HUSBANDRY MANUAL FOR THE LORD HOWE ISLAND STICK INSECT

TAXONOMY AND BIOLOGY

TAXONOMY

Common Name	Lord Howe Island Stick Insect
Scientific Name	*Dryococelus australis*
Order / Family	Order Phasmida (Phasmatodea) Family Phasmatidae Subfamily Eurycanthinae
Recent Synonyms	*Eurycantha australe* *Karabidion australe*
Other Common Names	Lord Howe Island Phasmid, Giant Lord Howe Island Stick Insect, Land Lobster

NATURAL HISTORY

1.1 Description

The Lord Howe Island Stick Insect (LHISI) is a large, flightless phasmid, with males reaching 120mm (more commonly 106mm) at adulthood and females 150mm (more commonly 120mm). Both sexes are black on maturity, often with a reddish-brown tinge. The body is generally smooth and shiny, and the membranous areas between joints are pale grey (appendix 1).

A number of features distinguish adult males from females, but they can be easily separated by two large spines on the hind femur of the male (which are absent in the female), and by the shape and length of the last segment of the abdomen (appendix 2). Females have a long, pointed ovipositor sheath underneath the last segment, which is absent in the males (appendix 3). Females also have a wider and more terminally tapering abdomen than males.

Upon hatching, LHISIs are pale to mid-green, and become darker green as they moult. Juveniles are pale brown, becoming darker brown with age, then very dark brown to black in the final instars (appendix 4).

1.2 Known Distribution

LHISIs were once common on Lord Howe Island but became extinct soon after rats were introduced in 1918. They were presumed extinct until rediscovered on Balls Pyramid in 2001. Balls Pyramid is the tip of a sea mount, 25km southeast of Lord Howe Island (appendix 5).

The only known range of LHISIs is amongst a group of melaleucas on the north-west face of Balls Pyramid. The melaleucas cover an area of about 30m by 10m, and are the only vegetation on the pyramid other than groundcovers. Smaller islands around Lord Howe Island have been extensively searched for LHISIs, without success.

1.3 Habitat

Lord Howe Island is covered with a range of lush subtropical habitats, from cloud forest at the tops of the mountains to coastal vegetation on the dunes. The temperature on Lord Howe Island ranges from 15°C to 25°C throughout the year (appendix 6), and the humidity is generally high year round. There is a great range of plant species throughout the habitats in which LHISIs were once known to occur, but on much of the island the largest tree is the Lord Howe Island Fig (*Ficus macrophylla columnaris*). In the forested areas, the canopy is high and there may be little lower level vegetation or ground cover, and the soil is deep and often sandy.

Balls Pyramid is much more exposed than Lord Howe Island, with a greater range of temperatures. The humidity is also high due to its exposure to the sea, but the rock itself is very dry and there are no sources of fresh water. Consequently there is very little vegetation and almost no soil. The melaleucas on which the LHISIs survive are very old and stunted, and growing very densely close to the rock. Due to the large numbers of sea birds which nest on the bushes, the foliage is covered with guano, and many of the plants are also being threatened with smothering from Morning Glory (*Ipomea indica*). There are quantities of melaleuca leaf litter at the bases of the bushes, in some places quite deep, but this is very friable and dry.

1.4 General Habits

There is only one source of published information on LHISI habits in the wild. Lea (1916) noted that “During the day they remain concealed in hollows in upright or slightly sloping stems of living trees, but their presence may be detected by examining the ground at the foot of the trees, where heaps of their excrement may be found. The hollows are seldom less than eighteen inches in length, and are sometimes much longer…On examining the heaps of droppings, frequently both fresh and newly-hatched eggs may be found, the females simply extruding their eggs as soon as these are ready.

“They appear to come out late at night to climb the trees directly for food. In the hollows considerable numbers live together in all stages, but with immature forms in the majority; from one hollow that was completely emptied sixty-eight specimens were taken; in the same hollow were several large spiders and cockroaches…In nearly all cases that I examined it was seen plainly that the phasmas had selected for their domicile trees that had been largely bored by larvae of a large longicorn beetle.”

In the wild on Balls Pyramid, LHISIs are known to emerge at night to feed on the outer foliage of melaleucas and are presumed to shelter during the day at the bases of the shrubs.

1.5 Wild Diet

The diet of the stick insects on Lord Howe Island is not known, as no records were kept before they became extinct there. The only related published information is that juvenile LHISIs were found in large numbers during the day in hollows of tree trunks, presumably of the dominant Lord Howe Island Figs (*Ficus macrophylla columnaris*). On Balls Pyramid, they are known to feed on Lord Howe Island Melaleuca (*Melaleuca howeana*), but they may have other additional plant sources there.

Other plants occurring on Lord Howe Island which may have been eaten by LHISIs include:

Blackbutt (*Cryptocarya triplinervis*)
Greybark (*Drypetes deplanchei* ssp. *affinis*)
Sallywood (*Lagunaria patersonia*)
Cotton wood (*Celtis conferta* ssp. *amblyphylla*)
Dogwood (*Omalanthus nutans (populifolius)*)
Coprosma (*Coprosma huttoniana*)
Coprosma (*Coprosma lanceolaris*)
Coprosma (*Coprosma inopinata*)
Maulwood (*Olea paniculata*)
Stinkwood (*Coprosma putida*)
Bullybush (*Cassinia tenuifolia*)
Sandalwood (*Hibiscus tiliaceus*)
Hopwood (*Dodonaea viscosa*)
Goatwood (*Coprosma prisca*)
Kentia palm (*Howea forsteriana*)

CAPTIVE HUSBANDRY

HOUSING REQUIREMENTS

2.0 Housing: Exhibit & Off Exhibit (for both larval and adult stages)

Nymphs

Young LHISI nymphs may be housed together in large numbers (up to 80 per enclosure) as long as sufficient food is available. The nymphs clump together on the roof of the enclosure during the day, piled four or five deep, and move out to feed individually at night.

