



## ACTHA CONTACT DETAILS

PO Box 160

Jamison ACT 2614

E-mail: [info@actha.org.au](mailto:info@actha.org.au)

Website: [www.actha.org.au](http://www.actha.org.au)

## ACTHA INC. NEWS JUNE - JULY 2013

*Newsletter of the  
ACT Herpetological  
Association Inc.*



### YOUR COMMITTEE FOR 2012 - 2013

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Vice President	Ric Longmore
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Committee Members	Iris Carter
	Greg Flowers
	Peter Child
Student Representatives	Angelique Harrison
	Sophie Sloane

\* Denotes Life Members

### A TRIAL RUN OF ELECTRONIC COPIES OF THIS NEWSLETTER TO ALL MEMBERS HAS ENDED

ACTHA members receiving this Newsletter in full colour via email was a good idea, however a random survey of members has found that the Newsletter tends to get overlooked in computer systems.

More importantly, **attendance at meetings has dropped** and we suspect that Meeting and Guest Speaker details are perhaps not being seen.

We are therefore returning to postal hardcopies **unless you indicate otherwise**. Please email your preference to: [mandyconwy@gmail.com](mailto:mandyconwy@gmail.com)

Don't forget that a full colour copy of each Newsletter is easily accessible on ACTHA's Website.

### IN THIS ISSUE

Two recent articles about conservation efforts for the **Grassland Earless Dragon**... pages 2 & 3.



### Saving frogs because we must!

Earlier this year Gerry Marantelli, ARC, gave an inspiring presentation on his Centre's role in conservation

efforts for the world's declining frog populations, see pages 4-11.

### Habitat use and body shape in Australo-Papuan Myobatrachid frogs:

Marta Vidal-Garcia, ANU, was our guest speaker in February this year. Did Marta's studies reveal whether morphological differences in frog species were related to habitat use? Find out on pages 12-15.



### The evolution of monitor lizards: Australia's lizard kings:

Gabrielle Openshaw, ANU, gave a very detailed presentation on the origins of her favourite reptile.

Gabi's research goes back to the

Cretaceous period, 145.5 - 65.5 million years ago. See pages 16 to 20 for the evolution countdown!



### The Australian & International Scene:

Controlling crocs means knowing who's boss, page 21.

### DIARY DATE

The *bi-monthly* meetings of the Association are held on the **third Tuesday of the month at 7.30pm**. Our usual venue is:

**Belconnen Soccer Club, Hawker  
(cnr Belconnen Way & Springvale Drive)**

### UPCOMING MEETING

**TUESDAY, 18 JUNE 2013**

This month our guest speaker is long-time member **Dr Arthur Georges**, Institute for Applied Ecology, University of Canberra.

Arthur has spoken about his research exploits and expeditions at ACTHA meetings since the mid 1980s. This Editor can recall many really interesting and often humorous presentations involving Australia's turtle species. Arthur has decided to base his talk on a different reptile this time: **Genomics for Dummies - A step by step introduction to the full genome sequence for the bearded dragon.**

Arthur's presentations are always in high demand so this one should not be missed!

## **TYMPO CAPTIVE BREEDING PROJECT**

By Geoff Robertson

When I lived in Russia, I learned that everyone has three names: a formal name, a casual name that friends and acquaintances use, and a name that intimates use. So it is with some of our most precious creatures. For example *Tympanocryptis pinguicolla* is the formal name for one of our favourite grassland species, Grassland Earless Dragon (GED) is their common name and their intimates call them Tympos.

Dr Lisa Doucette, Postdoctoral Research Fellow, is responsible for a much needed and belated breeding program on Tympos at the Institute for Applied Ecology at Canberra University. The second bit of good news is that they have had one hatchling. This is the first known member of this species to be bred in captivity, although ACTHA member Joe McAuliffe had great success with near relatives in the past.

Lisa explained to me that the Institute has started a breeding program for GED and have the first ever GED hatchling in captivity. The program has one pair (two Tympos) from the ACT and nine adults and one hatchling from a population on the Monaro Tablelands south of Cooma, NSW.

The breeding season is over for the year. Unfortunately "we never got any of the other pairs to breed" she said. "There is something not quite right despite our efforts to vary the conditions and try different things. I suspect it



Photos: Emma Carlson, UC Honours Student)



has to do with the artificial conditions (no natural light, air conditioning to control temperature). It may also be due to the fact that apart from the one female that laid three eggs, all the other females were caught as juveniles in May 2012. We will be changing the cage setup prior to next year's breeding season to ensure at least some of the pairs have access to natural light and air temperatures."



## **WORKSHOP ON THE GRASSLAND EARLESS DRAGON**

By Geoff Robertson

On 19 December 2012 I attended a one-day national workshop on the Grassland Earless Dragon (GED) (*Tympanocryptis pinguicolla*) on behalf Friends of Grasslands (FOG). The workshop, hosted by Tim McGrath of the Department of Sustainability, Environment, Water, Populations and Communities, DSEWPAC), aimed to gauge how the recovery of the species was tracking and harnessing the

expertise of participants to develop some important guidelines for those making decisions about the GED in Environmental Impact Assessments.

GED is a highly cryptic grassland specialist which is listed 'endangered' under the Commonwealth's Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). This reptile, presumed extinct in its former range of Victoria and the south west slopes region of NSW, now only occurs in natural grasslands in the Canberra, Queanbeyan, Cooma and Nymmitabel regions of the ACT and NSW. The EPBC Act is instrumental in the



protection of GED in its current range from urban and agricultural development which poses the biggest threat to the species existence.

Tim opened the workshop by saying, "There has never been a more appropriate time to bring together all the stakeholders and experts as the alarm bells are ringing for this species." making particular reference to a recent publication by Wendy Dimond and others from the University of Canberra. Their recent work indicates that extinction is a reality for this species in Canberra in the next 10 years.

Throughout the day, important presentations were given by experts on the species and some interesting discussions were had about the threats and actions required to recover the species right across the species range with representatives from the Commonwealth, ACT, NSW and VIC governments present, universities and community groups actively participating.

Some of the key discussion points included:

- How development activities and other impacts on the species might be ameliorated under the EPBC Act;
- Information coming from monitoring programs currently being undertaken for the species across its range;
- The captive breeding program that is underway for the species at the University of Canberra (*see story on page 2*);
- New information that has come to hand since the inception of the Recovery Plan for the species in 2010; and
- The status and management of the species habitat across its range.



*Photo: Tim McGrath*

The workshop was an extremely positive step in making sure the species is getting the due recognition it and its habitat deserves. Progress is being made with the key recommendations of the workshop already well underway. The workshop decided:

- To development of a draft Guidance Note for the species relating to Environmental Impact Assessment under the EPBC Act. This will be developed by DSEWPAC and soon be released on the Department's website for a four-week public comment period;
- Improved information to be prepared for the public on habitat identification. Descriptions and photos will be provided in the Guidance Note developed by DSEWPAC; and
- Improved awareness and education of the species in the agricultural sector. A pamphlet for landholders, local businesses and conservation groups is almost finalised with the assistance of organisations such as FOG, Kosciuszko to Coast, ACT Herpetological Association Inc. and the University of Canberra.



*Grassland Earless Dragon habitat on the Monaro Tablelands near Cooma. Photo: Tim McGrath*



## SAVING FROGS BECAUSE WE MUST!

*This summary of a talk given by Gerry Marantelli, Amphibian Research Centre, Vic, during ACTHA's Snakes Alive! Exhibition in January '13 is by Mandy Conway, who greatly appreciates Gerry's assistance with its presentation.*

After a brief introduction by ACTHA's President, Dennis Dyer, David Hunter formally introduced our guest speaker. "I first met Gerry Marantelli in 1994, who at that time played an important part in my shifting from someone who loved herpetology in general to someone who became passionate about frogs. The breadth of Gerry's involvement in frog conservation, including raising awareness of the value of frogs in our environment, has been huge. Not just in here in Australia, but globally. I cannot think of a single individual who is as passionate or who has played such a significant role in the breadth of frog conservation. Gerry is probably one of the most unconventional people I have ever known, particularly in his approaches and perseverance in the face of each and every impediment that he has faced."

