thereafter became regular. Data analysis was performed only on data collected after the febrile period.

Carotid blood temperature averaged  $36.5 \pm 0.1^\circ\text{C}$  ( $n = 5$ ) ranging from an average minimum of  $35.5 \pm 0.3^\circ\text{C}$  to a maximum of  $37.3 \pm 0.1^\circ\text{C}$ , giving an average daily range of  $1.8 \pm 0.3^\circ\text{C}$ . Body temperature was highest during the night and dropped rapidly early in the morning, reaching a nadir at 10:00, after ambient temperature and solar radiation had begun increasing. Body temperature then rose gradually during the day to reach a peak in the early evening. The nycthemeral variation in carotid blood temperature was independent of ambient conditions. Changes in dry bulb or globe temperature did not explain any of the small variation in mean, minimum, maximum, or range of body temperature. It has been suggested previously that the rapid decrease in body temperature in the morning is influenced by solar radiation causing a blood flow redistribution. We found no association between early morning radiation levels and the minimum body temperature reached.

In three of the animals we also measured brain temperature in the hypothalamus, coincident with carotid blood temperature, for between 3 and 63 days. On average brain temperature paralleled and exceeded carotid blood temperature by  $0.12 \pm 0.05$ ,  $0.38 \pm 0.08$ , and  $0.41 \pm 0.08^\circ\text{C}$  for the three animals. In each animal there were some data points where brain temperature was lower than carotid blood temperature. These times were always associated with rapid increases in body temperatures and we ascribe these data to a longer time constant for the brain probe than for the blood probe. Separate analysis of data when body temperature was increasing and when it was decreasing supports that conclusion. Thus there was no evidence of selective brain cooling in these large macropods.



## THE ECOPHYSIOLOGY OF JUVENILE SURVIVAL IN THE RED KANGAROO.

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The population dynamics of red kangaroos (*Macropus rufus*) in the Australian arid zone is tightly linked with environmental factors, which partly operate via the survival of juvenile animals. A crucial stage is the young-at-foot (YAF) stage when kangaroos permanently exit the mother's pouch. Here, I present an overview of the major physiological differences between YAF and non-reproductive adult female red kangaroos and consider how these relate to survivorship. Under thermoneutral conditions (ambient temperature [ $T_a$ ] = 25°C), YAF had daily energy requirements (watts) that were some 60% of those by adult females, and as much as 70% under cold conditions ( $T_a$  = -5°C). Also, despite being 3 - 4 times smaller, YAF red kangaroos had total evaporative water losses (watts) that were not significantly different from those of adult females. The small body size of the YAF red kangaroos, ca. 6 kg, also affected their ability to digest poor-quality, high-fibre forage (ie chopped oaten hay). Adult female red kangaroos, with a body mass of ca. 26 kg, were able to digest ca. 45% of the organic matter (OM) from chopped oaten hay. However, when fed chopped oaten hay YAF digested only ca. 36% OM and were unable to sustain body mass or growth. Also, when switching from a low-fibre, high-quality diet of chopped lucerne hay to the fibrous oaten hay, YAF showed significant reductions in daily OM intake (OMI) and digestible energy intake (DEI), by around 70% in each case. Conversely, adult female red kangaroos were able to maintain OMI and DEI when switching from chopped lucerne to oaten hays. Moreover, for YAF red kangaroos fed chopped oaten hay to attain energy intakes equivalent to those fed lucerne, an intake of 300 mL d<sup>-1</sup> of late stage red kangaroo milk would be required; this level being highly unlikely given red kangaroo mothers would also face feed and water restrictions during drought.