The enclosure may be composed of a wooden, recycled plastic, aluminium or steel frame with wire mesh and a large door to enable potted plants or browse to be easily changed (appendix 7). Care should be taken if using recycled plastic, as there is some evidence of toxicity from the plastic at high temperatures. The mesh should be large enough to allow airflow, and small enough to maintain humidity within the enclosure. There should be no gaps in the enclosure larger than 2mm. The minimum sized enclosure for a large group of nymphs is approximately 700mm cubed.

The enclosure should contain a potted food plant or cut browse in a jar of water. There is no need to cover the top of the jar, as LHISIs generally do not drown themselves as other insects do, except for very small nymphs on very rare occasions. The plants should touch at least one side and preferably the top of the enclosure at some point, but there should be sufficient space under the roof for the nymphs to hang whilst moulting unobstructed by the plants.

The substrate is not important but a dish of free water should be available (although this species has not been observed drinking free water, closely related species in New Guinea has been regularly observed to do so) and a petri dish full of water, changed weekly or every few days, is sufficient. If humidity is low, a piece of bark, tree fern or palm trunk soaked daily in water should be supplied.

Although young nymphs do not shelter during the day and will choose to sit on the roof of the enclosure in full sun, they will begin to seek daytime shelter as they mature, particularly as their colouring starts to darken to brown and then black. Consequently, a small 'nesting box' is required in the enclosures. The nesting box may be a hollowed log with a lid, a hollowed-out tree fern trunk, two coconut fibre hanging basket linings sewn together to form a 'drey', or a wooden nesting box used for finches etc. The latter is the most convenient and easiest to use, with a hole in the side for access and a hinged lid for inspection and cleaning. A nesting box 280mm long, 125mm wide and 120mm deep, with a 45mm diameter hole in the side and a hinged lid will house approximately 10 adults or 40 nymphs (appendix 8).

Adults
Adult LHISIs require similar enclosures to nymphs, but need more space per individual. An enclosure 700mm cubed will house approximately 10 adults. They will appreciate more space if available, and will happily live 'free range' in an entire glasshouse if given the opportunity. As with the nymphs, food plants, a dish of free water, at least one nesting box and water-soaked bark should also be supplied.

Once females begin laying eggs, egg-laying substrate should be provided. As mentioned below, females will push their abdomens into the substrate to deposit an egg, so a container at least 60mm deep filled with moist sand is required. A Tupperware container approximately 300mm wide by 220mm long by 100mm deep will cater for a number of females, but even a small rectangular Chinese takeaway container will suffice. Breeders of the closely related Thorny Stick Insect (*Eurycantha calcarata*) cover the base of the enclosure with peat moss in which the insects lay eggs, but this method has not been tried with LHISIs.

2.1 Housing Conditions (for both larval and adult stages)

Humidity
Housing conditions are paramount for this species. The humidity should be high, with a minimum of 50%RH, preferably 70%RH, both day and night. They seem to do best when the humidity is between 80 and 95%RH (appendix 9). Air flow created by heating should not be allowed to directly affect the LHISI enclosures, as a continuous flow of warm air will dry out the enclosures and desiccate the insects. Humidity can be provided by domestic or even industrial humidifiers (if available), by steamers if the holding area is small, or by continuously boiling large urns in larger holding areas. Humidity can also be increased by using smaller mesh sizes on the enclosures, by spraying the

foliage at least once a day, or by provisioning enclosures with extra free water or water-soaked material such as bark.

Temperature
The temperature on Lord Howe Island is never lower than 15^{o}C or higher than 30^{o}C. This species should therefore not be kept for extended periods outside this temperature range, and should preferably be kept between 20^{o} and 27^{o}C, night and daytime temperatures respectively (appendix 9). The captive population is descended from a population on Balls Pyramid, which is more exposed and has a greater temperature range than that on Lord Howe Island, so theoretically captive LHISIs should also be able to tolerate a greater range, but so far the captive population has been kept within the narrower temperature limits.

Radiant heat, such as that from a radiator or boiler, is preferable to convective heat, such as that from a blow heater or reverse cycle air conditioner, as radiant heat will not dry out the holding area as much. The type of cooling is not as important, as cool air blown over the enclosures will not dry them out as much as warm air will. If the enclosures are well insulated and kept within a larger holding space such as a glasshouse, it should be remembered that the temperature and humidity in the glasshouse will not necessarily be the same as that within the enclosures, but that the difference may be consistent and one can in this case be used as a guide for the other (appendix 10).

Lighting
LHISI nymphs are diurnal and adults nocturnal, so both should be kept under separate lighting regimes. Nymphs can be kept in direct sunlight as long as the temperature remains moderate, or under fully artificial lighting. Some natural light may be beneficial for the nymphs and is certainly beneficial for the foodplants, particularly potted ones. Adults can be kept under a natural daily light cycle or a reversed cycle, and extraneous lighting should be kept to a minimum, both day and night. As adults do not appear to see red light, red globes can be fitted as lighting or used in torches without affecting the insects' activity.