### A huge diversity of sizes and behaviours

Gerry started his presentation by saying that there are about 7,000 described frogs worldwide, not including those species still

waiting to be formally described! Most have been given names, some have a known natural history, but many are still in jars waiting to be formally identified. They range from the smallest of vertebrates you are likely to find, to very large ones.

*(Left: Gerry holding a giant Japanese salamander, which can grow to 6ft long and weigh nearly 80kg.)*

From the multi coloured frog with sticky pads living in a rainforest to white salamanders living in caves 1km below the earth's surface (below), amphibians appear to have tapped into every conceivable place on earth.



Living in the Arctic Circle, freezing into a solid block of ice during winter, is a frog who can restart its heart when spring arrives.

Australia's Water-holding Frog (right) can live in virtual suspended animation: aestivating, its metabolic rate falls below the level that any other organism would take just to stop themselves from decaying.



"Frogs play a phenomenal role in holding our ecosystems together. They operate as an effective predator whilst being prey themselves. They are both a tadpole and then a frog, fulfilling two completely different roles in the ecosystem." Gerry said.

"They are also just fascinating as animals. The breadth of reproductive behaviour is enormous and often strategic. From laying so many eggs that some are bound to reach adulthood to surrounding their eggs in air bubbles so they can rise to the water's surface to access warmth and oxygen to enable faster development." Gerry enthused.

"Frogs that lay their eggs in a tree, en masse, to develop as tadpoles, well away from predatory fish and those that have tadpoles which partially develop in the egg.







The egg membrane of the Corroboree frog contains toxins, possibly preventing fungus from attacking the eggs and/or herbicides to prevent encroaching

weeds "...we don't know exactly. We see snippets of things when these animals are being studied, however many questions remain unanswered."



Left: "If you can't predict when it's going to rain, grow your tadpoles in an egg and carry them on your back to deposit into a pond when it

does rain," Gerry said about this slide.

A frog that lay eggs which develop into mini adults within their egg membrane can help tadpoles pass that vulnerable stage in their lifecycle.

Marsupial frogs which carry tadpoles in a pouch, or frogs that absorb their eggs underneath the skin of their back, the young digging their way out to emerge when ready. The scope of reproductive behaviours seems endless.

The Gastric Brooding Frog is one of the most bizarre: a frog which eats its own eggs, allowing full development of juveniles in the stomach before vomiting them up. "How does this frog shut-down the digestion process to allow the eggs to develop? Studies revealed that the eggs produce a chemical which shuts off acid secretion in the stomach. This frog gave us the current cure for human gastric ulcers." Gerry said.

#### Disappearing act

The Gastric Brooding Frog, *Rheobatrachus silus*, was the first documented frog extinction in Australia. This frog's pristine QLD tropical

rainforest habitat was situated within a national park. How could this happen in such an environment and why were frogs disappearing from similar habitats all over the world.

Working at Melbourne Zoo at the time, Gerry experienced something still strongly embedded in his mind. *"It was a small brown frog I held in my hand that day, plain and utterly unremarkable, small enough to walk by without a second glance. It was a Torrent Frog – a Sharp Snouted one to be exact, an inhabitant of small forest streams in North Eastern Australia. Such a ubiquitous creature that no-one invested time in understanding it, in fact more than one biologist described it to me as so common you were bound to step on a few en route to more interesting and important research pursuits. But she was dear to me. I had raised her from a tadpole and now she was mature, ripe eggs visibly bulging from her sides. I should have expected to find her breeding, she was young and in her prime, she should not be unwell!"*

*"It was not overly unusual for me to find a dead frog while doing my rounds at work; after all we had many frogs and like any animal some were bound to die. It was however quite usual for me to find a dying frog. This final act, whether by choice or coincidence was usually experienced in private, unwitnessed, silently. But nonetheless here she was, laying quietly in my hand, legs outstretched in spasm, alone with me at the end of her life. And as she passed she took with her an entire species, quietly into the oblivion of extinction."*

*"How do you begin to describe extinction? Do you regurgitate clichés and platitudes? Do you drown its true meaning in science? Do you stomp your feet and demand it never happen again? I do not know how to describe it. I do not know what will reach people. But I do know what I saw, I do know what I felt and I do know what it did to me. So that is how I must tell it: as someone who watched extinction in my hand, who has walked in the lands of lost frogs and felt the silence of their ghosts."*

(Saving frogs because we MUST!, cont'd)

"My love of frogs hence took another, more urgent, leap forward. In my travels around the world to try and see what was causing these mass extinctions I came across so many similar stories. At a university in Quito, Ecuador, I met a man named Louis. He spoke only Spanish and I only English, but we managed to



communicate. He took me to a room at the back of the university (below), where he opened a cupboard door and removed bottle after bottle of preserved frogs. The room was full of over one hundred Ecuadorian species of frogs, now extinct, along with many more which had yet to be described.



Left: One of the first *Atelopus* species to disappear from South America. These mountain frogs lived in very similar habitats to Australia's Corroboree frog:

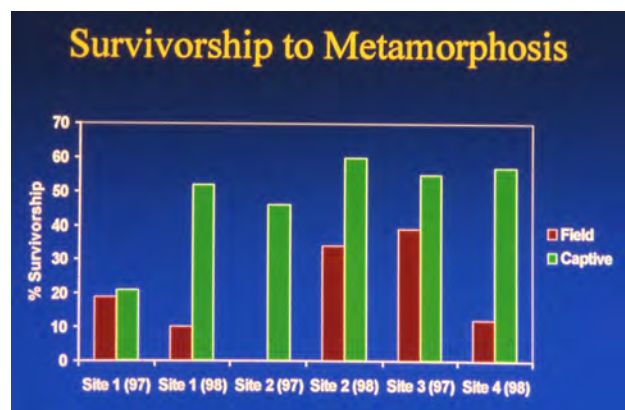
whatever was driving these extinctions was happening at a global level."

#### Gerry Marantelli's AMPHIBIAN RESEARCH CENTRE is born

Decommissioned shipping containers, previously used for frozen food export/import, were purchased and transformed into mini laboratories to house different species of frogs. Preliminary investigations focussed on which part of a frog's lifecycle was primarily affected by infection and/or death.



Early field surveys found that Corroboree frog egg clutches did not ultimately produce surviving adults. Captive breeding commenced in the mini labs and half of the progeny were released back into their natural habitat and monitored to see which group performed better. Some of these first experiments showed that raising young tadpoles to metamorphosis in captivity and then putting them back into the field was increasing wild population numbers.



The Spotted Tree Frog, *Litoria spenceri*, (right) another species in decline, was being studied by Graham Gillespie at the time. He used radio tracking (below right: a tiny transmitter) to look at population demographics, particularly what age the frogs reached sexual maturity and their longevity. Graham hypothesised that trout feeding were responsible for the frog's decline. A valid conclusion after a large population of the species was





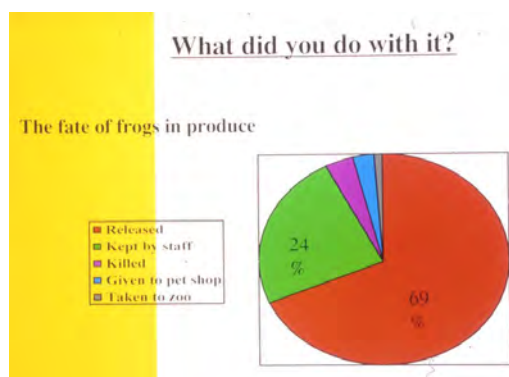
found at Bogong Creek in NSW where no trout was evident: that population collapsed shortly afterwards.

A little after Gerry began studying frogs in captivity, Lee Berger, a veterinary student being supervised in part by CSIRO, approached Gerry wanting to do some work on amphibian diseases. Joining forces, Lee and Gerry now played a significant role in the discovery and description of the cause of these extinctions. Further studies now concentrated on the culprit, chytrid fungus, and emphasis was placed on studying how the fungus could spread so effectively and be so lethal.

### Successes and failures go hand-in-hand

"Every event presented an opportunity to learn more. In the process of losing frogs we were able to test more anti-fungal drugs, amongst others. Disease outbreaks in captivity could now be treated. We were able to map the way the pathogen moved across the skin at metamorphosis." Gerry explained.

