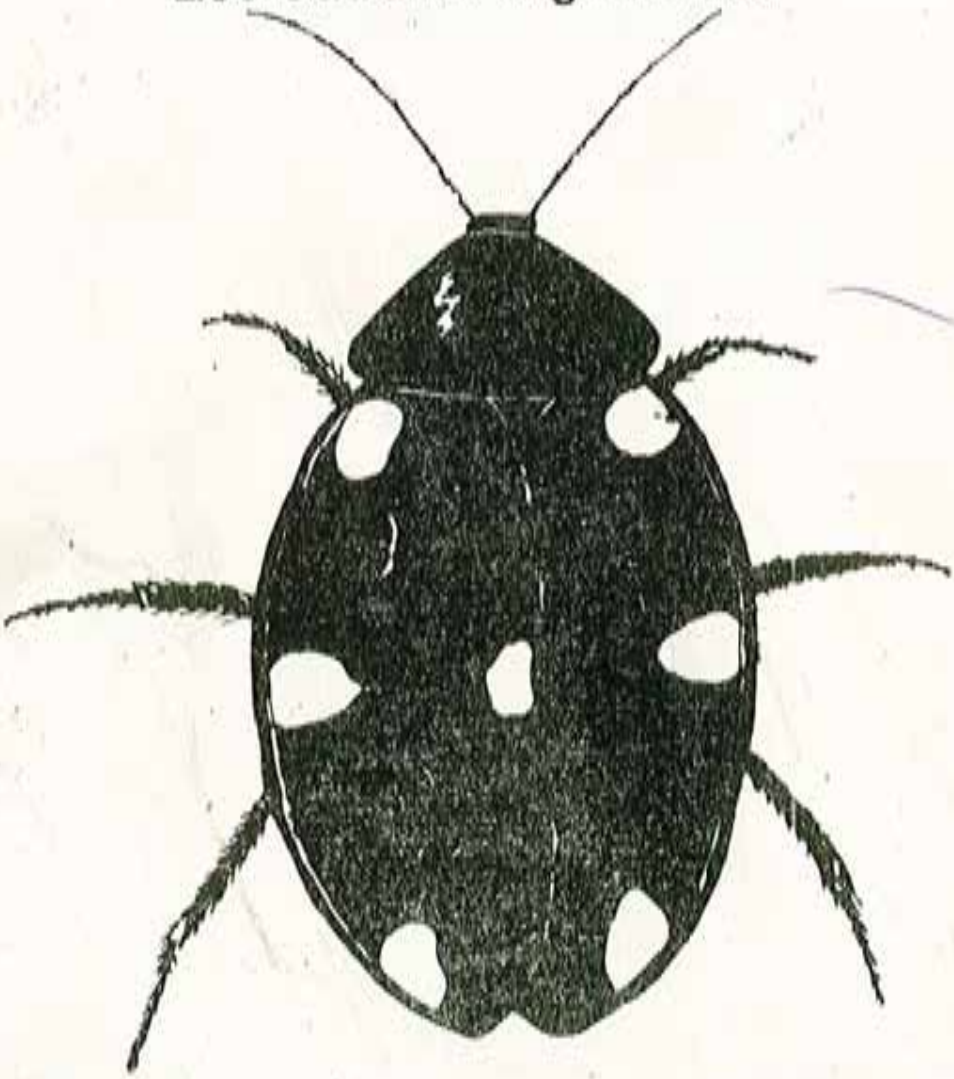
Hands on Workshop in Invertebrate Keeping

27 - 29 March 1997
Coimbatore

Coimbatore Zoological Park
British Council Southern Division
Zoo Outreach Organisation



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Compiled by B.A. Daniel
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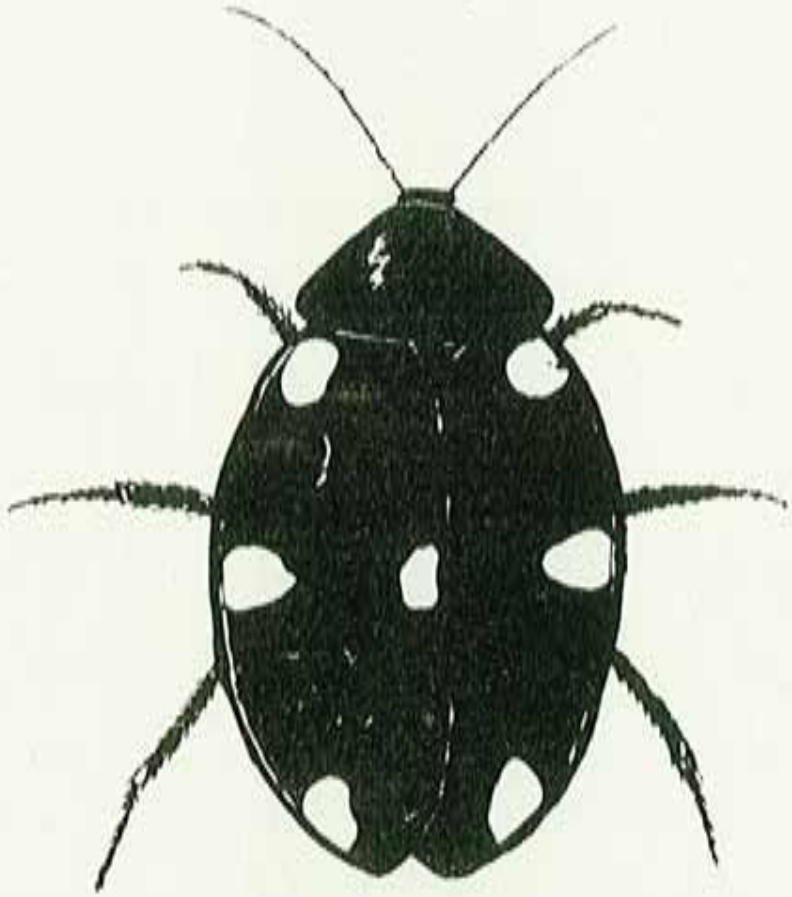

Corydia petivariana (Seven-spotted cockroach)

British Council Division
British Deputy High Commission

Agenda

27 March 1997- Day I

9.30 am.	Welcome and introduction
10.00 am	General introduction to invertebrates and their conservation
10.30 am	Life histories
11.00 am	Tea
11.15 am	Invertebrate displays
11.45 am	Demonstration of aquarium construction
12.30 pm	Invertebrate exhibits and decoration considerations
1.00 pm	Lunch
2.00 pm	London Zoo invertebrate conservation centre, a profile
3.00 pm	Aquarium and invertebrate maintenance and daily routines
4.00 pm	Tea
4.15 pm	Invertebrates as live food
5.00 pm	Disperse

28 March 1997 - Day II

9.30 am	Leave for Anaikatty - Coimbatore Zoo site
10.30 am	Tea
11.00 am	Introduction to Coimbatore Zoo, objectives and plans
11.30 am	Paradise garden plans for invertebrate exhibits
12.00 noon	Participants ideas on developing the paradise garden for invertebrate exhibition
1.00 pm	Lunch
2.00 pm	Exercise on development of paradise garden continues
3.00 pm	Invertebrate collection at the zoo site for setting up exhibits the next day
4.00 pm	Tea
5.00 pm	Leave for the city

29 March 1997 - Day III

9.30 am	Education and interpretation around invertebrates and the exhibits
10.30 am	Group exercise in designing educational material
11.00 am	Tea
11.15 am	Screen printing technology for making simple invertebrate signages
12.00 noon	Demonstration of screen printing and making an educational literature
1.00 pm	Lunch
2.00 pm	Group exercise on aquarium construction
4.00 pm	Tea
4.15 pm	Group exercise in printing educational material prepared in the morning
5.30 pm	End of workshop with commitments

CONTENTS

Articles

The Husbandry of Desert Arthropods

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The desire by zoological parks and aquariums to maintain terrestrial arthropods as part of their collections is steadily increasing. In some cases, taxa are chosen to illustrate a particular theme or behavior, or they may be chosen as representatives in a replicated biotic community. Due to its biological diversity and the relative ease of specimen acquisition from the area, many zoos find the Sonoran Desert region, particularly southeastern Arizona, rich in material to meet their arthropod exhibit requirements.

The diversity of this area is due to the influence of several biogeographic provinces which meet in southeastern Arizona. With plant communities representing the Madrean evergreen woodlands and Sinaloan deciduous thorn forests from the south, the Chihuahuan Desertscrub from the east and the Sonoran Desertscrub from the west, species diversity is quite high. Mountain islands punctuate the landscape and elevations range from 600-3000m. Most commonly exhibited arthropods occur at the lower elevations where annual precipitation ranges from 25-60cm. Desirable taxa are most readily available during the brief but heavy rainy season in July and August. The area's non-insect arthropods are of special interest due to their long lives and relative ease in providing proper captive care.