Monitoring
Temperature and humidity in particular should be monitored at least daily. This can be recorded manually using thermometers and relative humidity readers with conversion sheets, and preferably digitally with data loggers as well. Temperature and humidity (along with genetic management and food plants) are probably the two most important factors in maintaining a successful population of LHISIs.

2.2 Cage Furnishings

As mentioned in 2.0, enclosures should be furnished with food plants, nesting boxes, a dish of free water, a source of humidity and, for the adults, an egg-laying substrate. A range of other furnishings may be added, particularly if the species is being displayed, but there has been evidence of adults chewing materials such as plastic. It would also not be advisable to add plants that have not been tried successfully as food plants, without prior testing.

HEALTH REQUIREMENTS

3.1 Vet Procedures

Veterinary procedures have been carried out on a number of adult LHISIs, each with different symptoms and different treatments.

Case 1
The female originally collected from Balls Pyramid ceased feeding and started to become inactive about a week after being in captivity, following an episode of egg laying. Over several days her activity, particularly feeding activity, was notably reduced and for five days she ceased feeding altogether. During this period she was x-rayed to determine if she was egg bound due to a possibly inappropriate egg-laying substrate, and six eggs were clearly seen inside her abdomen (appendix 11). These egg were subsequently deposited by the female and later developed very thin, brittle shells, and eventually disintegrated entirely, presumably due to the effects of the x-ray, but all further eggs appeared undamaged. Other analogous stick insects (*Eurycnema goliath* and *Extatosoma tiaratum*) x-rayed at the same time showed dozens of eggs in the abdomen, so the LHISI female was apparently not egg bound. Her foregut was also seen in the x-ray to be full of air, suggesting aerophagy, a sign of distress in vertebrates, particularly birds (appendix 11).

After five days she became completely immobile and unreactive to touch or light, and a solution of melaleuca leaves (mashed with a mortar and pestle), glucose and calcium in distilled water was administered to her with an eyedropper on her mouthparts. Within a few hours, she became active again and resumed normal activity, subsequently living for another year. The cause of her morbidity and the reasons for the success of the treatment are still unknown.

Case 2
An adult male was found dead unexpectedly and autopsied by Melbourne Zoo vets. Upon dissection, his foregut was full of newly chewed leaves, his hindgut full of well-processed leaf material, his testes well-developed and plenty of fat throughout the body, suggesting a healthy condition and that he was feeding well right up to the point of death. However, his internal organs appeared very dry, with almost no free fluid in the body cavity, suggesting general desiccation. The enclosure in which he was being kept was moved off the floor to an area in the glasshouse where humidity was higher, the mesh of the enclosure was changed for a smaller mesh size, and humidity was increased in the glasshouse throughout the night. There have been no subsequent deaths attributable to desiccation.

Case 3
An adult female was found near death and the treatment used in case 1 was attempted, without success. The vets also administered a modified form of

Ringer's solution (see below), also without success. An x-ray revealed nine well-developed eggs in her abdomen, and like case 1, signs of aerophagy. Upon dissection, the foregut was found to be stretched like a balloon full of air, and the foregut was almost empty, suggesting she hadn't eaten for some time. There was a reasonable spread of fat throughout her body, but not as much as seen in previously dissected specimens (appendix 12). On the inside of the gut, at the junction of the fore- and hindgut was a small area of green pigment, which appeared to be part of, or embedded in, the gut wall. This was analysed by pathologists without result. The pigment may have come from a pelletised fertilizer used on the potted melaleuca plants, as the colour was identical to that of Greenjacket Osmocote, perhaps consumed inadvertently by the female. Greenjacket Osmocote has been removed from the potting mix and there have been no subsequent cases attributable to this.

Case 4

Nine adult LHISIs were found dead in a single enclosure one morning, with no surviving specimens in that enclosure. Seven appeared to have died whilst feeding, as they were lying upside down at the base of the plant, and two were found dead inside the nesting box. The food plant was tested for insecticide and herbicide but none was found.

Autopsies were conducted on the insects and all had fair to poor body condition inside, with a reasonable amount of fat, well spread throughout the abdomen, but not as much as seen in previous specimens. All specimens had some air in the foregut without any food present, and very little food in the hindgut. The hindgut contained mostly brown liquid, which was also found on the floor of the enclosure, with some semi-solid material and some air bubbles. The overall colour of the internal organs was duller than that seen previously.

Pathology found possible protozoan parasites in the wall of the gut of several specimens, but the protozoa has not yet been identified (appendix 13) (or even confirmed as protozoa by a specialist). There was also heavy growth of certain bacteria and fungi in the gut (also unidentified) and analysis of whole mounts of the insects' heads found a type of ulceration or lesion associated with fragmentation of the cuticle (appendix 14) and the presence of spirochaetes (appendix 15). Swabs of the nesting boxes found the bacteria *Klepsiella pneumonia*, but the significance of all these findings, and the cause(s) of the deaths are still unknown.