Attention now also turned to spreading mechanisms. Displaced Banana box frogs were suspected of facilitating disease spread through fruit and vegetable shipments. Fruit shop, supermarket and plant nursery employees were surveyed and asked what they did with these



frogs when they were found. Seventy percent of those surveyed replied "we release them into the wild". Wild Dwarf Tree frog populations have recently appeared as far south as Melbourne. A public education campaign ensued to explain the awful consequences of releasing displaced frogs into new environments, thereby potentially spreading disease further and more quickly.

A number of PhD and honours students have conducted trials on transmission, microclimate,

behaviour and treatment of thousands of frogs and tadpoles held in containers at the Amphibian Research Centre (ARC). The initial primary aim was to understand the disease process, but this was difficult because some species died to extinction, others declined to worrying levels and yet others seemed unaffected. Microhabitat factors such as humidity levels, water flow, heat and sunlight were altered and the results of these changes on the frogs were recorded and compared.

The effects of the chytrid fungus appeared to vary markedly among species. In some frogs the adults did not get infected but their tadpoles did, dying after they reached metamorphosis. Trying to infect the adults in these experiments resulted in no frogs getting sick. Some wild populations could be persisting because of this scenario.

Some isolates of the disease were having a different effect on different species. Some frogs died slowly, some quickly, some only died when they were completely 'saturated' with the pathogen, whilst others only required a brief encounter. Variability was enormous.

By 2005, the successful breeding of captive spotted tree frogs meant many frogs were able to be released back into their environment over several years. The population at Bogong Creek started recovering and individuals were tracked to see what proportion survived. 'Soft' frogs from captivity, who were used to being fed with crickets on a regular basis, had managed to survive in the wild. These results were good.

The Booroolong Frog, *Litoria booroolongensis* (below) was the next species to receive vital



attention. Captive bred specimens were released into habitats with grasses and rocks containing sediments from cattle grazing.

Infuriatingly, just after release, there was a cold snap which resulted in the deaths of many of these frogs. Tens-of-thousands of dollars and man hours had been spent raising hundreds of frogs over several years to produce over five hundred frogs to release, with complete project failure in the space of a few days. Gerry tenaciously told his audience, "Learning from each positive and negative experience is paramount. What we learnt was what we suspected – the damage to stream cobble banks by cattle and sediment rendered them unsuitable for the frogs who now had nowhere to insulate themselves from the frequent cold weather experienced in the area. We would not easily learn this by observing the very few frogs that were left in the wild, but we learnt it literally overnight with a release. We now have a stark example for at least one of the things we must do in all Booroolong habitat to secure the species."

Unfortunate events also occurred with captive bred Corroboree frogs. Many study sites where tadpoles were released fell victim to fire in 2003, so facilities were setup to breed more adult frogs for release. ARC built shipping containers were refurbished and two of these were installed at Tidbinbilla Nature Reserve in the ACT and another at Taronga Zoo. Both the ACT Government and Taronga Zoo have since built more container units modelled after the ARC units, with other States and Territories expressing interest or acquiring similar structures for their recovery programs.



Above: One of ARC's Corroboree Frog breeding facilities being delivered to Tidbinbilla Nature Reserve, Canberra.

### Promising advances

Research suggested that potential chytrid-free sites in Kosciuszko might exist along hilltop ridge lines. Surveys both on the ground and from the air, by helicopter, found eight chytrid free colonies of Corroboree and Alpine Tree frogs. Some of these colonies were surprisingly only a few kilometres away from infected populations. The level of inhospitable terrain is thought to be a determining factor in the movement of frogs and hence the spread of the pathogen. These pristine, chytrid free sites could be used as a model to start creating habitats for other frogs.

Removing the Common Froglet, *Crinia signifera* (below), a prolific species which carries chytrid,



from some areas was another possibility. This species was entering artificial ponds and immediately infecting Corroboree tadpoles at their most vulnerable lifecycle stage. As an interim measure, artificial ponds with high perimeters are now used to ensure the froglet is kept away. Sites are monitored to see if emerging young frogs from the artificial ponds, who had not had contact with the common froglet in the environment or the disease, would succeed in maturing at a greater rate than those which had contact with the pathogen early on. Initial success is promising.

Releasing adult Corroboree frogs was another strategy, as adults have a different ecology to the common froglets and would not commonly interact. To test this, ARC released adults at a number of chytrid infected sites and have seen some success with frogs returning to nest.

"Many of our releases are experimental and aimed at identifying and combating the causes of declines for the species in question.



Monitoring these releases, and analysing the results, gives us tools for assisting the species in the wild."

### **The economics of saving a species**

"Ecology and evolution are also about economics. If we don't generate that information by marking each individual and monitoring each and every parameter we will never know why some are successful and some are not, or why some site populations disappear completely and yet others survive. Tracking surviving individuals on a yearly basis is paramount."



Released 2006



Recaptured 2008

*Above: The belly pattern of each Corroboree Frog is a virtual fingerprint*

Were recaptured survivors all offspring of a single parent who might have a greater resistance to the fungus? and were they released as one or two year olds? Is the use of field enclosures with barriers more economical than raising frogs to adulthood in captivity? The most economic use of research funds will help more species in the future. If it costs ARC \$200 to produce a three year old Spotted Tree Frog and \$80 to produce a baby, which may only have a ten percent chance of becoming an adult, then it is obviously more effective and economical to produce and release the more successful two year old at a higher price.

People from around the world have started to approach ARC to build these mini laboratories, which have now been shipped to zoos and programs worldwide. Over thirty now exist worldwide, including those in Australia. Purpose-built design attributes include disinfection entry points, operating infrastructure, and inclusions to suit the requirements of different species. There are enough units around the world now for countries to copy and build their own.

### **Spotted Tree Frog recovery efforts at Bogong Creek, NSW**

Release and monitoring through mark and recapture have indicated that this frog is now breeding and recolonising the Bogong Creek site successfully, although many questions about past decline mechanisms still remain. Trout were causing Spotted Tree Frog populations to be depressed according to Graham Gillespie's studies, but not at this site. When the chytrid fungus arrived it wiped the population out almost instantaneously. A disease arriving in a large population spreads like wild-fire but spreads more slowly in lower density groups where it is likely to burn itself out before it can kill all the frogs. Other threats were perhaps keeping the populations low enough and dispersed enough that chytrid didn't kill all the frogs. Each outbreak would kill a proportion but some would survive.

So what will happen when the Bogong Creek population builds up to previous levels: is the frog population going to increase to high enough numbers to trigger another lethal chytrid out-break. Worryingly, this may have recently occurred. "The population has reached the threshold where the fungus has returned. We are now thinking we need to maintain multiple units of these populations in sites which have the greatest levels of protection. This would minimise the effect of a site falling victim to chytrid over five to ten years. This manages the species in a way which would give it some prospect of evolving some capacity to live with the fungus." Gerry said.

Spotted Tree frogs are now being released into other sites, including Buffalo Creek in Victoria. Gerry highlighted the fact that the cost in man hours and funds are substantial. Progeny are packed into boxes and shipped to field sites before being marked for release. Marking includes toe clipping and taking weight and



*Copyright: www.frogs.org.au*

other measurements. To highlight the monitoring difficulties of this species Gerry asked audience members to try and find the



frogs in the image above, which was taken ten seconds after their release. Audience members couldn't really locate any frogs in the picture: the frogs blended into their habitat too well. The thought of researchers trying to locate wild frogs at a distance of twenty metres with a headlamp was unfathomable.

"Can we manipulate other frogs, can we find field sites that are chytrid free, or can we build disease free field sites."

**Project: building a new site for Corroboree frogs where none have previously lived**

An experimental facility (*below*) is currently being built to get Corroboree frogs established and breeding, with an emphasis on keeping all other organisms which could potentially carry the pathogen out. Frogs and eggs will be released into the man-made ponds over the coming months. Water for the ponds will be pumped through a filtration system to remove



all particles of chytrid fungus size and above. This will eliminate any fungus spores from other external frog populations who have come into contact with the water before it enters the facility. Fencing will also stop any frogs from entering the area. Although there may still be threats from insects or the feet of water birds, eliminating the highest probability risks mentioned above is an important start. Gerry went on to explain, "if the fungus does appear in the confines of the facility then we will know it wasn't from other frogs or water. We would have to explore if it is transferred by birds or insects."