The husbandry of the most frequently displayed arthropods from this region is fairly straight forward. Sonoran Arthropod Studies, Inc. maintains a variety of local arthropods for its workshops and outreach programs in a building that was originally a small residence. Environmental conditions are maintained with a central air conditioning unit and a humidifier. A near constant temperature of 27°C (80°F) is maintained. The relative humidity fluctuates due to the conflict between the refrigeration unit and humidifier but an average of 50% is achieved. The basics of clean caging and substrates, adequate nutrition and fresh water are necessary in maintaining desert arthropods. Details of their husbandry are here presented.

Centipedes

The giant desert centipede, *Scolopendra heros*, with its striking black and orange aposmatic coloration is a popular display animal. Although frequently attaining a length of more than 20cm they are extremely agile and quick moving. Care in handling should be exercised as their bite is very painful. They, like most Sonoran Desert arthropods commonly exhibited, are most active during the summer rainy season. With proper

care, giant desert centipedes can live several years in captivity.

Centipedes may be kept in a variety of containers including wide mouth gallon jars, plastic sweater boxes and standard aquaria. A soil substrate of at least 6 cm facilitates the centipede's burrowing behavior and minimal ventilation helps to maintain desirable humidity within the cage. Exhibit situations where visibility is important may call for less substrate and a shelter carefully devised to provide for visitor viewing while providing a sense of security to the nocturnal animal. Centipedes should always be housed individually.

A dish of fresh water will help maintain higher humidity in the enclosure but may frequently be spilled or covered during burrowing activities and result in a soggy substrate. Giant desert centipedes will also drink water droplets off the sides of a glass aquarium or jar. They feed upon a variety of insects and crickets are most commonly fed. Large centipedes may also prey upon small rodents and lizards and some keepers have found them to relish chicken livers. Such food items, however, tend to foul caging rapidly. One cricket, three times weekly satisfies most appetites. After molting, the desert centipede eats its exuvia, presumably to recover valuable nutrients.

Millipedes

The desert millipede, *Orthoporus ornatus*, requires high humidity and prefers a moist porous soil substrate. While maintaining a high humidity is important, open ventilation has led to greater longevity. A flat rock or piece of bark will provide shelter for the animal during the daylight hours and when cage conditions become too dry. A daily misting provides a reasonably stable humidity and the millipedes regularly drink moisture from off the glass.

Millipedes eat both fresh and decaying vegetation. In captivity they can be fed leaf lettuce, broccoli, grapes (cut open), bananas, spinach and sweet potato. Several millipedes can be housed in a single container. Due to soil moisture requirements and the frequent problem of food stuffs becoming mouldy, daily servicing is generally required.

Arachnids

Vinegaroons or Whip scorpions (Uropygida)

The vinegaroon, *Mastigoproctus giganteus*, is common in southeastern Arizona where it is found crossing the roads at night during the summer rainy season. They are generally impossible to find except during the summer months even under rocks or in burrows where they spend the summer daylight hours. Vinegaroons are harmless and easy to handle but like many arachnids, are quite fragile. When threatened by predators, they spray acetic acid from the base of the telson.

Vinegaroons may be kept in plastic shoe boxes or aquaria and must be housed individually. Vinegaroons will readily burrow under rocks and leaf litter to make a small cavern, particularly if the cage is well ventilated. A dish of water should be available at all times although burrowing activities may result in soggy substrate. A periodic heavy misting seems to be enjoyed by vinegaroons. They will eat a variety of insects including crickets, small grasshoppers and beetles. One or two crickets per week are quickly eaten and vinegaroons have been maintained in captivity for more than six years.

Tailless whip scorpion (Amblypygida)

The tailless whip scorpion, *Paraphrynus mexicana*, is found in the drier south/central portion of Arizona. They are most active in the spring and summer and spend much of their lives secluded in rodent burrows, and beneath bark or rocks. Because they are fragile and very responsive to vibrations and movements, it is recommended they be handled as little as possible.

Tailless whip scorpions prefer vertical surfaces to rest on and to hide behind during the daylight hours. Multiple specimens may be housed together if adequate food and shelter is available. A regular misting of the enclosure provides water as amblypygids readily take droplets from surfaces. Crickets are the standard captive fare but other live prey may be taken. Prey items should not be too large. The author has maintained three adult tailless whip scorpions for more than three years.

Scorpions

Scorpions are abundant throughout southeastern Arizona. They are most active during the warmer months, hunting at night and resting during the day. Scorpions may be found readily with the aid of an ultraviolet light while walking through the desert at night. Bark scorpions, *Centruroides* sp. and devil scorpions, *Vaejovis* sp. can be found under rocks, loose bark and old debris throughout the year. Giant hairy scorpions, *Hadrurus arizonensis*, the largest and most desirable exhibit species, construct burrows in the ground and are not easily found during the cooler months. Scorpions are long lived and will survive several years in captivity with good care.

Only the bark scorpion, is potentially life threatening but all species commonly displayed from the region have painful stings and care should be exercised when handling. Use forceps to grasp the scorpion's telson (tail).

Plastic shoe boxes, aquariums or gallon jars may be used to house scorpions. Provided with sufficient shelter and food, many specimens of the same species can be housed together. Different species of scorpions should not be mixed. One will

feed upon the other as will individuals of the same species not provided enough food.

All scorpions are predatory and feed primarily upon soft bodied insects. Small prey items are grasped and readily eaten; larger insects are grasped and subdued with a sting. Due to commercial availability, mealworms or crickets are standard offerings. Live roaches, grasshoppers, flies and moths may also be taken. Long term captive scorpions may, on occasion, decline eating for several weeks. Removal of uneaten prey after a day or so is recommended to minimize stress. Although they hardly seem to drink, a shallow dish of water will help maintain higher humidity levels.

Scorpions give birth to living young which ride upon their mother's back until their first molt; one to three weeks depending on the species. Baby scorpions should be removed from the mother's cage after they crawl off her back as they will be considered prey by larger scorpions including the mother. Baby scorpions can be fed fruit flies or pinhead crickets. If you plan to rear young scorpions, it is easier to reduce the number of the original brood to a manageable size by allowing the young scorpions to prey upon one another.

Solpugids

Solpugids can be found wandering in search of insect prey during late spring and summer evenings. They are fast runners with a high metabolism and are easily agitated. As such, these harmless arachnids are difficult to keep for any length of time and do not lend themselves to long-term exhibition. They seem to do best with a deep silty substrate which should be kept slightly damp. They are persistent burrowers and construct intricate systems of tunnels, some of which may be visible against the glass.

Solpugids are efficient predators with voracious appetites. Their pedipalps have sticky tips to allow them to catch insects and pull them in with great ease. In captivity they may eat several crickets every day. The smaller species do well on fruit flies and can consume up to a dozen twice a day.

The author has had only moderate success in keeping solpugids. The smaller species have been kept for long periods, but the larger species rarely survive a month in captivity. Further experimentation in solpugid husbandry is warranted.

Tarantulas

Tarantulas, *Aphonopelma* sp. are the most commonly kept desert arthropod. During the 8-10 years tarantulas require to reach sexual maturity, they remain close to their burrows and are rarely seen. Mature males seeking females which remain in their burrows are commonly seen crossing roads in late summer and early fall. Male tarantulas generally die within the year

of achieving sexual maturity while females may live for another ten years or more. Immatures and females are considered superior exhibit animals for this reason.

As with all arthropods, tarantulas shed their exoskeletons in order to grow. Young tarantulas molt several times a year until they are 6 or 7 years old. At this age, they molt once a year, usually in April or May. A couple of weeks prior to molting, the tarantula may appear lethargic and reject food. Just before ecdysis (molting) it will turn over and lie motionless on its back. Do not disturb as the spider may be easily injured. Tarantulas always die right side up, legs folded beneath the body.

A plastic shoe box provides the minimum spatial requirements for a mature tarantula. Larger sweater boxes or aquaria are preferred. The substrate and cage furniture used is a matter of aesthetics and serviceability and may include paper toweling, newspaper or soil. Soil may be banked towards one side of the container to encourage burrowing or other materials can be used to provide shelter, particularly if a foreign substrate is used. Tarantulas are nocturnal and like to seclude themselves during the daylight hours. Reptile hiding boxes, paper tubes and broken flower pots may be used in non-exhibit situations.

Tarantulas eat a variety of live insects but are especially fond of crickets, grasshoppers and beetles. It has been shown that beetles are necessary for tarantula reproduction in captivity and variety of prey will increase longevity. Tarantulas will also eat pink mice and small lizards. Commercially available crickets are most commonly fed to tarantulas with one or two adult crickets weekly being adequate. Although tarantulas derive some moisture from their prey, they should have a shallow dish of clean water available at all times.