Ringer's solution

Ringer's solution is used generally by vets for therapeutic support of dehydrated or distressed vertebrates. Several attempts have been made over the years by a number of breeders to modify this solution for invertebrates, particularly tarantulas. Some studies have also been done on the physiology of stick insects, particularly comparisons between the mineral (and other) components of their food plants, and the components of the stick insects' bodies. The vets at Melbourne Zoo have attempted to modify Ringer's solution to cater for the differences between vertebrates and stick insects, but there is so little research available, and the results that have been published vary so dramatically, that it is difficult to know where to start. Particularly when, for example, papers published on the quantities of magnesium found in the bodies of stick insects vary by orders of magnitude between different species. We have attempted to administer a version of Ringer's solution intravenously (intracoelomically) to unwell specimens through membranes between tergites in the abdomen, but so far without success.

Euthanasia
Adults and nymphs can be euthanased by placing them in a container in the freezer for at least four hours. They can then be removed from the freezer and dried for mounting. If adults are to be preserved in alcohol, they should be injected with at least 90% ethanol and then submerged in a jar filled with ethanol.

3.2 Known Health Problems and other Problems

Disease
Apart from the bacteria mentioned in section 3.1, there is very little record of viruses and bacteria infecting stick insects, and there has been no direct evidence of LHISIs suffering from either. Hygiene protocols should be maintained as with other invertebrates reared in captivity, but at this stage there is probably no need for extra precautions with this species. Parasites are known from a number of stick insect species, but none are recorded for LHISIs.

Inbreeding
There is some evidence that LHISIs suffer inbreeding depressions in captivity. The population at Melbourne Zoo, being descended from a single pair, appeared to experience increasing symptoms of inbreeding over two generations until four adult males were introduced, descended from a second pair held at Insektus in Sydney, and their genes began to have an influence. Inbreeding symptoms included:

- unusual morphological abnormalities, particularly apparent in the abdomens of adults;
- small egg size and volume, which became more pronounced with each generation (appendix 16);
- low egg hatching rate;
- small size of the nymphs on hatching; and
- low survival rate of nymphs.

After new males were introduced, no further abnormalities were observed, the size of the eggs and nymphs increased, the hatching rate increased from less than 20% to about 80%, and the survival rate of nymphs and adults rose to almost 100%. Consequently the population at Melbourne Zoo, which hovered around 20 individuals at any time during the first three years of captive management, rose to 600 within 12 months of the males' genes taking effect (appendix 17).

This emphasises the importance of managing the captive population to maintain genetic integrity in the long term, keeping as many records as possible, and outbreeding whenever mating occurs.

Overcrowding

Because LHISIs appear to be a particularly gregarious species, large numbers may be kept together without problems caused by overcrowding. Leah (1916) reported that 68 nymphs were collected from a single tree hollow on Lord Howe Island, and there are also reports that large numbers sheltered within the roof spaces of houses on the island. When given the option of several daytime nesting boxes in captivity, groups of insects tend to crowd into a single nesting box rather than spread out into smaller groups.

Overcrowding in the nesting boxes may not appear to be a problem with LHISIs, but there may be problems with overcrowding in the overall enclosure. In other species, including stick insect species, overcrowding results in smaller adults (amongst other problems), particularly if overcrowded during development. This has not been demonstrated for LHISIs but should be kept in mind.

However, adult males are endowed with large spines on the hind femora, the exact purpose for which is unclear but may be used against other males. At Melbourne Zoo, males are not kept with other males in the presence of females, following the death of a female which may have been caused by one of several males sharing her enclosure. Adult female Eastern Goliath Stick Insects (*Eurycnema goliath*) have twice been observed to fatally injure other adult females by (inadvertently) squeezing the victim’s body in the crook of the well-spined hind legs. Male LHISIs have been kept in groups without females and without incident, and single males have been kept successfully with groups of up to 10 adult females.

3.5 Cleaning Routine

In captivity, LHISIs will consistently shelter during the day in small damp nesting boxes filled with their mouldy frass, in preference to sheltering in clean, dry boxes. Consequently, cleaning is required no more than once a week, following the routine outlined below:

- empty frass and eggs from nesting boxes;
- sweep out and wipe down enclosure floors;
- rinse out and wash any jars holding browse; and
- hose out the floor of the holding area (eg glasshouse).

3.7 Animal Records and Routine Checks

As mentioned in section 3.2 (inbreeding), record keeping is vital to manage the population over a long period. If a small number of LHISIs are kept, they can be marked individually (see below) and data entered into ARKS to track their life history and maintain provenance and genetic information. Because there is no available information of this species in the wild, and because any information may be useful in improving husbandry techniques, all observations should be recorded and entered into ARKS. This includes:

- incubation time for eggs (see appendix 18);
- length and width of eggs;
- weight of eggs;
- condition of nymphs on hatching (a subjective measure (eg poor, good, very good, excellent) that can be a fairly accurate predictor of nymph survival);
- size of nymphs on hatching;
- incubation medium;
- any other comments on eggs, including egg abnormalities such as changes to the micropylar plate or, as in one case at Melbourne Zoo, a double micropylar plate;
- moulting periods;
- any medical information and veterinary treatments;
- any behavioural observations;
- pairing for mating;
- observations of mating;
- nymph or adult deaths, particularly if unexpected; and
- dietary changes or supplements.

Record keeping for large numbers of LHISIs is more problematic, particularly when groups are broken up and transferred between enclosures, and there is as yet no easy method for tracking individuals that are being kept in groups, or for following particular genetic lines for more than one generation. At Melbourne Zoo, up to 10 adults are kept together in groups based on their parentage, and labelled with a group number which reflects their particular generation, their parentage plus an individual number. Individuals can be removed from a particular group and set up for mating to ensure maximum outbreeding without losing track of their history. The introduction of ZIMS may help this situation.