**A global effort**

The knowledge gathered in Australia to date has drawn much interest from overseas organisations and Gerry is now spending a great of his time overseas disseminating information about Australia's research processes and results, be they successes or failures. Many countries have no funding for research on this pathogen but may just have the capacity to replicate models that already work. Exporting ideas and information is becoming increasingly important.

"All is a work in progress. At the end of the day frogs cannot all be kept in captivity or remain in shipping containers or zoos. The most worthwhile place to save frogs is in the wild. We have to find ways to successfully re-establish populations in a cost effective manner. Even if these frogs have to evolve systems to cope with this disease over time, we have to find ways and opportunities for them to do that. If they're extinct there is no opportunity. These are holding mechanisms until we can change the conditions enough to give them a chance." Gerry said.



*Above: A modified container being installed in Chile.*



*(Saving frogs because we MUST!, cont'd)*

**Image at right:** "We call him 'hands' because that is all he had when he metamorphosed. Whilst he may not be a perfect example, he is symbolic. We can't retain or continue to breed all these animals in captivity forever: we are going to create all sorts of other problems like mutations and deformities if we do that. The captive tanks we have are an insurance policy against the wild populations disappearing completely."

"No matter how difficult it is, and no matter how much we have to work towards it, putting frogs back into these field enclosures and frog absence sites, perhaps even sites outside their range or natural distribution, is ultimately going to be a safer proposition without the risks of human error."

Gerry ended his presentation by describing ARC's commercial insect farming operations, which ship insects to zoos, herpetological associations and private keepers. Crickets, cockroaches, mealworms, flies, maggots etc, along with tours and public education, are the key funding sources for ARC. Monies received are all ploughed back into threatened species conservation, specifically research and breeding efforts.

**More information about frogs and the Amphibian Research Centre can be found at: [www.frogs.org.au](http://www.frogs.org.au)**



*Above and left: Simply attach a mural and the Corroboree frog enclosure constructed for Taronga Zoo in Sydney doubles as an exhibit.*





## HABITAT USE AND BODY SHAPE IN AUSTRALO-PAPUAN MYOBATRACHID FROGS



Marta Vidal-Garcia (left), from the Research School of Biology, ANU, gave a presentation on the above topic to members at ACTHA's meeting in February 2013.

This transcript of Marta's talk is by Mandy Conway, who greatly appreciates Marta's assistance.

[Photos by Damien Esquerre, Daniel Hoops, Stewart Macdonald and Marta Vidal-Garcia.]

**Animals inhabit almost everywhere on Earth and have adapted to the conditions of the habitats they live in over time.** There is a high morphological diversity in each species of vertebrates. For example, many species of monkeys are adapted to climb and live in trees, whilst the robustly shaped gorilla lives in open spaces on the ground. Similarly, fish like mackerel present a stream-lined body shape to enhance their swimming abilities whilst bottom dwellers have a very different morphology. Reptiles and birds are no different.

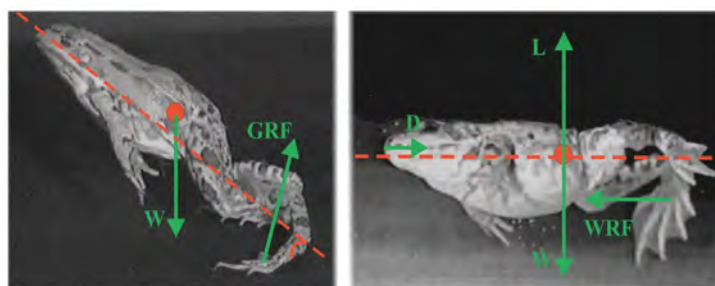
"We usually think of frogs and toads as a morphologically homogenous group relative to other vertebrate groups," Marta said. "They actually display a wide range of morphological specialization across all families however, and occupy a broad variety of habitats: from ponds and streams to tropical rainforests, grasslands

and even deserts. There are frogs such as the shrub frog family (Rhacophorids) with strongly webbed long toes that enable them to glide through tree canopy layers. There are frogs that live in streams, like the African Clawed Frog and Goliath's frog, which have long legs to improve their natatory abilities.



"As frogs display recurrent patterns of morphological specialization in different lineages, their body shape has been interpreted as a mechanical or physiological adaptation to the different environments they inhabit."

Jumping is the most characteristic mode of locomotion for a frog. Good jumpers usually have streamlined bodies and relatively long and muscular hind limbs to allow them to escape quickly from predators. Long limbs also provide better propulsion when swimming.



Nauwelaerts S, and Aerts PJ, *ExpBiol* 2003

Frogs that live in arid environments, such as the Western Spotted Frog, the Sandhill Frog or the Water-holding Frog, present a rotund morphology with short limbs that minimizes the ratio between surface and volume, effectively decreasing evaporative water loss.



Other specialization solutions include burrowing to keep 'safe' during dry periods until the heavy rains come, forming impermeable cocoons, or by covering their skin with wax for protection.

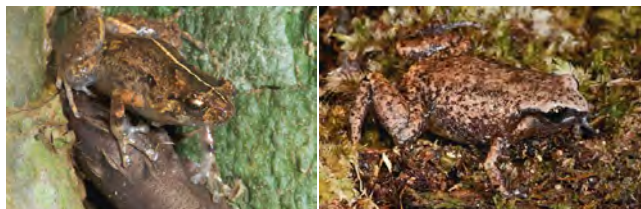
#### Australian frog diversity



Above: The **Myobatrachid** family, also known as southern frogs, contains 21 genera and more than 130 species.



Above: **Hylids**, or tree frogs, are the other major group in Australia, with 3 genera containing over 84 species living in a diverse range of habitats: from completely arboreal to fossorial specialists.



Above: **Microhylids**, or narrow-mouthed frogs, number 22 species within 2 genera. They are mainly found in tropical or subtropical areas of Australia.



Left: **Ranids**: There is only one species of 'True frog' in Australia: the Australian Wood Frog.



Left: **Bufonids**: The Cane Toad or 'True toad' is the only invasive member of this species living in Australia.

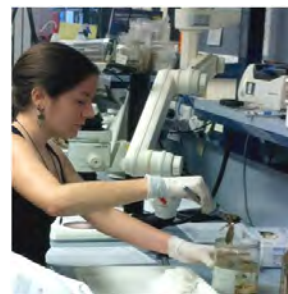
"For my study, I wanted to look at different body shape patterns of frogs belonging to the **Myobatrachid family** to see if they were an adaptation to the environment the frog currently occupies. Frogs from the Myobatrachid family were targeted due to the large number of species which could be used for comparison, representing 57% of frog diversity in Australia which are wholly endemic to the Australo-Papuan region, an old Gondwanan group."

The Myobatrachid family presents great diversity in many aspects. They vary greatly in size, from species that have a total body length of less than 1.5cm to the Giant Barred Frog, which reaches 12cm in body length and is the second largest frog in Australia. Their habitats vary from very dry desert regions (eg Notaden and Neobatrachus), cold and high mountain regions (eg the Corroboree frog), temperate and subtropical zones with rainfall peaks (eg Heleioporus and Uperoleia), and those from a range of tropical habitats and fast-flowing streams, like Mixophyes. Many members of this family are burrowers. Egg laying attributes are also diverse: some deposit their eggs in water, some in foam nests, whilst others lay their eggs on land to develop. "And then there's the gastric brooding frog." Marta added.

"We also have at our disposal a very robust phylogeny generated by my research supervisor, Scott Keogh, which includes specific nuclear and mitochondrial genes for all the species in this family, as well as the genetic relationships amongst them."