## ECOPHYSIOLOGY OF A SYMPATRIC RODENT AND DASYURID IN A SEMI-ARID ENVIRONMENT.

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Behavioural and physiological adaptations of sympatric *Sminthopsis murina* and *Pseudomys pilligaensis* were studied using radio-telemetry in Pilliga East State Forest during autumn and winter, 1999. Body temperatures, activity patterns, burrow structure and temperatures, nesting and burrowing behaviours were investigated. Both species were found to rest during the day in burrows, using a preferred burrow type, with *S. murina* also found in logs and old *P. pilligaensis* burrows. Most *P. pilligaensis* burrows were more complex, consisting of tunnels dug into flat ground with entrance holes at both ends and a larger nesting chamber in the deepest part of the tunnel. These chambers were filled with nesting material and huddling behaviour was also observed. *S. murina* burrows were simple tunnels dug into slopes on mounds, with one entrance and a wider terminal nesting area; no nesting material was identified and dunnarts appeared to nest solitary. *P. pilligaensis* burrows were a little deeper and longer than *S. murina* burrows, up to 22 cm deep and 60 cm long and tended to have a north-south orientation. Burrows at this depth were found to be very humid, with a high soil moisture keeping evaporative water loss to a minimum. All burrow temperatures varied only 2-3° C for any 24-hour period; the shallower *S. murina* burrows (10.3°-15.8° C) were cooler than *P. pilligaensis* burrows (15.4°-19.3° C). Ambient surface temperatures varied between 3.5° to 24.6° C during the same period. *P. pilligaensis* burrows were better designed to induce passive ventilation, namely by the use of a specific orientation, a tunnel with one entrance at a different angle to the other, the construction of extra entrance holes and the location of burrows under bushes or young trees. *S. murina* changed shelter sites regularly and were active, very mobile throughout the night and sometimes after sunrise, *P. pilligaensis* tended to be burrow-specific, less active and social, rarely moving more than 50m from

their burrow. Average activity bout length for *P. pilligaensis* was 11 hours and 47 minutes, and average resting bout length was 11 hours and 25 minutes. Both basking behaviour and torpor were observed in *S. murina* while inactive. Normothermic rest period skin temperatures show an overall average  $T_{\text{skin}}$  of 32.3°C, with a range of average temperatures of between 30.7 and 33.8°C, torpid periods were variable in minimum body temperature and arousal rate. A minimum body temperature of 18°C was observed during torpor. The duration of torpor bouts differed considerably ranging between 58 minutes and three hours and 42 minutes. Nocturnal resting behaviour in *P. pilligaensis* showed an average resting  $T_{\text{skin}}$  for *P. pilligaensis* at 34.07°C, with an average resting  $T_{\text{skin}}$  range for all rest periods recorded was between 32.59 and 34.75°C. Despite phylogenetic differences, both convergent and divergent physiological and behavioural strategies were observed in these two species of small mammals while surviving in a winter semi-arid environment.

## **MOLECULAR ACTIVITY OF SODIUM PUMPS IN THE KIDNEY OF MAMMALS AND BIRDS**

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Metabolic intensity is allometrically related to body size in both mammals and birds, with smaller species having an increased metabolic intensity compared to their larger counterparts. Our current investigation has compared sodium pumps from the kidney of mammals ranging in body mass from 31g to 340kg and birds ranging from 13g to 35kg. The purpose of our study was to examine whether the molecular activity of sodium pumps from the kidney of these species, reflected the differences in their metabolism.

The species examined in the study were for mammals: mice, rats, sheep, pigs and cattle, and for birds: zebra finches, sparrows, starlings, pied currawongs, pigeons, ducks, geese, and emus. Na+K+ATPase activity was measured in kidney tissue homogenates, and negatively correlated with body mass. Sodium pump density, measured in tissue biopsies, was essentially constant in mammalian kidney (~5000 pmol/g tissue), but scaled negatively with body mass in the kidney of birds, ranging between 3600 -12500 pmol/g tissue.

Molecular activity was calculated by dividing Na+K+ATPase activity by sodium pump density to give the turnover rate of ATP by each individual sodium pump. Molecular activity of mammalian sodium pumps was related to body mass, with mice having a molecular activity of 23,000 ATP/min compared with around 8000-9000 ATP/min in the larger mammals. The molecular activity of bird sodium pumps however, was fairly constant at around 4000-8000 ATP/min and showed no relationship with body size. These results will be discussed relative to kidney membrane fatty acid composition which also varies with body mass.