Marking individuals

Individual nymphs and adults may be tagged using queen bee markers, available from Australian Entomological Supplies. These are small coloured plastic discs which are fixed to the backs of individuals using a non-toxic glue (appendix 19). Each bee marking kit contains five sets of coloured discs, numbered 1-100, enabling 100 individuals to be marked using different colours for different instars. Nymphs as young as three months old may be tagged, but tags are lost at each moult and require retagging. Theoretically, individuals can be tagged and kept in groups, and every day the group checked to ensure that any individual that has moulted overnight is retagged. However, LHISIs have the bad habit of moulting in twos or threes, so the following morning there is no way of knowing which individual belongs to which number.

The bee markers can be fixed to the back of the thorax, and for nymphs the marker should be fixed slightly to one side, so it doesn't interfere when the thorax splits down the middle during moulting. Because LHISIs have a tendency to choose to spend the day in damp, mouldy conditions, the tags quickly become covered in frass and dirt which can be removed by gentle scrubbing. Bee markers will last several months on the back of an adult, but may fall off soon after affixing if the glue is not fresh.

BEHAVIOURAL NOTES

3.0 General Behaviour

LHISIs demonstrate very different behaviours to most other stick insects, particularly Australian species. They are unusual, but not unique, amongst stick insects in their gregarious habits in both nymphal and adult stages. They are more active and move more rapidly than other species, are often appear to be particularly aware of their environment. They also spend extended periods exploring their environment (appendix 22). In many ways their behaviour is more akin to cockroaches than other stick insects. There is some evidence of territorial behaviour in adult males, but this and other behaviours require further investigation.

Feeding behaviour
LHISIs feeding on *Melaleuca howeana* will consume leaves of all ages, from those at the base of the plant to the tips of the stems. Like many other chewing insects, they eat leaves starting at the tip and chew in a semi-circular fashion downward towards the base of the leaf before starting again at the top. If reaching across from another branch and feeding on leaves perpendicularly, the feeding stroke is across rather than down the leaf, and takes longer because more strokes are required for the same leaf.

LHISIs will methodically consume every leaf on a branchlet, moving from the tip to the base, so extended bare patches are left after feeding. The leaves are consumed right down to the petiole and the insect will often continue on to chew the bark, leaving small raised scars in the stem. Small branchlets may be chewed through as the insect pushes the stem right into the base of the mandibles (appendix 20). Feeding appears to be in sessions of about 1-1.5 hours (although they may extend up to 260 minutes) (appendix 23), followed by extended periods of inactivity.

The leaf is physically manipulated by the mandibular palps, which vibrate rapidly at the top of the feeding stroke then hold the leaf as the insect moves down the leaf. If a piece of leaf is severed during feeding, the insect will hold the severed portion in the mandibular palps until it is consumed. The maxillary palps remain underneath the edge of the leaf during feeding and don’t appear to assist mechanically in the eating process.

LHISIs will also chew non-plant material, such as plastic. Despite vigorous and audible chewing, the material is usually left unmarked, so the significance of this behaviour is unknown. They will chew bark of other trees and plants such as tree ferns, but again it appears that little or no material is actually consumed.

Mating behaviour

Mating takes place usually with the female horizontal on the ground and the male above her, but it will sometimes occur with both hanging vertically on a plant or at an angle of 45^{o} (appendix 21). If mating vertically, the male may lose his grip on the female and hang downwards by the abdomen until he is able to gain a footing and return to the upright position, still attached to the female.

Mating begins with the male climbing onto the back of the female and curling the tip of his abdomen underneath hers. The thorax of the male is parallel to that of the female, but the abdomen curls upwards at the anterior end then arches downward underneath her abdomen to loop back up so the tip is horizontal where it meets the tip of the female's abdomen. The body of the female is parallel to the male's except that the last three segments of her abdomen angle sharply upwards at 45^{o} to meet the male's.

The tip of the female's abdomen opens widely dorsoventrally to accommodate the male during mating, with a split clearly visible from the tip of her abdomen to about three segments (1.5cm) from the tip, along the side. The stretched intersegmental membranes appear as a light yellowish brown within the split, and at regular intervals a pulse passes across the membrane from the male to the female. The male's copulatory organ is located about three segments from the tip of his abdomen.

Mating episodes take between 14-25 minutes, and there may be up to three episodes per night, usually with one to two nights in between episodes (appendix 24). The female may continue to feed during mating, but generally both sexes remain completely immobile, with not even the antennae moving. The male may remain on the back of the female for some time following mating.

Egg-laying behaviour

When about to lay an egg, a female moves her body backwards slightly and immediately probes with the tip of her abdomen into the soil. She arches her body as she pushes the tip down into the soil and after a period of usually only a couple of seconds, begins to grind her entire abdomen back and forth sideways with vigour. This continues for a variable period until she moves her body forward slightly and removes her abdomen from the soil, leaving behind an egg.

She will then pat down the soil with her abdomen. Every time the abdomen touches the soil it moves to one side slightly to smooth the soil, and the end also curls under the abdomen towards the front slightly, further smoothening the soil. This is repeated a variable number of times, sometimes with pauses in between, before stopping. She then seems to rest for a couple of minutes, during which time another egg will appear at the tip of her abdomen. The process is then repeated.