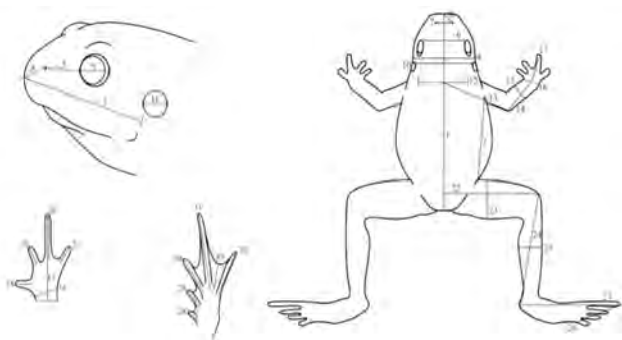
Marta went to museums Australia-wide to collect all the morphological data for the species in the Myobatrachid family (NSW, Qld, Vic, SA and WA). She examined 630 specimens from a total of 127 species. Only three species of the family were not included, however all 21 genera were represented.

"I preferentially measured female adult frogs in order to avoid the confounding issue of sexually selected traits in males and sexual-size dimorphism."



"I would usually identify females by external cues, eg absence of vocal sacs in *Adelotus* and *Mixophyes*, lack of hip-pouches in *Assa darlingtoni*, absence of spines on fingers in *Heleioporus*, lack of black throats in *Crinia*, cloacal fimbriation and lack of black throats in *Uperoleia*, lack of nuptial pads in *Limnodynastes* and *Platyplectrum* species, or eggs visible through the ventral skin. But in some instances that was not possible, so specimens had to be dissected to detect the presence of ovaries."

Using a digital caliper, thirty-three external measurements (see below) were taken of each



specimen in order to form an accurate picture of body shape specifics: eg snout-vent length as a measure for total body length, eye length, distance from eye to naris, interorbital span, arm, leg, hand, finger and toe length.

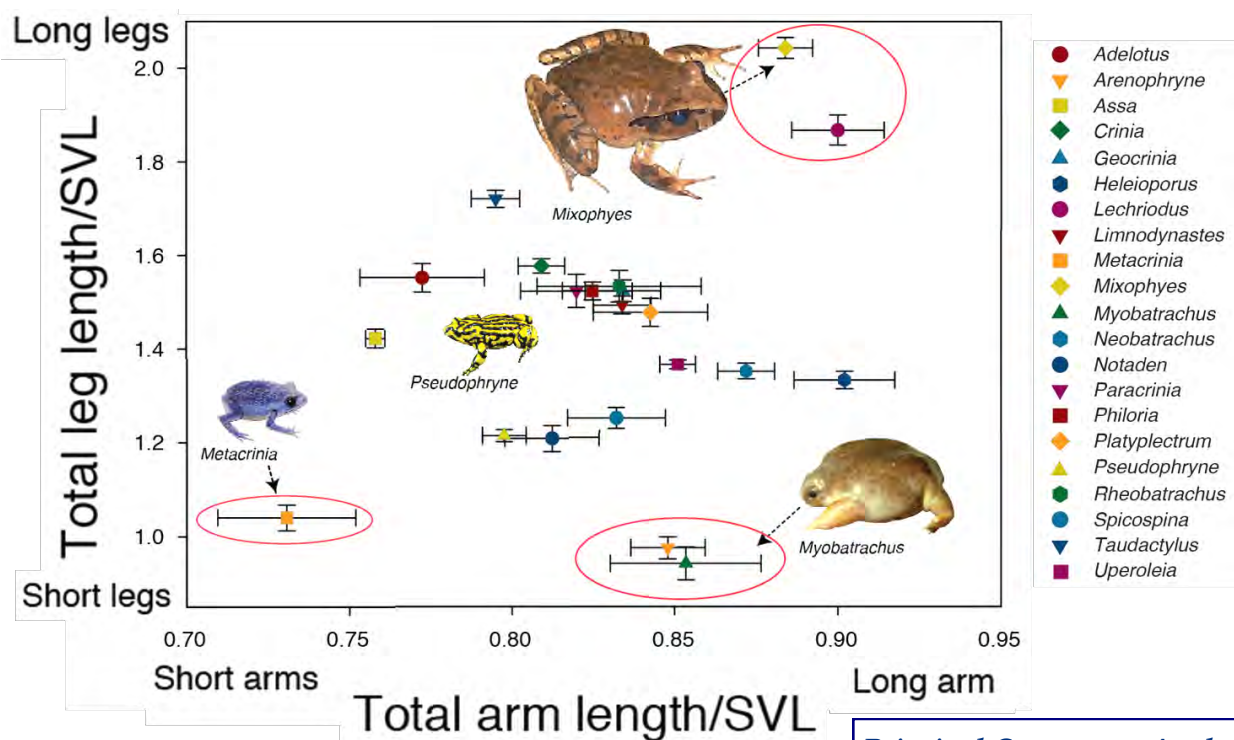
Environmental variables that are considered to be of importance to frogs (such as evaporation, precipitation, temperature, soil nutrients, etc.) were sourced from the online database 'Atlas of Living Australia' and included in the study.

For each species, Marta took the mean values for all the environmental variables based on museum records of presence and absence of each species in each 10x10 squared km blocks in Australia.

Marta also assessed the burrowing behavior of Myobatrachid family using two field guides: Cogger 1979, and Tyler & Knight 2009. All the frogs were then classified into three simple categories: No burrowers, Forward burrowers (that burrow firstly with the head and fore limbs) and Backward burrowers (that burrow first with the hind limbs, regardless of whether they used sliding or circular burrowing).

**Principal Component Analysis** was used to find the differences between genera and species, including which variables explained the greatest differences. (See chart below.)

- *Metacrinia*, the Sunset Frog, was found to have the shortest limbs, while the rainforest genera of *Mixophyes* and *Lechriodus* displayed the longest arms and legs.
- The forward burrowers *Arenophryne* and *Myobatrachus* appear closely related to the Sunset Frog; relatively long arms adapted to their forward burrowing behavior, with quite short legs.
- Other genera such as *Pseudophryne*, which includes the Corroboree frog, presented a more conservative or typical limb length.





## Results

Considering the environmental dataset, most of the differences were attributed to the humidity of the habitat the frogs occupy. There was also a good match between habitat use and the expected body shape pattern. "There is a trend of long-limbed species mostly occurring in wet environments, short-limbed frogs in arid environments and frogs with a conservative body shape occurring in both."

Marta wanted to test if this trend was also applicable within genera, and hence used the froglets *Crinia*, and the toadlets of the species-rich genus *Pseudophryne* and *Uperoleia*. Each species occupied very different environments but presented very little morphological variation.

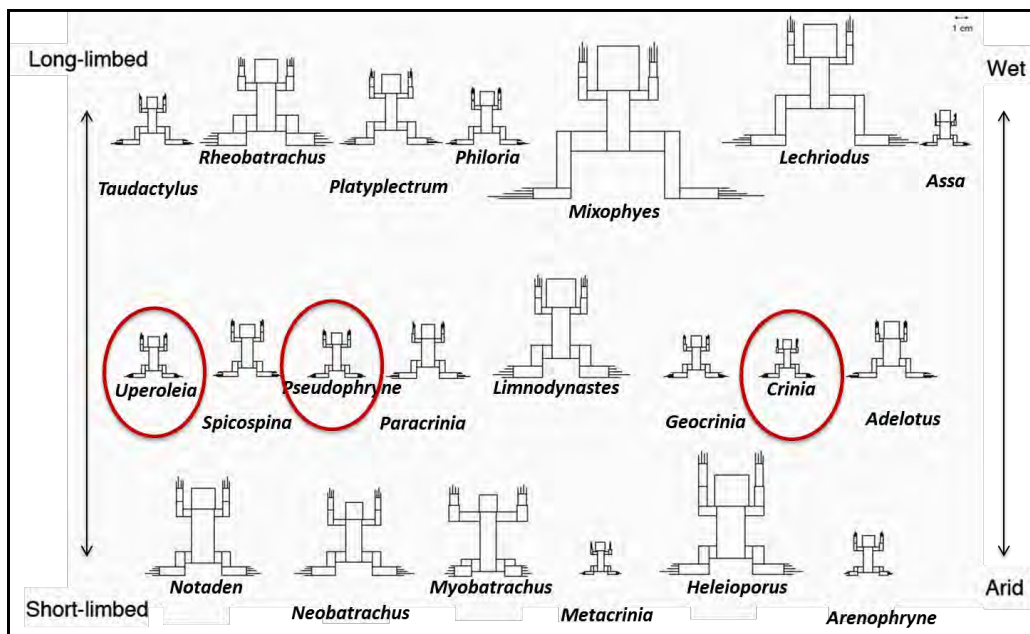
prediction that morphological differences are related to habitat use, however the conservative body shape that is displayed by so many species is one that can work under a wide variety of environments."