Insects

Due to their shorter life spans, more exacting requirements and regulated importation, insects are not as frequently sought for exhibition purposes as the animals previously discussed. There are a few, however, which are long lived and easy to maintain in captivity and are frequently encountered during a visit to southeastern Arizona.

Darkling beetles, Tenebrionidae, are easily obtained and maintained for many years in captivity. Many species of these beetles can be found in southern Arizona. A 10 gallon terrarium with a soil substrate can house many individuals of one or two species or larger community tanks can be developed for many species. Darkling beetles readily oviposit into moist soil and a dampened area within the cage will quickly be teeming with larvae. Captive raised adults (*Eleodes*) are frequently dwarfed

but the larvae can be provided as prey to other organisms which eat the closely related mealworm beetle, *Tenebrio*.

Darkling beetles are general feeders and will eat a wide variety of natural and processed foods. Leaf litter sprinkled around the cage helps maintain a natural appearance and provides food for most species. Wheat bran and germ are readily accepted as are rodent pellets, primate chow and fish food flakes. Sweet potato and carrots are also eaten and are especially relished by larvae which feed upon them from below the surface. Water is provided by a regular misting.

Longhorn cactus beetles, *Moneilema* sp. feed on numerous cactus species but are most regularly found on prickly pear and cholla, *Opuntia* sp. Fresh prickly pear pads, mounted on a spike in an aquarium with a soil substrate provide both food and 'cage furniture.' The cactus should be changed when it starts to rot. In larger cages, rooted and growing cactus may be used. Ova are regularly deposited just below the soil next to the cactus and larvae feed at the base. Larvae take a year to mature and tend to be dwarfed.

Velvet ants, Mutillidae, are easily maintained for long periods of time. Actually wasps, the females are flightless and are generally the only sex kept in captivity. Since they are parasitic on burrowing bees and wasps, continuous cultures are not possible. A dry sandy substrate in a shoe box or aquarium works well for keeping specimens for more than one year. A shallow dish or test tube with cotton stopper can provide water. Velvet ants naturally feed on nectar but can be fed split grapes or a drop of honey in captivity. Do not use refined sugar mixed in water.

CONCLUSION

Desert arthropods are easily maintained in zoos, museums and nature centers. Many species obtained in southeastern Arizona during the summer months are being exhibited by institutions around the country. For some, particularly the popular arachnids and myriapods, their husbandry is simple. For others, including many which offer great interpretive value, little is known about their captive care requirements and successful husbandry techniques await development.

REFERENCES

Bardwell, J., Prchal, S. 1990. Bug Ranching: a primer for livestock husbandry. Backyard BUGwatching, Special Issue #1.

DISPLAY, BREEDING AND CONSERVATION OF THERAPHOSID SPIDERS

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They are known by different names in the different parts of the world. In Africa, they are called "baboon spiders" because of their hairy appearance. In South America, they are called "bird spiders" because they are thought to capture and eat birds. In Asia, they are called "earth tigers" and in North America they are called "tarantulas". (The name "tarantula" comes from the name of a hairy wolf spider in Europe (Italy) that is actually in a different suborder.) All of these names refer to the theraphosid spiders: the large hairy representatives of the primitive suborder Orthognatha.

For many people, theraphosids provoke fascination and a need to know more. For others they provoke an unreasoning fear and repulsion. The fear is due mainly to the bad propaganda theraphosids receive. Their large size and hairy appearance often give people the false idea that they are highly venomous; in fact, almost none are deadly to humans. Like many misunderstood creatures, theraphosids are portrayed in movies as heinous villains, sometimes achieving greyhound-bus proportions and dispatching human victims with calculated, sinister purpose.

The facts are very different. The largest theraphosids can attain an impressive 25-centimeter leg span, but this is their physiological size limit. As to sinister purpose, the theraphosid spider is an unreasoning creature whose instinct tells them to stay away from humans.

Displaying, breeding and conserving theraphosids demonstrates their importance in a diverse biological world and provides zoos a way to teach others about biological diversity.

Display

To dispel misconceptions about this little-represented species, The Louisville Zoological Garden constructed "The Arachnid Exhibit" with its main representatives the theraphosid spiders. The exhibit is not a complicated affair. Specimens are housed in standard-size glass aquariums ranging from 40 to 122 centimeters long. The exhibits are presented at heights of 90 to 125 centimeters to allow easy viewing by children. Graphics over each exhibit help dispel the myths and misconceptions people hold about theraphosids and arachnids in general.

Theraphosid spiders are not difficult to display and maintain if you understand their biology. Most theraphosids (e.g. Euathlus smithi, the Mexican red knee) live on or in the ground while some like Poecilotheria regalis (Indian ornamental), live in trees. All

theraphosids produce silk but not the traditional web of the modern spiders of the Labidognatha suborder.

Ground dwellers are furnished with organic substrate such as cypress mulch, rocks and live plants. Tree dwellers are provided with limbs and heavy foliage; even with dense greenery, the spiders remain visible on the leaves. An area inside each tank is set up to provide a retreat if needed. Many spiders use the provided retreat but some construct their own.

Humidity is a key element in proper display of theraphosids. Even species that live in desert climate maintain a high humidity inside their burrows. Humidity requirements vary with species, ranging from 65% for desert species to 80% for tropical species.

Theraphosids are well known for their habit of eating their own kind, so specimens are usually housed as individuals. An exception is Avicualria avicualaria, the pink-toed tarantula, which tolerate each other if similar-sized spiders are fed well and given adequate room. Two other exceptions are male/female combinations of Pterinochilus murinus (Mombasa Sunburst Baboon spider) and Psalmopoeus cambridgi (Trinidad Chevron); healthy males are able to keep females at bay until senility sets in when the male is unable to sustain energy levels for mating and defense.

Mechanical timers simulate natural day and night cycles including seasonal fluctuations. In the wild, theraphosid are more active at night but a standard light cycle does not seem to disrupt them.

Breeding

Theraphosid reproduction is tricky even in the wild. Immature males and females are not sexually dimorphic: Until the final maturing molt, males are virtually indistinguishable from females (Gertsch, 1979). Females are often heavier, larger and more powerful than mature males (Foelix, 1982). Males tend to grow faster and mature earlier.

After the maturing molt, the male's abdomen becomes thinner and his legs longer. The femurs of each of the two long front legs now have large femoral hooks. The biggest change is to the two pedipalps at the front of the body. Each palp has a stiff spur called the embolis. The embolis contains the spermatophore used to inseminate the female (Preston-Mafham, 1984).

Spiders are unique in that fertilization is indirect and is referred to as "sperm induction". The theraphosid male does not transfer his sperm directly to his palps from his genital opening at the base of the opsitosoma but deposits sperm from his genital opening onto a sperm web (Foelix, 1982). The male then fills the emboli on his pedipalps from the sperm web. In captivity, you can easily observe a male filling his palps and know that he will soon be ready to mate.

Recently one of the exhibit's newly-molted male Euathlus emilia (Painted tarantula) constructed a typical sperm web. He anchored it to a rock and the base of his tank. The web looked like a lean-to tent made of thick silk. The male crawled underneath, reached over the top of the web with his palps and filled his emboli by tapping on the deposited sperm. He later abandoned the web. (Some species will actually destroy the old sperm web.)

In the wild, the mature and excited male sets out in search of females never returning or even establishing a permanent residence. There is a good reason for his wandering ways: a female spider may live more than 20 years, but the mature male only lives a year at most. He may no longer even take food. His sole purpose is to find and mate with as many females as possible. The male becomes much more aggressive, faster and more difficult to handle. Males should be mated as many times as possible in the shortest time period because some species start getting senile within 8 to 12 weeks and become physically unable to deal with the female.

Captive mating starts with introducing the sperm-charged male into the female's enclosure because the wandering male seeks out the sedentary female. Mating well settled females enhances successful breeding because the presence of female webbing and hairs alerts and excites the male (McKee, 1984). The male approaches the female slowly and cautiously. Although theraphosids have 8 eyes, the eyes are tiny and virtually useless, so mating proceeds by sense of touch. As he approaches, the male vibrates his body rapidly to signal the female of his mating intentions and to let her know he is not a food item. If the female does not react to his initial advances, the male may touch the female while vibrating.

If the female is not receptive, she may either try to flee or she may rapidly attack the male. Be on the alert to perform a quick rescue: in captivity the male has limited escape opportunities (McKee, 1984). Forceps or a long thin piece of wood or plastic can be used to put in front of the female's fangs so you can retrieve the male.