Pair bonding

'Pair bonding' is unusual in insects and not clearly defined, but there are reports that adult males and females of the Thorned Devil (*Eurycantha horrida*) from New Guinea, probably the LHISIs' closest living relative, form bonds if kept together for a period. The FAQ website www.small-life.co.uk sites the example of "when a pair of adult New Guinea stick insects that have been particularly close, living together as adults for a year, and then one dies [sic]. In these situations, when one dies (of old age) the surviving stick insect not only stays with the other stick insect as it dies, gently touching it, but remains with the corpse for a few days afterwards. Sometimes the survivor refuses to eat or drink and dies as well. This behaviour is not seen in New Guinea stick insects that are not in close bonds."

This particular behaviour has not been observed for LHISIs, but the behaviour of individual pairs that have been kept together for a long period suggests a bond developing between some pairs. Nine pairs kept separated at Melbourne Zoo for several months were observed daily over a month to determine the relationship between male and female, and their location in relation to the daytime nesting box. There were four possible combinations:

- male inside nesting box and female outside;
- female inside nesting box and male outside;
- both sexes within nesting box; and
- both sexes outside nesting box.

Behaviour was found to be markedly different between pairs, but remarkably similar within each pair over time (appendix 25). In one pair, both sexes were found together in the nesting box every day of observation, with the male's body lined up beside that of the female and with three of his legs stretched over her; in other pairs both were outside the nesting box on most occasions, or the male outside the box and the female inside. Of the total 270 observations, never once was the male found inside the nesting box and the female outside. This behaviour obviously requires further observation.

Locomotion

Nymphs tend to rely on camouflage and will remain immobile when threatened until the camouflage is no longer effective, when they move rapidly in a jerky fashion and will generally not stop until they feel secure again. Adults tend to move slowly unless threatened, when once again they will run rapidly and will not stop until secure. A hand cupped over the top of the insect in this situation will generally stop it moving and settle it down. Adults move much more easily on a flat horizontal surface than do other stick insect species, due mainly to their slightly different morphology.

LHISIs will not readily walk on to a person's hand, and will continue changing direction if a hand is placed in front of them. Upon encountering a solid object, they will stop and test the object with their antennae, and then usually climb the object. Adults are able to climb smooth surfaces such as glass, sheet metal, smooth varnished timber and plastic electrical cords. They can also walk backwards, on the underside of a horizontal surface, and down a vertical surface head downwards with the abdomen curled over the rest of the body.

Walking tends to be in bursts, lasting between 30 seconds and five minutes, interspersed with periods of inactivity for several minutes. In general, whilst on the move, more time is spent resting than walking. Adult males in particular walk slowly and methodically along the ground, with legs out to the side, in a very rhythmic fashion.

Perception
Although their eyesight appears poor, adult LHISIs are very sensitive to white light, and may react strongly if even a dull torch is shone on them. They do not appear to be bothered by red light, regardless of the brightness or proximity. Young nymphs do not react to white light and readily sit in full sun throughout the day.

The antennae appear sensitive and important to perception. LHISIs sweep the antennae in circles when moving, regularly touching the ground, in much the same way as a cockroach. They will then sit with the antennae pointing upwards when at rest. As mentioned above, the eyesight appears poor, and they will walk past even large objects, such as a log, without changing direction until the object is 2-3cm away, then turn towards it before climbing.

They also react strongly to being touched, and particularly to being handled. They do not appear to react to sound or vibration, even when very close, and will continue feeding at night whilst their enclosure is serviced as long as there is no light and direct contact is not made.

4.1 Mixed Species Compatibilities

Young nymphs are particularly susceptible to predation by almost any predator, and so should not be kept with other species. As they are limited to nocturnal display, LHISIs cannot be kept with other diurnal stick insect species. However, there is no reason they cannot be kept with any herbivorous nocturnal invertebrate or vertebrate species.

FEEDING REQUIREMENTS

5.0 Diets and Supplements

In captivity, LHISIs have largely been fed on Lord Howe Island Melaleuca (*Melaleuca* howeana). They have also been successfully fed on Tree Lucerne (*Chamaecytisus prolifer*) and Moreton Bay Fig (*Ficus macrophylla*). They show signs of being adaptable to a range of food plants. Juvenile LHISIs have also done very well on Blackberry (*Rubus fruticosus*) but have not to date fed on this species for a full generation. All stages have done particularly well on Tree Lucerne, with more than one generation now having been reared on it.

Mirror Bush (*Coprosma repens*) has been tried unsuccessfully, but may be worth further attempts, as several other *Coprosma* species occur on Lord Howe Island (although they are not common there). Several plant species have been offered to the insects at the same time as Lord Howe Island

Melaleuca, but this has been unsuccessful whilst the melaleuca is present. Species offered but rejected include Sandalwood (*Hibiscus tiliaceus*), Queensland Poplar or Dogwood (*Omalanthus populifolius*) and various species of melaleuca. See section 1.5 for other potential host plant species.

There is some evidence that their captive diet is lacking in either particular plant material, minerals or other nutrients, but there is not yet enough evidence to be conclusive. As they may have had other food sources on Lord Howe Island or even Balls Pyramid that are not yet known, a supplementary diet of Orthopteran mix was offered to LHISIs in captivity at Melbourne Zoo. Small dishes of 10g of the mix were placed in LHISI enclosures and weighed and changed nightly for a month (with control dishes outside the enclosures), but the Orthopteran mix was not touched throughout the trial.