"The work I have done to-date was for my Masters and now, for my PhD, I will be expanding this research to include all the Australian tree and narrow-mouthed frogs."

Marta will also use advanced and cutting-edge methods for the analysis of shape using Three-Dimensional data of the frogs. She will use an X-ray micro-CT scan in order to obtain 3D images of the skeleton. "This will allow me to obtain really accurate data without having to dissect to look at the bones of each frog, thus avoiding any damage to the museum

vouchers." Marta will use landmark-based 3D Geometric Morphometrics in order to assess the skull's shape differences among all the Myobatrachid genera. For the rest of the skeleton, she intends to use a different mathematical approach, Spherical Harmonic Analysis, to compare the entire surface and each protrusion or intrusion different bones might have.

"I have been focusing on the morphological differences in relation to



"To summarise, in the figure below you can see a representation of the body shape for each genera. Body size and shape differences were found between genera, but not within."

Marta took the mean of each of the measurements with a digital caliper and drew scaled figures for each genus before arranging them according to the habitats they occupied, from wet to arid. This showed a predominance of long-limbed frogs in wet environments and short-limbed frogs in arid environments.

"In conclusion, the most compelling picture that emerges from our study is that Myobatrachid frogs display substantial morphological differences and that this usually depends on the environment. Our results support our

limbs. I now want to look at the locomotion performance of each frog and how this relates to body shape and environment. To do that, I will be going to North Queensland to collect different species of frogs from the three main families. And finally, I would like to analyse their jumping abilities in an eco-morphological and phylogenetic context."



3D shape analysis using Spherical Harmonics



## THE EVOLUTION OF MONITOR LIZARDS: AUSTRALIA'S LIZARD KINGS



Gabrielle Openshaw (left), from the Research School of Biology, ANU, gave a presentation on the above topic to members at ACTHA's meeting in April 2013.

Mandy Conway provided a draft transcript of the presentation to Gabi, who used it to produce this article (thankfully!).

[Photos by Stephen Zozaya.]

### Anguimorpha: A Diverse Clade

There are approximately 200 living species belonging to Anguimorpha, which include limbed and limbless lizards whose sizes vary from large species like the Komodo Dragon (3m!) to the very small Californian Legless Lizard (18cm). Fossil records extend over 130 million years and span every continent. They are a group who can successfully inhabit a wide variety of terrestrial habitats and have also invaded marine habitats, which is unique among lizards. They additionally belong to the clade 'Toxicofera' which includes all squamates that supposedly possess venom. They are therefore central in understanding the clade's evolution.

### How is this very diverse clade divided? Taxonomy, fossils and phylogenetics!

"The living species are split rather conveniently into two main groups according to geography," Gabi explained. "There are the families that are currently found in the New World 'Neoanguimorpha', and those currently found in the Old World 'Paleoanguimorpha'." A summary of the current phylogenetic taxonomy based on living species is given in **Figure 1**.

"This broad, simple split among extant Anguimorphs hides a much more confusing taxonomic history! When I first started researching this group of lizards it became clear that many people had studied them throughout history and the iconic names created have persisted, despite recent revisions showing they are no longer valid biological groupings. Varanoidea, for example, refers to Monitors (*Varanus*), the Bornean Earless Monitor (*Lanthanotus*), and the venomous lizards of North America (*Heloderma*). These lizards were thought to be part of a natural grouping for a long time however this is no longer believed to be the case, based on molecular evidence. The term Varanoidea is still used, causing confusion in the literature, with the inclusion of fossils making matters worse. Redefinition of the taxonomy in a phylogenetic framework was

Geographic Split	Family	Genus/Genera	No. Sp	Common Names
New World: Neoanguimorpha	Anguidae	<i>Abronia</i> <i>Anguis</i> <i>Anniella</i> <i>Barisia</i> <i>Celestus</i> <i>Diploglossus</i> <i>Dopasia</i> <i>Elgaria</i> <i>Gerrhonotus</i> <i>Mesaspis</i> <i>Ophiodes</i> <i>Ophisaurus</i> <i>Pseudopus</i>	~117	Slow Worms Alligator Lizards Glass Lizards
	Xenosauridae	<i>Xenosaurus</i>	6	Knob-scaled Lizards
	Helodermatidae	<i>Heloderma</i>	2	Gila Monster Beaded Lizard
Old World: Paleoanguimorpha	Shinisauridae	<i>Shinisaurus</i>	1	Chinese Crocodile Lizard
	Lanthanotidae	<i>Lanthanotus</i>	1	Bornean Earless Monitor
	Varanidae	<i>Varanus</i>	~73	Monitor Lizards

Figure 1.



long overdue when, in 2011, Conrad *et al* devised a scheme to try and balance the name Monstersauria. This name had been created some 15 years earlier (Norell & Gao, 1997) to refer to all taxa leading to modern day *Heloderma* (i.e. the venomous Gila Monster and Beaded Lizard in North America). So, for the old world they erected the names Shinisauria (the living Chinese crocodile lizard) and Goannasauria." Gabi explained.

### When did this clade appear?

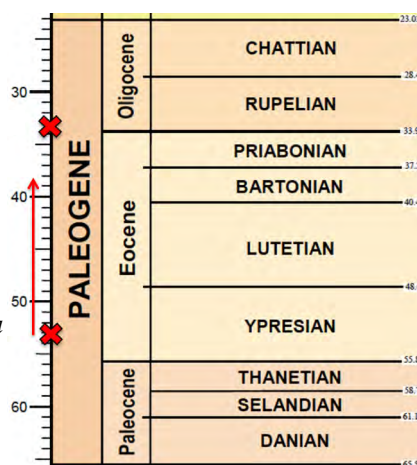
"Based on fossil records, the Anguimorph clade was born in the Cretaceous 145.5 - 65.5 million years ago (mya). The oldest Anguimorph is a Shinisaur, known from China ~125mya. Anguimorphs had reached North America by ~100mya, as the first Monstersaur is known from this time. Mosasaurs, the giant aquatic Anguimorphs closely related to modern day Monitor lizards, appear in the fossil record ~98mya in North America and Israel. After this time, they appear to have spread quickly and widely, achieving a global distribution, before going extinct ~65mya. The oldest Goannasaur comes from a few localities across Mongolia. These localities have produced a large number of fossils; distinct taxa that are more closely related to *Lanthanotus* and *Varanus*. This is interesting because in the Cretaceous we already have most of the key lineages that make up Anguimorpha today. The presence of each of these established lineages already in the Early Cretaceous makes it the 'minimum divergence time' for Anguimorpha, with the general belief being therefore that the clade actually first arose before that in the Late Jurassic."

The family Varanidae is believed to have its origins in the Paleogene (65.5-23mya). (Fig 2.)