If the female is receptive, she will slowly turn to face the male, raise her forelegs, and partially open her fangs. She may tap the male to signal receptiveness, but female tapping has seldom been seen. The male then places his femoral hooks on the female's partially open fangs, pushes upward and begins rapidly drumming on the female's sternum. If receptive, the female will suddenly relax and almost bend the front half of her body, her prosoma, back over her abdomen. This bending or "swooning" exposes the female's genital slit (epigastric furrow) to allow the male to insert his pedipalps and deposit his sperm. He may insert each pedipalp once or several times to insure proper insemination.

Once the sperm is deposited, the male pushes the female as far away as possible before he releases her fangs and beats a hasty retreat. When you see the male push the female away, be ready to extricate the male as soon as he releases the female's fangs.

Viable males can be returned to their enclosures to build a new sperm web and recharge his pedipalps for additional matings. You can mate the recharged male with different females or again with the same female to insure fertilization.

After successful mating, give the female privacy to produce her egg sack. Half of a clay flower pot works well with Trinidad Chevrons while Mombasa Starbursts use any covering as they do in the wild. Provide an area with deep substrate to allow burrowing. Deep substrate is a strong egg-laying stimulus for some species. Maintain humidity at 70 to 80 percent and temperature at 24° to 27° C. Temperatures of 27° to 32° C may produce spiderlings faster but you must watch the eggs closely to make sure they don't desiccate.

The female produces an egg sack in four weeks to four months depending on the species. The female begins by digging a shallow pit in the substrate or removing all the substrate from the nesting location. She puts down several layers of thick silk matting and deposits her eggs on this mat. She covers the eggs with several layers of silk and rolls silk and eggs into a ball. The female rotates and protects the eggs during incubation. Incubation time varies with species and temperature. Some genera, such as the Grammastola species, incubate less than 60 days. Euathlus species can incubate 3 to 4 months.

While incubating, some species such as the Mexican Red Knee, are easily disturbed and may eat the egg sack. In these species, it is best to remove the egg sack and incubate it artificially. The key to artificial incubation is making sure the egg sack is rotated. Artificial rotation can be done using a plastic cup and lid attached to the rotating dial of a standard 24-hour light timer (McKee, 1986).

Some species such as Mombasa Starburst and Ceratogyrus darlingi (horned baboon spider) produce non-spherical egg sacks which apparently do not require rotation. These African species exhibit excellent parental care and their egg sacks do not need to be artificially incubated.

When the eggs are ready, the female opens the egg sack and continues to protects the spiderlings until after their first molt. The females of some species eat the discarded egg sack. Spiderlings should stay in the incubation chamber with their mother until after the first molt when they may start to eat each other. After the first molt, separate the spiderlings into containers maintained at high humidity. Check the containers daily for adequate humidity to prevent desiccation of the spiderlings. Food, such as pinhead crickets, can be offered after about 7 days.

CONSERVATION

Theraphosid conservation is still a new concept. They play an important role in maintaining a balance in the food chain. Only a few institutions are working on any type of spider conservation program. The Louisville Zoo is working on propagation projects for the Mexican Red Knee and Microhexura montivega the Carolina Moss Mat spider. Carolina Moss Mat spiders are tiny relatives of theraphosids.

The Mexican Red Knee is listed as CITES II and its population status is under investigation. Collection for the pet trade has severely impacted the wild Red Knee

population. Successful captive breeding can decrease and eventually eliminate the demand for wild-caught spiders.

The Carolina Moss Mat spider faces a more uncertain future. Population surveys have shown that this species is rapidly disappearing from its native spruce forests in the Smoky Mountains of North Carolina. Recent studies have shown that their population decline has accelerated and it is feared they may be extinct within a year. The Moss Mats may soon be listed as a federally endangered species. Acid rain and pesticides such as lindane are cited as the main reason for their disappearance (Harp, 1992). The key to the survival of the Moss Mat spiders is finding a way to feed the microscopic young until they reach their full size of 3 to 5 millimeters.

Theraphosid colonies are sensitive to environmental changes and serve as important indicators of environmental problems. Entire theraphosid colonies can disappear if there is a decrease in rainfall (Baerg, 1955). Destruction of habitat is surely effecting species not yet known to science.

Captive breeding is an important part of theraphosid conservation. It not only insures zoo populations, but will also provide animals for restocking decimated wild populations. Now that theraphosids are becoming a "status" pet, captive breeding will reduce the pressure on wild populations.

As the theraphosids go, so go all those creatures connected with them and their environment as well.

REPRESENTATIVE THERAPHOSID SPIDERS

Illustrations by Michael Praether, Louisville Zoolological Gardens Design Artist.

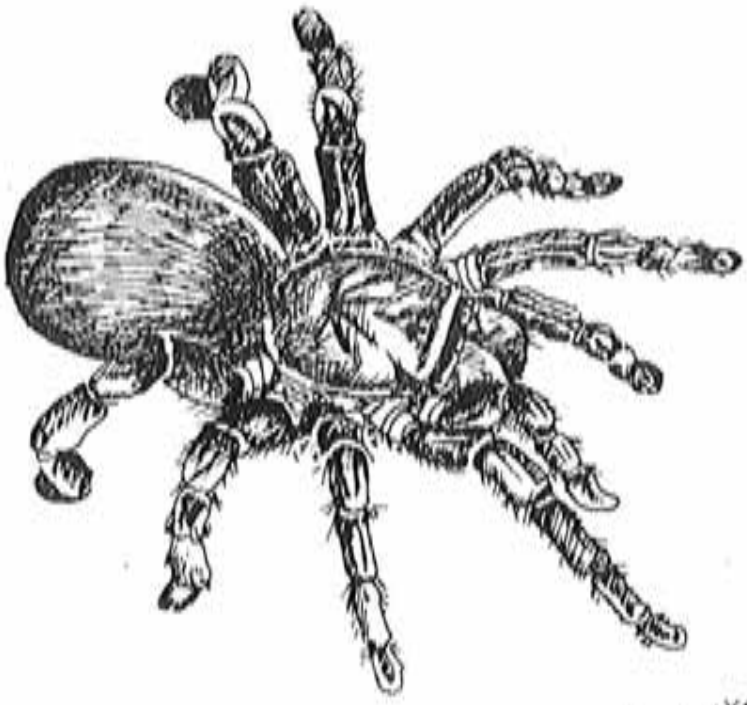

FIG. 1. *Citharischius crawshayi*
King Red Baboon Spider
Leg span to 23 cm.

FIG. 2. *Euathlus smithi*
Red Knee Tarantula
Leg span to 15 cm.

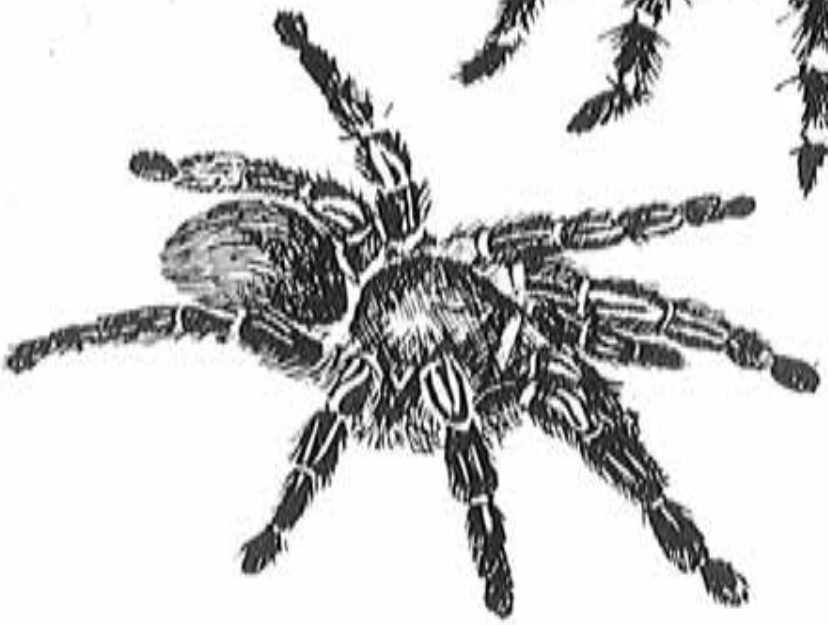

FIG. 3. *Aphonopelma seemani*
Zebra Leg Tarantula
Leg span to 15 cm.

