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The Dynamics of Water on the Skin of Australian Carphodactyline and Diplodactyline Geckos

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Title page photo

Top – *Strophurus krysalis* (juvenile); spine from the dorsal surface of *Phyllurus ossa*; *Oedura marmorata* (Winton population)

Middle – Hair sensor with bottlebrush-shaped bristles from *Carphodactylus laevis*; three drops on the dorsal surface of *Lucasium steindachneri*; primary scale from *Phyllurus nepthys*

Bottom – *Saltuarius cornutus* (juvenile); spinules from the primary scale of *Phyllurus ossa*; *Carphodactylus laevis* in a defense posture

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Statement of contribution of others

While undertaking this thesis, I was responsible for the design of the project, collecting all specimens and data from the field and laboratory, statistical analysis and interpretation, and the synthesis and preparation of this thesis and manuscripts. All chapters will be published in collaboration with my supervisor Dr. Lin Schwarzkopf. Andrew J. Scardino (a collaborator) assisted with the preparation of moulds in Chapter 2. Mathew J. Vickers (a collaborator) assisted with specimen and data collection, and data analysis in Chapter 3. Simon Robson (a collaborator) assisted in the use of the scanning electron microscope and provided materials and support in Chapter 3.

I obtained financial support from the James Cook University Program Grant Scheme.

Declaration on ethics

All data were collected to the legal requirements of Queensland, Australia (Scientific Purposes Permit No. WISP03476106 and the Take, Use, Keep or Interfere with Cultural or Natural Resources Permit No. WITK03036906) and South Australia, Australia (Permit to Undertake Scientific Research No. C25337) and the ethical guidelines for treatment of animals of James Cook University (Animal Ethics Approval A977)

....	....
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Abstract

Detailed examination and description of structures in nature, relative to the environments in which they occur, provides evidence for the function of these structures. Here I describe the oberhautchen (outer skin surface) of 24 species of Australian carphodactyline (Squamata: Carphodactylidae) and diplodactyline gecko (Squamata: Diplodactylidae). Using methods specially adapted for the purpose, I describe details of skin microornamentations, examined at high magnification, of these geckos, and examine relationships between these skin characteristics and environmental conditions, substrate use, hydrophobic properties, and evaporative water loss (EWL), with a view to determining the function of these features.

I used 24 species (and populations therein) of geckos collected from northern and western Queensland, and from the Great Victoria Desert, South Australia, as subjects for my descriptions. To examine the oberhautchen of living lizards, I adapted and tested a method for creating extremely detailed moulds of surfaces using polyvinylsiloxane impression material and epoxy resin (Epirez 123®, ITW Polymers & Fluids). This method produces exceptional quality reproductions of complex microornamentations within the oberhautchen of living lizards.

Using scanning electron microscopy on the moulds I created, I examined scale characteristics (primary scale size, secondary scale size, spinule length and density, pit diameter and density, furrow width and depth, percentage of knobs covering scales, and hair sensor characteristics including hair sensors per scale, hair sensors per square millimeter, bristles per sensor, bristles per square millimeter, and hair sensor diameter), I related these to body size, substrate use, environmental conditions at the centre of each species' geographic range, and phylogeny, using univariate statistics and canonical discriminant function analysis. Carphodactyline geckos are quite different from diplodactyline geckos, and have larger body size, larger primary scales, shorter spinules, greater numbers of hair sensors and bristles per square millimeter, knobs and larger hair sensor diameters. Examining both carphodactyline and diplodactylines together, I found that terrestrial geckos tend to be smaller, live in xeric conditions, and usually have smaller

scales and higher numbers of bristles and hair sensors per square millimeter. Non-terrestrial geckos tend to be larger, and live in more mesic and hydric conditions, and usually have larger scales and fewer hair sensors and bristles per square millimeter. Because geckos in xeric habitats live in dry conditions, they may need more sensory information about their environment, to enable them to select appropriate shelter. I traced the character evolution of hair sensor bristle shape, and found that bottlebrush-shaped hair sensors with many hairs appear to be primitive, whereas tapered hair sensors of various shapes with fewer hairs appear to be derived. The causes of evolutionary differences in bristle shape and hair sensor number was not clear from the variables I examined.

Hydrophobicity is thought to enhance the adhesiveness of geckos with adhesive toe pads, by keeping these surfaces clean. Because specialized adhesive foot scales are evolutionarily derived from the body scales, I examined the hydrophobic properties of body scales. To estimate hydrophobicity, I used a sessile drop technique to quantify contact angles of droplets of distilled water. Tiny (0.25 µL) droplets of distilled water were incrementally increased in size and photographed at high resolution, and contact angles of droplets were used to predict the hydrophobic properties of the dorsal skin surface of geckos. I established which species were most hydrophobic and which dorsal scale characteristics had the strongest relationships with hydrophobic properties. Several species had superhydrophobic skin (advancing contact angles greater than 150°), including *Lucasium damaeum, Strophurus taeniatus*, *Diplodactylus conspicillatus* (Winton population), *Oedura rhombifer*, and *Lucasium steindachneri.* Geckos with high hydrophobicity were characterized by skin characteristics that promoted rough surface adaptation, especially small primary scales and long spinules.

The great range of variation in gecko oberhautchen is likely to have some functional significance. However, most functions suggested in the literature (ecdysis, coping with varying temperatures on different parts of the body, pheromone capture, retention, and dispersal, the creation or reduction of friction, the reflection or channeling of solar radiation, wear prevention) can be rejected as explanations for variation in the oberhautchen of Australian gecko skin. I provide evidence that high hydrophobic properties of the skin help geckos remain clean. Hydrophobicity was, on average, higher in terrestrial species and in species living closer to the ground (and hence, likely to come into contact with dust and dirt), than in non-terrestrial species living away from the ground.

Terrestrial geckos, as a group, had longer spinules and smaller scales than saxicolous and arboreal geckos, enhancing their hydrophobic properties. With the effects of phylogeny removed hydrophobicity was related to distance from the ground, indicating that these two characters evolve together.

Recent studies have linked evaporative water loss rates with scale characteristics of reptiles. I measured the EWL of Australian geckos gravimetrically, using the flow-through chamber technique, to examine patterns in water loss rates of Australian geckos in relation to scale characteristics, body size and habitat. Evaporative water loss was strongly correlated with body size, larger geckos had larger body surface area and lost more water than smaller geckos. Mass-specific water loss rates were correlated with habitat use; terrestrial species lost more water than arboreal and saxicolous species, which did not differ in their water loss. In addition, species with larger scales tended to have lower water loss rates, and the evolution of deeper scale furrows was correlated with the evolution of higher EWL.

In summary, my work provides evidence that, not only are variations in Australian gecko skin morphology influenced by phylogenetic relationships, but at least some characters appear to have functional significance. Xeric-dwelling, terrestrial geckos have more sensory organs than do non-terrestrial mesic and hydric-dwelling geckos, likely because they require accurate information on environmental conditions. Terrestrial geckos tended to have smaller scales and longer spinules than non-terrestrial geckos, possibly to enhance their hydrophobicity. Terrestrial geckos also had higher EWL rates than saxicolous and arboreal geckos, but may be able to avoid high water loss by using burrows as shelter. Finally, terrestrial and xeric dwelling species tended to be smaller than non-terrestrial mesic and hydric dwelling species.

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