**Figure 2: The Paleogene: Family Origins**

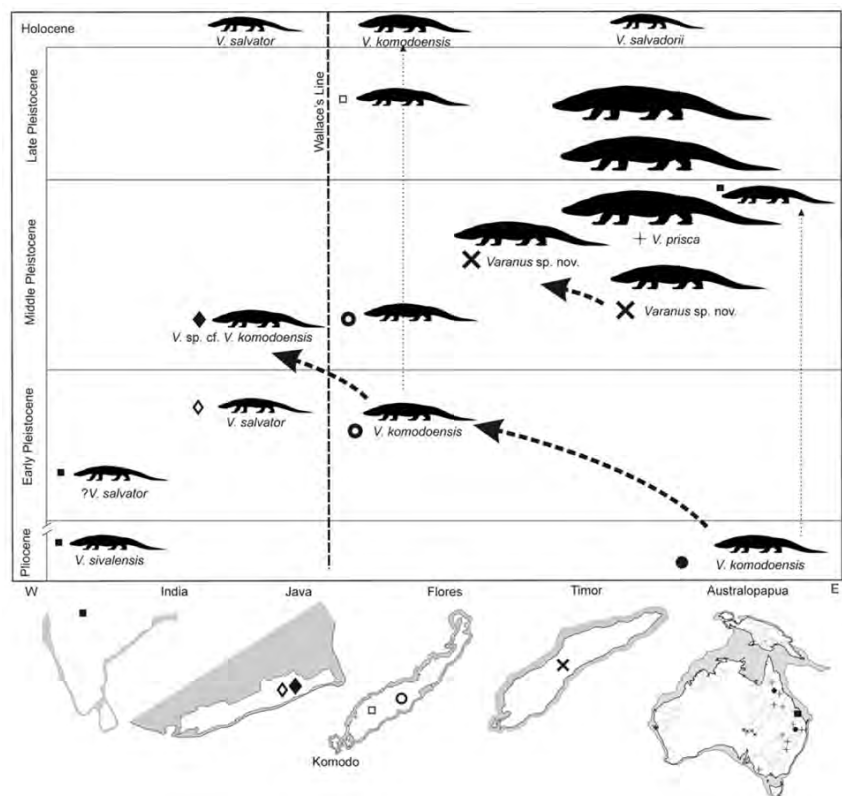
Africa: Oldest possible *Varanus*

North America:  
Family Varanidae: *Saniwa*



The oldest possible Crown *Varanus*, or monitor lizard material, comes from Africa, 33mya. This material is only tentatively assigned to the Genus *Varanus*. Crown *Varanus* were spread across Africa, Europe and Central Asia throughout the Neogene period (23-1.8mya). The first well-described taxon, *Varanus rusingensis*, comes from the early Miocene period (~17.8mya), in Africa. Fossils are known in Australia from the Pleistocene period (starting ~1.8mya).

### Giant Monitors



Hocknull *et al.* (2009) *Dragon's Paradise Lost: palaeobiogeography, evolution and extinction of the largest-ever terrestrial lizards (Varanidae)*. PLoS ONE, 4(9).

Giant monitor lizards first appear in the fossil record in the Pliocene (~5-2mya) in India (*Varanus sivalensis*) and Australia (Komodo Dragon). The Komodo Dragon is believed to have evolved on mainland Australia in the Pliocene and persisted until the Middle Pleistocene. The species appears to have dispersed westward to Timor, Flores and Java. The largest terrestrial lizard to have ever lived, *Varanus 'Megalania' prisca* (estimated body size of 6 to 9 metres in length), is believed to have inhabited the eastern coast of Australia from mid to late Pleistocene. Also believed to have existed was a monitor intermediate in size between these two giants from central Australia.

"So we have at least three species of giant monitor co-existing on mainland Australia. What is interesting is that the Komodo Dragon was originally thought to have evolved its large size on the islands on which it now lives, but we now know that this species is just a remnant of an entire phylogenetic lineage that evolved giant body size here on mainland Australia before dispersing upwards." Gabi explained.

### Monitor Morphology

It is generally agreed that there is morphological conservatism amongst the



monitor species. They all have strong, well developed limbs with big claws and a characteristic sprawling gait and strut. Some species stand on their hind-limbs which probably gave them the name of monitor lizard; 'to monitor'. They are generally long, slender animals with long necks, snouts and tails and their scales do not overlap.

Monitors are at home on land, on rocky outcrops, in trees and also in water. There have been few studies in relation to niche partitioning, i.e. how they can co-exist in the wild, because their acute sensors make them difficult to observe in the wild. Being generalist feeders, they will eat almost anything they can, although some smaller species do feed predominantly on insects. They are renowned for having the most derived chemosensory system amongst lizards, due to their long and deeply forked tongue: they are able to move each fork independently of each other as well. Advanced vomeronasal organs set in the roof of their mouths add to their armoury.

Sight capabilities of this group are still being studied, although Merten's Water Monitor has been found to have excellent visual cues in water.

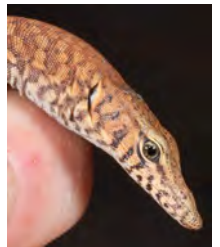
Monitor venom is still a controversial topic and seems to depend on the presence of a venom delivery apparatus, which is defined by grooves in the teeth. Even though some species of monitors have been shown to have venom proteins, whether they serve as 'venom' or something that aids in digestion is not well understood.

### Extreme body size disparity

"Monitors have the biggest size range of any terrestrial vertebrate genus: adult body size ranges from 23cm to the Komodo dragon's 3m. Body size disparity has evolved as a consequence of selection associated with different habitat use patterns. Species living amongst rocks have evolved pygmy body size, and arboreal inhabitants have an intermediate body size between these two extremes."

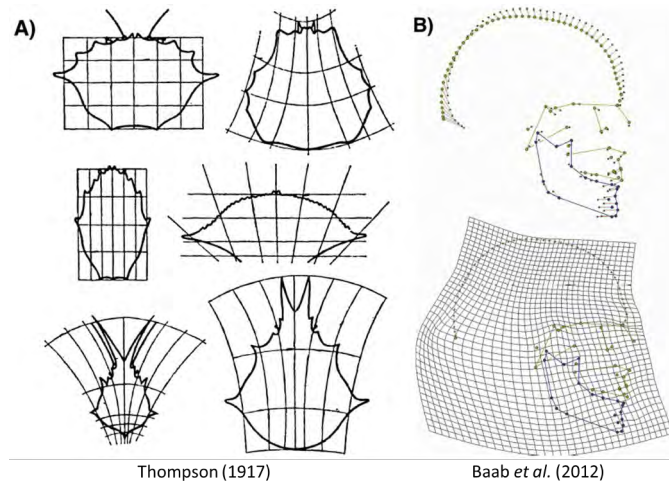
"Similar results can be seen in body shapes. The Thompson Group in Western Australia has carried out a lot of work on this over the years. There is morphological conservatism within this genus however this implies something quite specific, i.e. geometric similarity or isometry, which means that limbs will grow in a similar proportion to the body. The animal has to develop different muscle loading or biomaterial properties so that it develops strength to cope with a larger body size. It has been shown that there is positive allometric scaling between the body and limbs of most monitor species. Additionally, body shape has been influenced by aspects of habitat, retreat choice and foraging mode."

When Gabi started her honours she became very interested in **head morphology** and the way it seemed to fairly accurately reflect the ecology of the animal. To date, much work has been done on body shape and size however no one appears to have studied head shape disparity in monitors, which surprised her.





Geometric Morphometrics is of great interest at the moment and could be an invaluable tool to researchers. Gabi explains, "In 1917 D'Arcy Thompson wrote a book 'On Growth and Form'.



**Figure 3: Geometric Morphometrics Revolution**

In **Fig 3**, a crab carapace **A)** (*above*) has been drawn on a grid, which is then manipulated to form different characteristic shapes. In his book, Thompson stressed the importance of maths in analysing morphology and variation. Today, personal computer technology has become so advanced that we are able to create accurate 'deformation grids' that quantify the differences in shape changes. **B)** (*above*) shows shape changes to this skull by the distorted grid cells; this reflects the amount and direction of shape change."

#### How does the method work?

"Whilst traditional approaches to the study of morphology uses linear measurements, angles and ratios to *describe morphology*, geometric morphometrics uses 2 or 3D landmarks in a Cartesian coordinate system (standard 'x,y,z' coordinates) to *quantify shape*. Shape is defined as 'the geometric properties of an object except its size, position, and orientation'. So, once all landmark coordinates in a dataset are collected, these effects are removed through a process called Procrustes superimposition. The key advantage to the method is that the spatial information in the landmarks (based on the coordinate system) is preserved during analysis, so shapes can be projected back into 'real space' and visualized in astounding ways."