REPRESENTATIVE THERAPHOSID SPIDERS

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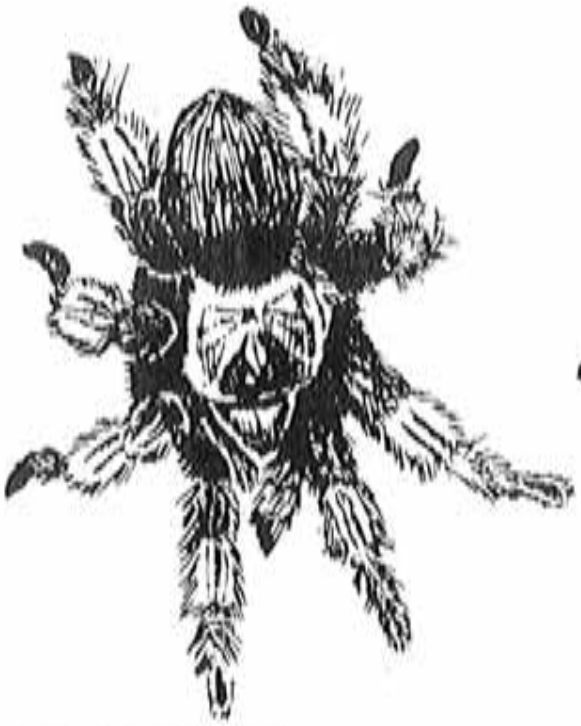

FIG. 4. *Euathlus emilia*
Painted Tarantula
Leg span to 15 cm.

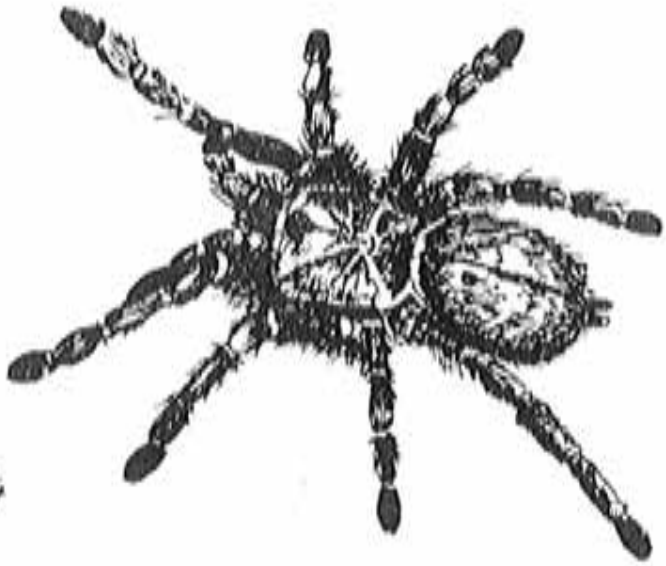

FIG. 5. *Pterinochilus murinus*
Mombasa Starburst
Leg span to 15 cm.

FIG. 6. *Avicularia avicularia*
Pink-Toe Tarantula
Leg span to 13 cm.

FIG. 7. *Psalmopoeus cambridgi*
Trinidad Chevron
Leg span to 18 cm.

BIBLIOGRAPHY

Baerg, William J. The Tarantula. Lawrence: University of Kansas Press, 1958.

Foelix, Ranier F. Biology of Spiders. Cambridge: Harvard University Press, 1982.

Gertsch, Willis J. American Spiders. 2nd ed. New York: Van Nostrand Reinhold, 1979.

Harp, J. A status Survey for the Spruce-Fir Moss Spider Microhexura Montivega. Report of 15 July to the U. S. Fish and Wildlife Service, 1992.

Klass, Peter. Vogelspinnen im Terrarium. Stuttgart: Ulmer, 1989.

McKee, Allan W. Tarantula Observations: A Guide to Breeding, Vol. II. Kenmore: Tarantula Ranch Press, 1984.

-------, Allan W. Tarantula Observations: A Guide to Breeding, Vol III. Kenmore: Tarantula Ranch Press, 1986.

Preston-Mafham, Ron and Ken Preston-Mafham. Spiders of the World. New York: Facts on File Publications, 1984.

Schmitt, Gunter. Vogelspinnen. Minden: Blucher & Philler Verlag, 1989.

Smith, Andrew M. Baboon Spiders Tarantulas of Africa and the Middle East. London: Fitzgerald Publishing, 1988.

-------, Andrew M. The Tarantula Classification and Identification Guide. London: Fitzgerald Publishing, 1990.

LEECHES SUCK: EXHIBITION AND CULTURE

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Abstract. The first and most important consideration in exhibiting animals is the opportunity for interaction between visitors and an interpreter. The leech exhibit at the National Zoological Park serves as an excellent example of this. The second consideration is maintenance and culture of the animal. Whether visitors back up against the wall in total disgust or sit in enthralling curiosity, people notice leeches. The interaction between a person and an animal, with a special focus on the person, is the primary interest of the Department of Invertebrates (DOI). The Invertebrate Exhibit has presented *Nephelopsis obscura* (ribbon leech), *Placobdella ornata* (turtle leech), and *Hirudo medicinalis* (European medicinal leech) in this manner for four years with an emphasis on the ribbon leech. Interest in displaying leeches has grown, along with the commercial use and renewed medical uses of the leech. Other zoos and aquariums share this interest in exhibiting and culturing leeches.

INTRODUCTION

On 7 May 1987 the Invertebrate Exhibit opened to the public. It embodies an effort to combine the elements of a zoo, aquarium, botanical garden, museum, art gallery, and nature center. The exhibit brings together the excitement of hands on exploration and a group of animals, invertebrates, seen in a new way. The exhibit gives visitors a compelling sample of the diversity of invertebrates. For example, microscopic organisms on a slide swim across a 20 inch video screen. A microscope magnifies a water sample taken from a tank in the exhibit. A person situated behind the microscope discusses magnification, rotifers, or the latest world events with inquiring visitors. Further into the main hall, bright red sponges, green fighting anemones, an inquisitive giant pacific octopus, an alien looking cuttlefish, long legged crabs, hurried parasol ants, large orb weaving spiders, and undulating leeches captivate guests in a colorful, active array of displays. An octopus on an ancient Minoan jug, a set of indian hieroglyphic panels, and back lit paintings are interspersed throughout the exhibit. This holistic approach creates an environment that surrounds and involves each visitor.

The exhibit is presented in a dramatic setting rather than a symmetrical row of tanks which draw blank stares and encourage a hurried flow of people looking for breathing room. What does a

person get from racing through an exhibit? They can say, "we did it." Less crowded, dark halls and brightly lit tanks improve the atmosphere. In a side hall, people may sit or rest upon stools as they set their own pace through the exhibit. The leeches reside in one of the many 65 gallon tanks in this horseshoe shaped hall of changing exhibits. This interpretive area runs along side the main hall and is accessed through several archways linking the halls.

EXHIBITION

Exhibition is really interpretation. Exhibition without interpretation limits the picture painted in the viewers mind. DOI considers the entire setting when creating an exhibit of leeches: the mood being created, the story being told, the intrinsic impact of the animal, and the possible interaction with an explainer. Conversation and exclamations increase around the leech tank. It is common to hear, "Oooo! Leeeches! They suck your blood!" Actually many leeches are scavengers or predate on other invertebrates. There is an even greater level of attention and frenzy of activity when leeches are pulled out for first hand inspection. A person best bridges the gap between visitor and animal. In the Invertebrate Exhibit, people are always available to share their enthusiasm and passion for the animals. The staff serves as educator in addition to caretaker. They hold regularly scheduled shifts in the public areas where they interact with visitors. Also, volunteers are afforded time and direct experience working with animals. This serves to increase the authenticity of the visitor's experience. The explainer's information and stories are first hand.

Most exhibitors hope to change or enhance the way people view or think about the presented topic. A visitor's energy can be redirected to an appreciation for, if not a love for, the topic. Many visitors enter the Invertebrate Exhibit with preconceived fears or prejudices about what they will see. Squirming leeches serve as a wonderful surprise for most people. Once a visitor is in an excited frame of mind, he or she can be lured into a new understanding of leeches. The drama of seeing leeches quickly brings to mind personal memories of clinging worms, famous lines such as, "I hate leeches," in the film African Queen or the image of a leech covered boy fainting in the movie Stand By Me. Someone mentions one of these films almost everyday. Once you have a person's attention, or they relate an animal to an experience in their life, they are much more ready to talk and ask questions.

A strong emphasis on education coupled with the direct involvement of the animal staff and volunteers with visitors creates an environment where animals are utilized as teaching tools and the visitor is the honored guest. There is a conscious effort to shift away from merely herding crowds and their screaming voices through an exhibit. A greeter at the front door

of the Invertebrate Exhibit entertains visitors with artifacts and conversation while controlling the number and flow of people into the building. Removing the barriers between animal and visitor, and creating a personalized, sensory experience is central to the exhibit's mission. People see spiders displayed in an open corner. Soil insects can be sifted from a dirt box surrounded by scopes for a more detailed search. One staff person and from one to five volunteers are always available for planned or impromptu demonstrations, questions, and discussions. Considerable time and resources are devoted to interpretation and, more specifically, to the presence of people as explainers.