## **KANGAROOS AND RAT-KANGAROOS: LOCOMOTION ENERGETICS AND LIFE IN ARID AUSTRALIA**

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Many species of kangaroos and rat-kangaroos (superfamily Macropodoidea) live in arid or semi-arid habitats. A contributing factor to their success in these dry environments may be their gait: at fast speeds, hopping by kangaroos and wallabies is energetically cheaper than running (3), (1). This may be

advantageous if extensive travel is required to access water and feed. However, there has been debate about whether economical locomotion energetics occur in small hopping mammals (2), (5). A good group for investigation of this question is family Potoroidae, the rat-kangaroos, and particularly the bettongs (*Bettongia*, *Aepyprymnus* and *Caloprymnus*). In general, bettongs are more accomplished hoppers, and live in more arid environments than potoroos (*Potorous*).

We examined the locomotion of the brush-tailed bettong, *Bettongia penicillata*, which is an obligate hopper at fast speeds. Five bettongs were exercised on a motorised treadmill at speeds from 0.6 to 6.2 ms<sup>-1</sup>. Oxygen consumption was measured using an open-flow respirometry system. Maximum energetic output was measured by exercising the bettongs on an inclined treadmill. Gait parameters were obtained from video footage of the bettongs during exercise.

*Bettongia penicillata*'s locomotory energetics were different from those of a running quadruped. Although there was an increase in metabolic rate as speed increased, this increase was significantly lower than expected. Thus, a bettong hopping at speeds of 2 ms<sup>-1</sup> or above uses less energy than a running quadruped of the same mass. The mean maximum level of metabolism was about 17 times resting levels (2.20 ± 0.131 ml s<sup>-1</sup> kg<sup>-1</sup>), an aerobic scope less than that of a red kangaroo. Gait patterns followed those seen in red kangaroos (4): stride frequency was invariant across all hopping speeds (at 3.5 strides s<sup>-1</sup>), while stride length increased linearly with increasing speed (to a maximum of 1.8 m).

We suggest that economical fast hopping and a constant stride frequency during hopping are conservative characteristics of the superfamily Macropodoidea, with an evolutionary history of at least 30 million years. Some more derived features of the Macropodidae include a further reduction in the energetic cost of locomotion and an enhanced capacity for aerobic performance; these may be linked to the recent extensive radiation of this group some 5 million years ago. The economical gait of both kangaroos and rat-kangaroos may have contributed to their success in arid and semi-arid environments.

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## PELVIC LIMB ANATOMY OF THE RED KANGAROO AND BRUSH-TAILED BETTONG

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Hopping kangaroos and wallabies show rates of oxygen consumption that do not change over large ranges of speeds (1), (2). Recently, a similar pattern was observed for hopping Brush-tailed Bettongs (Webster and Dawson, unpublished). Although the relatively low cost of locomotion in kangaroos has not yet been fully explained (3), it appears to be associated with both storage of elastic strain energy and powerful locomotory muscles.

We have examined the pelvic limbs of the Red Kangaroo (mass 25-80 kg) and the Brush-tailed Bettong (mass 1 kg). In both species, probable areas of elastic energy storage were the large, thick tendons associated with the gastrocnemius and caudofemoralis muscles. Muscles used for power production during hopping were the biceps femoris, the quadriceps group, caudofemoralis, adductor, gluteal group and gastrocnemius. There were some small differences in relative size of these muscles between the two species.

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# THE ECOLOGY OF INSECTIVOROUS BATS IN THE SIMPSON DESERT: HABITAT USE