5.1 Preparation and Presentation of Food

Plants may be offered as cut browse or potted plants. Cut browse should be changed at least twice a week, or more often if it dries out. The amount of food consumed depends on the size and number of LHISIs in the enclosure – small nymphs will not make an impact on the plants, no matter how many are present, but a few adults together will consume a substantial amount of foliage over a few nights. Adults will also chew the bark of host plants, particularly melaleuca, causing branches to die prematurely.

Juveniles will sit upside down on the top of the enclosure during the day, so the browse should be also touching the top to allow them easy access to food. Like other stick insects, LHISIs will not drown in water jars containing browse, so no precautions are needed as for other types of insects.

Cut branches of Moreton Bay Fig will dry out very quickly, but their life can be extended by using the following method. When cutting a stem off the tree for browse, cut at least an extra 10cm of branch off, then immediately place the cut end in water. Cut the extra 10cm off the stem under water, then submerge a jar into the water and place the cut end in the jar, before removing the jar and setting it up in the enclosure. Using this method, the stem will not be exposed to air after the initial cut from the tree.

As mentioned in section 3.1, one adult LHISI that died prematurely was found to have a small patch of dark green pigment in the gut during autopsy. This green was very similar to that of greenjacket osmocote, which was present on top of the soil of the potted melaleuca on which that insect was feeding before death. There is no other evidence to suggest that the insect consumed the osmocote, but it is better to remove any osmocote from the surface of the soil as a precaution.

5.4 Plant propagation

Tree Lucerne (*Chamaecytisus prolifer*)
A native of the Canary Islands, now well established in Australia as a garden ornamental and as a useful fodder crop. Prefers rich, well composed, moist

soil in a sunny position. Frost resistant and drought tender. May be deciduous, depending on the situation. Grows to 6m with a spread of 3m. Propagation is by seed.

Moreton Bay Fig (*Ficus macrophylla*)
A native of NSW and Queensland, the subspecies *F.m.columnaris* occurs on Lord Howe Island. It is evergreen and grows to 30m high, and prefers light to medium soils. It grows in an open, sunny position, and is drought resistant but not frost tolerant. Propagation is by tip cutting in autumn.

Mirror Bush (*Coprosma repens*)
A native of New Zealand, now well established in Australia and is a serious weed in many areas. Adaptable to most soils and conditions, and is drought, frost, salt spray and fire resistant. Grows to 3m with a spread of 2m. Propagation is by seed or cuttings.

CAPTURE, RESTRAINT AND TRANSPORT

6.2 Transport Equipment

Adult LHISIs have been successfully transported inside a 110mm external diameter PVC tube, cut in half lengthwise and hinged on one side to enable it to open up completely. A PVC endcap is fixed at each end to keep the tube closed during transport, and each endcap is lined with rubber bicycle tyre tubing to help it stay fixed. The PVC tube is lined on the inside with short pile carpet to enable the stick insects to maintain a firm grip. A piece of the foodplant should be fixed inside the tube as a food source and a further means of maintaining a grip. Because of the habit of LHISIs to collect together inside their daytime retreats, up to 5 adults or 15 nymphs may be transported inside a single tube. Eggs can be transported in film canisters filled with sand.

Australia Post does not allow live insects to be posted through the general mail (other than bees, leeches, silkworms and entomological specimens, all specially labelled), and most couriers will not accept live insects. Ventilation during transport is not particularly important, but it should be noted that insecticides may be used on international flights, so in this case transport containers should be kept airtight. On three occasions, LHISIs have been transported interstate in Australia by plane, and on all occasions special permission was obtained to keep the insects in the cabin rather than the hold (where temperatures can be very low), and to be taken through customs without being x-rayed.

CAPTIVE PROPOGATION

7.0 Enclosure Modifications / Specifications

Individual enclosures, each holding a number of LHISIs, may be set up in a room or glasshouse where the lighting, temperature and humidity is controlled for all enclosures at the same time. Using this method, up to 20 groups can be kept in separate enclosures but managed together with regard to their environment. The enclosure design and the environment should be the same whether this species is kept off-limits or on display.

Alternatively, large numbers of individuals may be kept free range in a single glasshouse. Large potted plants can be located around the glasshouse and changed only when necessary, and a number of nesting boxes should be available to allow the stick insects to choose their daytime retreat. Large, shallow containers of sand or other egg-laying medium should also be placed around the glasshouse or, alternatively, the entire glasshouse floor may be covered with sand which is sifted every four months to ensure the eggs are collected before hatching. The glasshouse should be escape-proof, with screens covering air conditioners or heaters, as well as louvres or any other means of exit that may be inadvertently or automatically opened (appendix 26).

7.1 Season & Behaviour

Because Lord Howe Island has a very temperate, unchanging climate, there is probably very little seasonal variation in the wild population and no evidence of reproductive or behavioural changes with the season in captivity.

7.3 Gestation, Laying Period and Incubation

The gestation period, the ability of females to store sperm and the influence on the eggs of multiple matings with different males is not known. Males of this species do not transfer an obvious spermatophore as do other stick insect species.