In the summer of 1987, a study was held to evaluate visitor behavior in the exhibit. One hundred and forty-three visitors were tracked, and notes indicated where they stopped and how much time they spent there. People spent an average of 25 minutes in the exhibit. By contrast, similar studies revealed a 14 minute meantime in the reptile and small mammal exhibits at the National Zoo which are more conventional exhibits with rows and rows of displays (Marcellini, pers. comm). Within the Invertebrate Exhibit, more people stopped at the large, colorful tanks with big specimens such as the lobster and large, colorful corals or anemones. The unattended sites that could be manipulated, such as the soil table and computer insect identification game held the visitor's attention the longest. Visitor interaction with keepers or volunteers significantly increased the stopping and holding power of the display. Graphic panels had very little stopping or holding power. The leech exhibit has had surprising results. This relatively modest and simplistic 65 gallon presentation stopped 78% of the visitors and held them for as long as five minutes. People are amazed to learn that leeches are worms. Many are reassured to learn the they are segmented like earthworms. Once again, they find something they can relate to and then make a connection with the animal. By having people talking to people, a tailor made, case by case method bridges the gap between each person with their own biases or needs, and leeches.

RIBBON LEECHES

Ribbon leeches are very active and therefore highly visible. Observation reveals the tremendous elasticity of their bodies. Longitudinal and concentric circular muscles coordinate the locomotion of the animal. After closer study, people begin to see the more narrow front end, the head, searching its surroundings. The broader basal disc acts as an anchor. The anterior sucker surrounding the mouth, and the posterior sucker enable the leech to lunge in an inchworm fashion. Contortions of the body result in many varied body shapes when hanging on the side glass or swimming through the tank. Swimming is characteristic of Erobdellidae leeches. Dorsoventral muscle strands flatten the body while longitudinal muscles create wave-like undulations to move it forward through the water.

In Minnesota, ribbon leeches have become very popular fish bait. In one year 65 tons of animals were harvested and 3 million dollars of revenue were generated (Collins, 1981). The motion of the leech free swimming or hooked, as well as its grey-brown color attracts walleye, crappie and small mouth bass. Fishermen began to use ribbon leeches in the 1970's. While other leeches were tried they did not attract the fish, because they were not as active. Ribbon leeches will hook a visitors attention in a similar fashion.

The leech tank measures 92.3 cm x 46.2 cm x 62.8 cm, a commercially made 65 gallon tank. The aquarium lid requires modification with silicone sealer and tape to seal off any escape routes. A 30 watt fluorescent light illuminates the system for 14 hours during summer months, May-August, and 12 hours the rest of the year. Deionized water and one gallon of 33 ppt stock salt water creates an aquatic system with two ppt. Undergravel biological filtration, two one-inch air lifts, and biweekly partial water changes keeps water quality in balance. Heavy feedings occasionally require early water changes. Ribbon leeches are not blood suckers, but scavenge and predate larval insects, snails, worms, and other small invertebrates. Chicken liver, shrimp, or fish parts are offered twice a week. Chicken liver generates the strongest feeding response. Water temperature in the interpretive area ranges from 23-25°c. This is believed to be too warm as other researchers maintain 16-18°c. (Holmstrand 1985). A chiller system for the display tank and a cooler location for holding tanks are necessary.

The first leech display contained two acrylic hide boxes, one opaque and the other clear. The clustering under the opaque box demonstrated the photophobic nature of the leech. Photoreceptor cells are abundant, but concentrated in the dorsoanterior region. Similar looking species are differentiated by the pattern of eye spots on the head. A second arrangement, a more naturalistic display, includes sporadically spaced aquatic plants and small rocks. Leeches attach to and hide under plants and rocks without crawling completely out of view.

Crowded conditions result in high mortality rates as leeches tend to cannibalize each other. This is most evident if fed and unfed leeches are kept together. The dying leeches sport numerous white foci 1-2mm in diameter randomly located on the integument. These are clear signs of individuals feeding on each other. In addition they develop a fuzzy fungus, *Aspergillus fumigatus*, that surrounds the exterior muscular walls. The fungus is probably a secondary development. Cause of death is generally related to trauma from being fed upon or natural death after cocoon deposition.

Leeches are hermaphroditic. Two individuals couple for mutual spermatophore implantation (Holmstrand, 1985). At DOI, ribbon leech copulation occurs in late May or June and cocoon production begins within two weeks. This coincides with Collin's (1983) findings. Several days after copulation very exaggerated constrictions around the clitellum indicate the beginning of cocoon production. Narrowing and lengthening of the body moves the gelatinous cocoon across the female gonophore to pick up fertilized eggs. The resulting brown encasements are affixed to submerged plants or other objects. In approximately one month, throughout July and August, an average of seven leeches emerge from each cocoon. Collin's (1984) culture of leeches emerged in 27 days and weighed an average of 3mg.

TURTLE LEECHES

Turtle leeches, which are not very active, are displayed in a five gallon tank because seven leeches concentrated in a smaller area are more visible. The tank is placed within a dry 65 gallon tank with a facade that frames the smaller tank of animals. Turtle leeches tolerate the warmer 25°c temperatures. A sponge filter is used to filter the water; and water is changed every two weeks.

Like other Glossiphoniidae, turtle leeches are poor swimmers and cling to the bottom. However, they lurch into action when the water surface is disturbed. The anterior end reaches up waving about in search of a possible host to feed upon while the basal disc is firmly anchored. If there is not a prospective meal, they huddle tightly to the substrate or roll up in defense.

Turtle leeches do not form cocoons in the same way as Erpobdellidae leeches. In March of 1991 the ventral surface of three of the seven leeches was littered with a large number of bright yellow eggs in membranous capsules. By mid-April miniatures of the adults were visible still clinging to the parent. It was not until later May that the larger young were swimming free of their parent. Fish and worms are thought to be adequate food items. However, the only successful feeding encountered at DOI was a turtle blood feeding.

MEDICINAL LEECHES

Now centuries later, medicinal leeches have again been welcomed back by the medical profession. In the 18th century a sick person was thought to have bad blood. Doctors tried to cure the illness by getting rid of the bad blood. The practice of bloodletting involved attaching medicinal leeches to the patients neck to gorge on their blood. This practice lead to more harm than good and the near extinction of medicinal leeches (Fackelmann, 1991).

Currently a more successful clinical use has been developed in microsurgery. Re-attachment of digits and ears in plastic and reconstructive surgery can result in insufficient venous blood flow. Attaching a leech to the distal end of a finger or ear creates extended blood flow as long as arterial blood flow is good. The leech creates a wound and injects a secretion that contains anticoagulants and anesthetics. The blood continues to flow even after the leech releases. This flow prevents blood from stagnating and starving tissue of oxygen. The vascular pathway can heal and establish normal blood flow due to the time provided by the leech.

The anticoagulant in medicinal leeches, hirudin, has been isolated. As an antithrombotic agent, hirudin continues to be studied and developed as a weapon against blood clotting. A recombinant version of hirudin holds even greater potential because the human immune system tolerates it more than the leech derived hirudin.

The London Zoo has developed a display for medicinal leeches under the consultation of Roy Sawyer of Wales. Sawyer's extensive work with leeches has afforded him a reputation as the world's foremost authority on leeches. The resulting enclosure measures 120cm x 50cm x 60cm, and contains 50 liters of distilled water. Dissolved hirudo-salt, a Biopharim UK product, maintains an osmotic balance in the proportions of 0.5g per liter. The water is chilled to 15-18°c.

Medicinal leeches lay their cocoons out of water in moist soil and among roots. Moist sphagnum moss serves as a good substrate for attachment. From May to July reproduction is observed after a large feeding. Cocoon deposition occurs from 30 to 60 days after reproduction. Between 18-20°c leeches emerge from their cocoon in approximately 35-45 days and at 24-25°c in 28 days. They can weigh 20-60mg and measure from 0.7-3.5cm in length (Sawyer, 1986).

The London Zoo offers fresh human blood in a petri dish every several months. Other researchers spin platlets out of beef blood and place it in sausage skins for feeding. With the first feeding at ten days, followed by feedings at one month, and every two months following, a leech can weight 3 g in ten months. Recently fed leeches are best isolated from the display, and from unfed leeches as they might regurgitate or be fed upon by other leeches (Pierce-Kelly, unpubl).

CONCLUSION

Ribbon leeches have been displayed most effectively at DOI. Undergravel filtration or sponge filters, two week water changes, and deionized water are important elements of a life support system. A consistent temperature between 15-20°c maximizes survival and reproduction. Overcrowding can be prevented by limiting the population to one leech per two gallons, and providing separate tanks for just fed leeches.

Ribbon leeches can be acquired through Carolina Biological Supply of Burlington, NC and Express Bait of Minneapolis, MN. Turtle leeches were caught in the field, Allegany County, Maryland. Medicinal leeches are available through Carolina Biological Supply or Biopharum USA of Charleston, S.C.