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Bats living in Australia's arid zone have been largely ignored by researchers. The honours project aimed to identify the species of insectivorous bats that occur in the Simpson Desert and to investigate aspects of their ecology. This poster will focus on habitat use by the bat species present. Seven species of insectivorous bats were positively identified with the combined use of harp traps, cave inspections and ultrasonic call recordings (using Anabat II detector systems). These species were *Nyctophilus geoffroyi*, *Vespadelus finlaysoni*, *Chalinolobus gouldii*, *Scotorepens balstoni*, *Taphozous hilli*, *Saccolaimus flaviventris* and *Tadarida australis*. An additional species, *Scotorepens greyii* was tentatively identified by call recordings. The bats foraged most often over water and on calmer nights, when insects were more active. Bats predominantly utilised water sources, rocks, dune/swale near woodland, dry creek line and coolibah woodland habitats. However, they rarely used open habitats (open plain and dune/swale), acacia scrub and gidgee woodland. Several different requirements may influence habitat use by bats in the Simpson Desert. One study site at the Field River contained the highest activity of tree-dwelling bat species, and here the coolibah woodland is more dense and contains a larger number of hollows and dead trees than coolibah woodland at the other sites. It appears that both tree and cave roost sites may be a limiting resource, resulting in bat activity being predominantly restricted to the 'oases' in the Simpson Desert study area. Food availability (total abundance and biomass of insects) and permanent water, surprisingly, do not appear to determine the use of different habitats. Although highly active over water in some areas, bats may survive in the Simpson Desert without access to permanent water. Larger sample sizes and further investigation during harsher periods of less rainfall, and during warmer months in the year, are necessary to evaluate the temporal stability of the results presented.

## COCOON-FORMING FROGS OF WESTERN AUSTRALIA

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Most frogs are intolerant of high temperatures and low moisture, so it seems surprising that frogs are such a conspicuous element of the fauna of deserts, at least after rainfall. Frogs avoid the extremes of desert environments in various ways, but a common pattern is to burrow underground and aestivate during the hot, dry periods. During aestivation, frogs typically reduce their metabolic rate to conserve energy stores, and many form a cocoon to reduce water loss.

The diversity of Western Australian frogs and the wealth of their general background information allowed detailed physiological studies of cocoon-formation by both hylids (*Cyclorana* spp and a *Litoria*?) and myobatrachids (*Neobatrachus* spp). The cocoon of these frogs consists of accreted layers of shed skin, which are continually added to the cocoon during aestivation. Consequently, the resistance of the cocoon to evaporative water loss continues to increase and the rate of evaporative water loss progressively decreases over time. Concomitant with the reduction in EWL is a decrease in metabolic rate, to about 1/5 of normal, and this metabolic depression extends the time that a frog can survive aestivation by about 5 fold (to over 5 years in some species). While cocooned the frogs accumulate their nitrogenous waste product, urea, and the body fluid concentration can exceed 300 mM. Normally, such high concentrations of urea perturb the functions of proteins, and this is why animals that normally have high urea levels (sharks, rays) have counteracting solutes (TMA, betaine); however, aestivating frogs do not have counteracting solutes, perhaps because perturbation of cell function might contribute to metabolic depression.

**BREEDING IN WILD POPULATIONS OF THE DASYURID MARSUPIALS  
*PLANIGALE INGRAMI*, *SMINTHOPSIS MACROURA* AND *SMINTHOPSIS  
DOUGLASI*.**

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The timing of breeding in the wild of three species of dasyurid marsupials has been investigated by examination of the remains of individuals eaten by feral cats. The cats were collected as part of a separate study on the diet of introduced predators (cats and foxes) in north-western Queensland in an area where the three species, *Planigale ingrami* (Long-tailed Planigale), *Sminthopsis macroura* (Stripe-faced Dunnart) and *Sminthopsis douglasi* (Julia Creek Dunnart) occur in sympatry. Over 20 months in 1995 and 1996 188 cats were shot. The stomachs of 70 of these contained the remains of dasyurids including 123 *P. ingrami*, 20 *S. macroura* and 18 *S. douglasi*.

Specimens were grouped into one of three age classes (juvenile, sub-adult and adult) based on their dentition. The reproductive status of each individual was assessed as either immature or mature and the data from 1995 and 1996 were combined and analysed by month of collection.

Reproductively mature adults in breeding condition were present between August and late January. Juvenile, sub-adult and reproductively immature adult individuals were present from January to August. Specimens that were assessed to be reproductively mature, but not in breeding condition, were collected during March, April and May. It was conclude