The eggs of LHISIs (appendix 27) are relatively large, about 6.2mm long and 3.6mm wide. At the top is a flat operculum through which the nymph emerges, and on the side towards the opposite end is a tear-shaped micropylar plate, about 2.4mm long. The entire egg is about the size and shape of a tic tac. The egg surface is whitish to pale cream and is covered with a fine, raised, net-like structure. On contact with moisture, the egg will become very dark in colour, ranging from dark grey-brown to black, and if sitting on a moist surface the egg may be black on one side and white on the dry side. The dark colour fades as the egg dries out, suggesting the egg wall is very porous and/or absorbent. Unviable eggs also become very dark as they pass nine months of age.

Females will begin laying eggs about a fortnight after reaching adulthood, whether a male is present or not. Whether this species is able to reproduce pathenogenetically is not yet known. The first several batches of eggs produced by each female tend to be smaller than those produced later on, and the very first eggs may be slightly misshapen. The eggs produced at the end of a female’s life may also be smaller than those produced previously, and females will continue producing eggs until death, although the rate of egg production drops off dramatically towards the end.

7.4 Fecundity

Females generally produce eggs in batches of 9-10, about a week to 10 days apart. Smaller batches are commonly produced, and single eggs may be deposited in the intervening periods. The sex ratio is probably about 50:50 overall, but there is considerable variation in this ratio over time. There is some evidence that the early eggs from any individual female will produce female offspring, and later eggs tend to be male, although this requires further conformation. This situation leads to dramatic changes over time in the sex ratio of the entire population, with the adult population at Melbourne Zoo varying between 10% female in one period and 98% female in another. A single female may produce up to 300 eggs in her lifetime.

7.5 Development of Young

LHISI nymphs measure approximately 20mm on hatching, varying between 16-22mm. They emerge from the egg usually underground, and burrow to the surface to climb the nearest large object. If kept in Chinese takeaway containers they will always be found clinging to the underside of the lid. Most individuals appear to hatch during the night, but will also hatch throughout the day, including the afternoon.

Although there is still plenty of data to be obtained on the life history of LHISIs, they appear to have five instars between egg and adult, but the length of the each instar can vary significantly between individuals. Nymphs may moult within a fortnight of emerging from the egg, but there is overlap between different stages of different individuals throughout the rest of the instars. The intermoult period in the later instars may be as little as 10 days. LHISIs reach maturity at between 201 and 224 days, averaging 210 days (seven months). In other stick insects species, females undergo an additional instar to males and therefore take longer to reach adulthood, but this has not yet been determined for LHISIs. Adults may live for up to 18 months after maturing.

7.6 Propagation techniques

At Melbourne Zoo, moist sand trays containing eggs (see section 2.0) are collected and sifted weekly, and the eggs are individually weighed, measured and labelled with the generation number and parentage and assigned an additional number which identifies that particular egg. The eggs can then be placed singly in Chinese takeaway containers to record the exact incubation period (appendix 28). If there is a delay between sifting out and processing the eggs, the eggs should be kept in film canisters filled with sand, as keeping them dry will dramatically decrease the subsequent hatching rate.

Females will usually bury their eggs but will also deposit them in the daytime nesting box, as well as throughout the enclosure, particularly in corners and around the edge of the enclosure. When burying eggs, the female will deposit them at an average depth of 25mm. When eggs are processed and reburied in an incubation medium (such as vermiculite) for hatching, they should be placed at about the same depth. Eggs should be placed with the cap (operculum) facing upwards, as this enables them to emerge more easily and may increase the hatching success.

Trials using sand, vermiculite, soil, compost and a mixture of soil/compost as an incubation medium have found that there is little difference to hatching rate, although vermiculite is slightly more successful than the others. Trials on the moisture level of the incubation medium, including wet (sprayed with water every day), moist (sprayed with water twice a week) or dry (not sprayed at all) demonstrated that there is no difference to hatching rate, as long as the generally environment in which the egg containers are kept remains humid.

APPENDICES

Further research

The following questions have arisen during observations and research at Melbourne Zoo.

- Is there a link between nightly activity and temperature, humidity, moon phases or barometric pressure?
- Are individuals of this species able to see infrared? Filming them under infrared light gave some vague suggestions that they can.
- Is the male able to follow the path of the female via a pheromone trail or some similar mechanism? This suggestions arises from the original male at Melbourne Zoo walking around the rim of the large cage on the same night as the female (20/3/03) whereas neither of them exhibited this behaviour on any other occasion.
- Are the large spurs on the males' hindlegs used for defensive or aggressive behaviour and if so, on whom and under what circumstances? If they are used for defence, how does this fit in with other defensive strategies, depending on the type of threat and direction of approach?
- What is the significance of adults, particularly females, chewing bark and other plant parts? And if the reason is nutritional, how important is it to their diet, are there particular plants that are more favoured, and can other supplements be added to the diet?
- Does parthenogenesis occur, and is it obligate or facultative?
- What are the factors that cause adults in particular to orient towards various objects, especially large objects such as tree trunks?
- What ranges of light can adults see and how do they react to different forms of light, including moonlight?
- What is the range of plant species that LHISIs will consume? For each plant species trialled, the rate of feeding, development time, timing of moults and weekly weights should be noted.

These is also a number of interesting genetic paths to follow, such as analysing their chromosome number and chromosome number variation (cf *Didymuria violescens*), comparing their genetics to Eurycanthines in Papua New Guinea, and to specimens collected from Lord Howe Island in the early twentieth century. The genetic variability of the wild population would also make interesting research, particularly in comparison to the genetic variability of the captive population.

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