The London Zoo, Portland Zoo, and New York Aquarium now exhibit leeches. DOI's future plans are to add UV filtration and reduce the number of leeches in a system. First year leeches will be used instead of animals in their third and final year. Most importantly, people will continue to be available to discuss leeches with our guest.

Leeches clearly captivate an audience. There is an intrinsic fascination that accompanies these animals. The importance of interpretation has been stated as crucial to DOI's success in displaying leeches. However, there is not a decrease in attention given to the animals and their care. Both carry a great deal of importance; but visitors in the past have not received the attention they need or deserve as honored guest. Signs help build a story; but the presence of an explainer creates an opportunity for a memorable or thought provoking moment that can change a visitor's way of looking at leeches. DOI strives to provide this opportunity around each display for every visitor.

REFERENCES

Collins, H.L., Holmstrand, L.L. and Denny, J. 1981. *Nephelopsis obscura*, its nature and nuture. Superior Advisory Notes 12. Minnesota Sea Grant Extension Program. 4pp.

Collins, H.L. and Holmstrand, L.L. 1983. Indicators of sexual maturity in the leech, *Nephelopsis obscura* (Annelida: Hirudinea). *Am. Midl. Nat.*, 112(1):91-94.

Collins, H.L. and Holmstrand, L.L. 1984. Early life history and growth of *Nephelopsis obscura* Verill, 1872 (Pharyngobdellida: Eropobdellae). *J. Freshwat. Ecol.*, 2(6):549-554.

Fackelmann, K.A. 1991 Bloodsuckers reconsidered, leech saliva inspires medical quest. *Science News*. 139(11): 172-173.

Holmstrand, L.L. and Collins, H.L., 1985. Reproductive biology of the Erpobdellid leech *Nephelopis obscura* Verrill, 1972 in Culture. *Freshwat. Invertebr. Biol.*, 4(1):30-34.

Pearce-Kelly, P., Clarke D., Robertson, M. and Andrews, C. 1991. The display, culture and conservation of invertebrates at London Zoo. Unpublished.

Sawyer, R.T. 1986 Leech Biology and Behavior. Clarendon Press, Oxford. II:575.

GIANT PERUVIAN DINOSAUR ANT BIOLOGY, HUSBANDRY AND DISPLAY.

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INTRODUCTION

The giant Peruvian ant *Dinoponera longipes* (Fig 1), popularized as the Dinosaur ant, is an exciting public educational display animal. Since these ants are among the world's largest, about 3 cm long, insectarium visitors easily can observe their social behavior. Colonies also are relatively simple to manage, feed and house.

This paper begins with a *Dinoponera* literature summary. A biological sketch of *D. longipes* is provided based on field work at the Amazon Center for Environmental Education and Research (ACEER) and insectarium captive study (Morgan 1993). I also report husbandry procedures including observation nest construction and insectarium display techniques.

LITERATURE SUMMARY

Taxonomy and Biogeography: The ponerine ant genus *Dinoponera* is restricted to the Neotropics. Kempf (1971, 1972) described seven species and two subspecies native to various savanna, dry forest, and wet forest habitats.

Individual and Colony Reproduction: Haskins and Zahl (1971) described reproduction in *D. grandis*, Overal (1980) reported colony founding by *D. gigantea*, and Dantas de Araujo *et al.* (1990) studied reproduction in *D. quadriceps*. Unlike most ants having morphologically distinct queens, *Dinoponera* reproduces via inseminated workers, called gamergates in a review by Peeters (1993).

New nests are formed by colony splitting and migration. When colonies move to new sites, workers either carry nestmates or closely follow one another in tandem. Hölldobler and Wilson (1990) note that such ants seem to rely relatively little on odor trails for group recruitment to nest sites or food. Instead, chemical markings are used mainly for individual orientation.

Nests and Colony Population: *Dinoponera australis* nests are rather deep below ground, with up to 15 large chambers, each big enough to hold the entire colony, which at most contains 30 large workers (Paiva 1993). *Dinoponera quadriceps* nests contained 40-92 workers and 1-10 gamergates per colony (Dantas de Araujo *et al.* 1990).

Defensive Behavior: Schmidt (1990) reported that *D. grandis* sting pain intensity was comparable to that of the honey bee, and had a 2-10 minute duration.

Captive Husbandry: Paiva (1993) noted laboratory *D. australis* colonies housed in Gypsy nests. Mendez (pers. comm.) maintained a captive *D. gigantea* colony for several years in both hydrostone and natural soil nests; mating was observed in the nest, and the ants' diet included "pinkie" or newborn mice. Morgan (1993) detailed captive care of *D. longipes*.

BIOLOGY OF *DINOPONERA LONGIPES*

Taxonomy: Voucher specimens preliminarily were identified as *D. longipes* Emery. However, slight anatomical differences suggest that the specimens may in fact represent a new undescribed *Dinoponera* species near *longipes* (Cover pers. comm.).

Habitat: ACEER habitat predominantly is primary, non-seasonal, upland rainforest. This region is characterized by mostly large mature trees and open understory. Heavy rainfall occurs throughout the year, though the ground surface is well drained. Temperatures near the forest floor are relatively stable and generally remain near 24° C.

Nest Site: Twenty-two *D. longipes* nests were found along a 810 m survey baseline (Morgan 1993). Nest position seemed independent of the area's variable topography. Nests were placed around, between or under plant bases or roots, but their location seemed unrelated to any particular plant species. Most nests seemed heavily shaded by overhead vegetation, though at least two nest mounds received dappled sunlight at mid-day. Most nests also were found in sparse understory vegetation and lightly littered ground. Overall, the nest site pattern suggested that some degree of spacing (avg.=35 m) was maintained between nests. This, in turn, suggests that intraspecific factors such as competition between colonies may affect nest position.

Nest Architecture: The majority of nests exhibited slight to well-developed earthen mounds. These apparently were formed from an accumulation of excavated, rain-compacted soil, and seemed to be most noticeable when surrounding terrain was fairly level, or when vegetation provided structural support and protection from rain erosion.

The number of nest surface openings (tunnel entrances) ranged from 1-30, and averaged about 11 openings per nest. These were 2-3 cm diameter holes penetrating the mound or ground surface, and frequently were surrounded by thinly spread piles of newly excavated clay soil particles. Often some openings were partially hidden under a light covering of forest litter.

Two nests were excavated; one of these appeared relatively large while the other was small. The large nest had 21 surface openings roughly scattered over the ground throughout a 2.1 x 0.6 m area. Most nest opening tunnels gently angled downward, and broadly interconnected with nine subterranean chambers. These were horizontally oriented, roughly linearly aligned, and all shallowly positioned, generally about 30 cm from the surface.

Nest chambers were round or oval; most were 10-15 cm wide, but two were about 25 cm wide at their longest axis. The chambers tended to be slightly domed and about 3-4 cm high from floor to ceiling. Some chamber floors were lightly covered with a layer of what appeared to be dry vegetation bits. Several spot temperature measurements made at the nest surface and within nest chambers were similar. These generally ranged closely to 24°C both during the day and at night.

The small nest had a single surface opening surrounded by freshly excavated soil. The opening accessed a 13 cm deep vertical tunnel leading to a single subterranean chamber. The chamber was oval, horizontally positioned, and measured about 10 x 13 cm wide, and about 3 cm high from floor to ceiling.

Nest Population: The large nest contained 120 females (all morphological workers, hence no distinct queen), 5 winged males, 57 cocooned pupae, six large larvae, over 30 small to medium-sized larvae, and 25 eggs. The male presence suggests that this colony was reproductively mature. The small nest held 7 morphological worker females and 11 eggs. The absence of brood other than eggs suggests that this nest contained an incipient or very young colony.

Foraging Behavior: In the field, females appeared to forage alone, remain on the ground, be more active at night, and readily exhibited observer avoidance behavior. Over 30 observations were

made of ants away from their nests, presumably foraging. All were solitary, were crawling on the ground surface, and were never seen on plant bases or elevated vegetation. Foragers seemed to be principally nocturnal, since most were observed at night, but a few were active at day, both mornings and afternoons. During a "friaje" or brief cold front, night air temperatures became atypically cool (approximately 19°C), and foragers were conspicuously absent. Foragers also seemed highly visual and timid; in response to nearby observer movement, they usually darted under leaf litter and temporarily hid, or paused in position and crouched.

In captivity, the ants behave as predator-scavengers and appear to be exclusively carnivorous on a wide variety of live, injured, or recently dead animals. Small live prey is bitten with the mandibles and carried whole to the nest. Strongly struggling prey may be grappled with and stung.

Food items too large to carry are first cut into pieces. The mandibles are serrated and seem adapted for cutting in two very different ways. Against large items, they are pushed open and used like a curved saw blade with back and forth head movements. Against narrow objects, when mandibles are mostly closed, a ratchet or leverage mechanism seems to be used, evidenced by audible clicking noises in conjunction with head lurches.