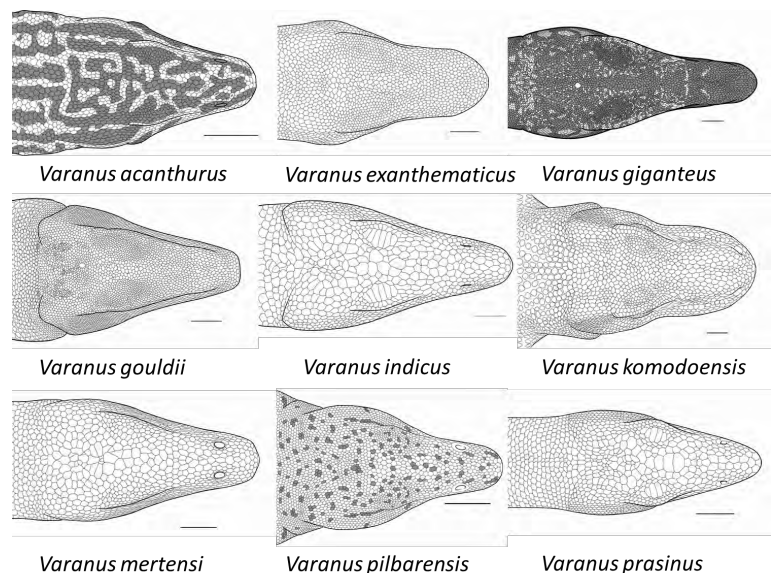
There are three main questions that Gabi hopes to answer during her Honours project.

1. **Determine the extent to which size variation explains interspecific head shape variation.**
2. **Assess the phylogenetic structuring of head shape using an independent molecular phylogeny.**
3. **Examine ecology (habitat) as an additional influence on head shape evolution.**  
(Unfortunately Gabi ran out of time to talk about this today).

#### So far...

"I am looking at the head evolution of all major monitor lizard lineages, with a heavy focus on Australian species. I have already taken SVL measurements, which I averaged for each species for later use, and photographed a dorsal view of heads for geometric and morphometric analysis. I covered over 400 specimens belonging to 36 of the 38 species included in the molecular phylogeny. I then assigned each species an ecological category corresponding to the preferred habitat. I considered the element of the habitat for which the species was most dependent on to be the best scheme. I designed a landmark configuration of twenty-four 2D landmarks in the dorsal view. I chose this scheme because I knew I could always locate the landmarks and they adequately covered head shape."

"A friend, Erin Walsh, drew the monitor head sketches on the slide below, which are all species belonging to one genus: it really shows how much variation exists between them."



### Gabi's aims in her Honours

#### Q1) Size and Head Shape Variation.

"The standard way of assessing this in geometric morphometrics is by regressing the 'shape' data (landmark coordinates) against an independent measure of size (calculated thankfully by the computer). After doing this, I found that a substantial, and significant, amount of head shape variation was being explained by head size (33%!). This was even after I had performed Procrustes superimposition, the process that is supposed to remove the effects of size. I then used the residuals from this regression as the 'size-corrected shape data' for all other analysis."

"I performed a Principal Component Analysis (PCA) on the size-corrected shape data to display the major features of head shape variation among monitor lizards. "Most of the head shape variation was being accounted for by changes in head width. These changes were mostly evident in the snout, with many species having nostrils of different shape and in a different position."

#### Q2) Phylogeny and Head Shape Variation.

"I found phylogeny to be a strong predictor of head shape, i.e. head shapes vary according to evolutionary relationships. The two African species have the most distinct head shape amongst monitor lizards; and are the sister group to the Indo-Asian and Indo-Australian

species. Interestingly, the head morphology is incredibly similar between *Varanus dumerilii* (an Indo-Asian species) and the two African species." Gabi believes they are more closely related than is currently understood. Another species with distinct head shape is a pygmy species found in the Tanami Desert (*Varanus eremius*), which is strongly terrestrial, and has probably evolved from rock-dwelling ancestors.

#### Q3) Habitat and Head Shape Variation.

"It appears that head shape variation within phylogenetic lineages is largely explained by habitat differences (whether the species are arboreal, terrestrial, amphibious or rock-dwelling), however these results are preliminary and I unfortunately do not have time to go into them in this talk. One interesting result to note, however, is that all arboreal species appear to have very similar head shapes regardless of their evolutionary history."

#### What now?

Gabi will continue her monitor lizard studies, firstly in phylogenomics using hundreds of genes instead of a few to study the evolutionary history of the group. This will include comprehensive sampling of monitors from Africa and Asia, which will hopefully give an accurate dispersal scenario and then timing of the radiation events. "I aim to focus on different areas of phylogeny before integrating morphological attributes."



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## THE AUSTRALIAN & INTERNATIONAL SCENE

### CONTROLLING CROCS MEANS KNOWING WHO'S BOSS

Hamish Campbell & Ross Dwyer, Uni QLD,  
*The Conversation*, 3 May 2013

The estuarine crocodile is the top predator in waterways across Northern Australia. Large crocodiles pose a risk to humans, so local governments take measures to control crocodile abundance and distribution.

#### Keeping crocs away

Crocodiles are regularly trapped and removed from around urban centres and areas that lots of people visit. While this strategy appears to

work reasonably well in reducing human-crocodile interactions, it may in fact give the public a false sense of security.

Both the Northern Territory and Queensland have 'zero-tolerance zones'. All crocodiles over a certain size are removed from these. In the Northern Territory this comprises a large area around Darwin Harbour. In Queensland, zero-tolerance zones occur across the boundaries of various local councils, and these zones are generally much smaller but more numerous.

The 'problem crocodiles' that turn up in these areas are predominantly males between 2m and 4m long. The number of crocodiles



trapped and removed each year is rising. The capture, removal and transport of crocodiles requires significant man-power, so the costs of this management strategy are rising too.

### **The role of large males**

David Lindner, a local crocodile enthusiast, suggested to us that a large male crocodile (which he called the 'boss croc') dominated a local billabong. The billabong had a lot of permanent females, and when the boss croc was around the other male crocodiles seemed to disappear.

This behaviour implies that estuarine crocodiles exist within a socially structured population. That made us reflect on how removing very large male crocodiles would affect the dynamics of the local population.

In researching our recent scientific paper we attached high precision satellite transmitters to eight male and four female estuarine crocodiles and monitored their movements continuously for six months.

We wanted to understand the social interaction between boss crocs, females and subordinate males, and assess how far and fast subordinate male crocodiles travel.

We found that the boss crocs inhabited defined territories of between 7 and 12 square kilometres on the river. The boss croc would patrol back and forth within the confines of this territory at least once and sometimes twice a day.

A number of breeding females would live inside the boss croc's home range. They moved only a few hundred metres each day and always returned to the same location. Our satellite data really supported the observations of David Lindner. That is, boss crocs dominate good crocodile habitat containing a number of females. Although unconfirmed it is likely that resource rich areas have the largest male crocodiles and the greatest numbers of females.

The satellite tagged subordinate male crocodiles, which at 3.5m were still large crocodiles, bore many scars from aggressive encounters with other crocodiles. These individuals moved quickly through the territories of the boss crocs and travelled great distances (up to 1000km) during the six-month study.

This evidence suggests that boss crocs aggressively excluded subordinate males from within their territories. The nomadic behaviour of the subordinate was in response to their exclusion from high quality habitat and was an attempt to locate unguarded females.

### **What happens when you take out the boss?**

Our study illustrates that estuarine crocodiles are incredibly mobile animals, and may routinely travel up to 40km a day. Furthermore, it suggests that removing a dominant male crocodile from an area is likely to disrupt the social structure of the local crocodile population.

Removing these dominant individuals is likely to create a vacuum which may serve to increase movement and immigration of other males from neighbouring areas.

This study demonstrates that estuarine crocodiles exist within a social structure that is far more complex than we previously considered. Furthermore, social dynamics are likely to be controlling crocodile abundance and distribution.

Trophy hunting estuarine crocodiles in the Northern Territory has been proposed as one way to bring needed money into remote communities. While we do not think sport hunting will make any significant impact on crocodile numbers, the hunters are likely to focus their killing on the largest male crocodiles. This is of concern, because we don't know how removing these boss crocs is going to affect the dynamics of the population.

In African lion populations, it has been shown that when sport hunters remove the large dominant males, it causes much greater rates of movement in the subordinate males.

We strongly recommend a thorough evaluation of the impact crocodile removal has on the social dynamics of the population. Evaluation is the only way to make sure management strategies achieve what they set out to do: keep people safe from crocodiles.



*Above: Tracking crocodiles has shown they routinely travel 40km a day.  
Photo: Ben Beaden, Australia Zoo*



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