Food includes both invertebrates (mostly insects) and various vertebrates. Invertebrates eaten included Dictyoptera (roaches, mantids), Phasmatoptera (stick insects), Orthoptera (crickets, grasshoppers, katydids), Isoptera (giant termites), Neuroptera (dobsonflies), Hemiptera (back swimmers, giant water bugs), Homoptera (cicadas), Coleoptera (mealworms), Diptera (flesh flies), Lepidoptera (waxworms), Hymenoptera (male *Paraponera*, honey bees), Arachnida (orb spiders), Chilopoda (centipedes), and Annelida (earthworms).

Vertebrates eaten include mammals (pinkie mice), birds (a week-old domestic chick), amphibians (wood frogs), fish (a fresh water minnow), and reptiles (an anole lizard). One pinkie was fed live, demonstrating that the ants could capture and kill such prey, but most large food items were first incapacitated. Pinkies, frogs, and fish were dismembered and eaten in entirety. The chick's eye was eaten *in situ*, while its foot and lower leg, both leathery and bony tissues, were removed, macerated and eventually consumed over a two day period. The anole's leg was removed, nibbled, and abandoned.

Nesting behavior: Colonies appear to be readily mobile. When initially released into captive housing, ants quickly explore newly found openings and, within minutes, carry their brood inside observation nests. Eggs most often are held and moved in small clumps, while larvae and pupae are transported individually.

Similarly, if nest chambers are opened or otherwise disrupted, the ants carry their brood to secure areas. Observation nest chamber temperatures generally remained close to 24°C, but when one chamber was slowly warmed, the colony began to move out as the temperature approached 27°C.

Once settled in a nest, workers often partially cover and hide, or sometimes reduce or temporarily block nest openings with mulch. This behavior perhaps helps camouflage nest openings, or makes them more defensible.

Fecal droplets are used to line nest chamber walls, and to a lesser degree, crevices and spaces outside observation nest boxes, and possibly contain chemical cues for forager orientation or nest recognition. The droplets are applied as a dark gray liquid but soon dry and blacken.

The brood tends to be segregated according to stage and size (Fig 1). Eggs are narrowly elongate (about 1 x 3 mm), and are grouped on chamber floors or held with the mandibles, either singly or in small clusters. The eggs readily adhere to one another, apparently facilitating their movement. Several observations suggest that small numbers of eggs normally are present in nests, even when developing larvae and pupae are not.

Hatchling larvae are tiny and coiled, while older larvae are grublike and exhibit long flexible necks. Larvae obviously feed while being held or carried between the females' mandibles; the larvae are characteristically positioned ventral side up such that they have easy access to the ants' brush-like mouthparts. Older larvae grouped on nest chamber floors also feed on items placed on or near them (Fig 1).

When fully grown and ready to pupate, larvae are lightly covered with mulch, providing a supporting framework for cocoon silk spinning. Cocoons are brown and oblong (Fig 1); those producing males generally appeared slightly smaller than those for females. Females seem to be long lived since several wildcaught females survived for about two years. However, captive eclosing males lived no longer than a few weeks.

Two repeatedly observed behavioral interactions between nestmates are probably dominance related, and may be used to control reproduction and social organization (see Peeters 1993). The first behavior, called antennal drumming, is exhibited in the nest between meeting or facing ants. The antennae of one are drummed rapidly for about 1 second against a nestmate's head region; this frequently is followed by an immediate, reciprocating response. The other behavioral interaction, called biting and tucking, mostly was directed at newly eclosed females. One or several females bite and hold a nestmate's body, effectively immobilizing it, often for many minutes at a time. Usually legs and thorax are held, but sometimes it is the head or abdomen. Biting recipients typically tucked their heads and curled their abdomens underneath and forward in an apparent defensive or fetal-like position, and some ants assumed this posture even when not being bitten.

HUSBANDRY AND DISPLAY

The insectarium rearing room is maintained at 24-27°C, 40-60% relative humidity, and illuminated primarily with fluorescent lights on a 16-hour day cycle.

Laboratory Housing: Stable shelves support observation nest boxes contained within standard sized glass aquaria. Observation nests consist of cast hydrostone (gypsum cement) chambers and tunnels covered with glass; allowing overhead viewing (Fig 1). Except during observation, viewing glass is covered by opaque plastic sheets to darken nest interiors. The hydrostone was tinted with mortar color to provide natural color and to facilitate evaluation of water content, since colored hydrostone appears markedly darker when damp. Moisture lost through evaporation is replaced by occasionally dribbling water onto hydrostone nest surfaces.

Naturalistic nest cavities were cast, using removable clay molding, in about a 5 cm thick hydrostone layer poured into 33 x 27 x 10 cm deep clear plastic specimen boxes. Nest openings were created by drilling each box end with 2 cm diameter holes aligned with internal tunnels. Though heavy, observation nests are modular, and can be easily removed for colony manipulations since the specimen boxes have hand grips.

Various standard size glass aquaria contain either nest boxes or serve as foraging areas. Aquaria are bedded with a layer of cypress bark mulch, used because it is relatively clean and rot-resistant. Before aquarium use, silicon sealant in the inner corners was removed with a razor blade to prevent the ants from finding footholds, although the ants proved to be extremely poor climbers. They often slip when crossing smooth surfaces, can not climb vertical glass, and therefore do not escape aquaria. Tanks are left uncovered to facilitate routine management.

The large wild-caught colony currently is housed in three interconnected aquaria off exhibit for laboratory study. Tanks are connected to one another via two 3.75 cm diam x 15 cm long, clear plastic tubes positioned horizontally; these tubes are used by the ants like tunnels. Two tanks serve as nesting areas and are nearly filled by four observation nest boxes. These contain 2-4 chambers each for a total of 10 nest chambers. Nest boxes are not directly interconnected with one another and colony

members travel openly between them. To help maintain nest humidity, the surrounding cypress bark mulch is kept moist.

Food, Water and Cleaning: In the foraging area tank, a flat brick provides a stable, elevated, mulch-free area for dish placement. A petri dish, regularly supplied with fresh drinking water, is routinely visited by the ants. A wide variety of both invertebrate and small vertebrate prey items are provided from insectarium surplus. Mulch in the foraging area tank is kept dry to retard decomposition of old discarded or uneaten prey items. Ants place colony trash at the foraging tank's far end, facilitating regular large debris removal. Every 2-3 months, the old mulch containing fine debris is replaced with fresh clean mulch. An oily material, possibly related to fecal droplet application, slowly accumulates as a film on the underside of observation nest viewing glass. Periodically, viewing glass is temporarily removed and wiped clean.

Display and Publicity: The small wild-caught colony was established in an observation nest later incorporated into an insectarium public display tank. The exhibit depicts a naturalistic habitat with the ground surface cut away to show the nest interior. Insectarium visitors may see dinosaur ants outside their nest foraging for food, or within their nest consuming prey and caring for brood (Fig 1).

The exhibit tank is fronted by a stout glass covered rail that contains interpretive information, but also offers the public a place to lean while display viewing. A brief text outlines Dinosaur ant habitat and social organization, and emphasizes the timid nature of these rainforest giants. A preserved specimen also is shown for quick reference. Many insectarium guests clearly are astonished by and want to learn more about Dinosaur ants. Visitors commonly are heard exclaiming to one another, "Wow! Take a look at these giant ants!"

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REFERENCES

Cover, S. (pers. comm.): Department of Entomology., MCZ Labs., Harvard University, Cambridge, Massachusetts.

Dantas de Araujo, C.Z., J.P. Lachaud, and D. Fresneau. 1990. Le système reproductif chez une ponérine sans reine: *Dinoponera quadriceps* Santschi. *Behav. Proc.* 22:101-111.

Haskins, C.P. and P.A. Zahl. 1971. The reproductive pattern of *Dinoponera grandis* Roger (Hymenoptera, Ponerinae) with notes on the ethology of the species. *Psyche* 78(1-2):1-11.

Hölldobler, B. and E.O. Wilson. 1990. *The Ants.* Cambridge, MA: Belknap Press of Harvard Univ. Press., 732 pp.

Kemph, W.W. 1971. A preliminary review of the ponerine ant genus *Dinoponera* Roger (Hymenoptera, Formicidae). *Studia Entomologica*, n.s., 14(1-4): 369-394.

Kemph, W.W. 1972. Catálogo abreviado das formigas da Região Neotropical (Hymenoptera: Formicidae). *Studia Entomolgica*, n.s., 15(1-4): 3-344.

Mendez, R. (pers. comm.): Exhibit Consultant, Portal, Arizona.

Morgan, R.C. 1993. Natural History Notes and Husbandry of the Peruvian Giant Ant *Dinoponera longipes* (Hymenoptera: Formicidae). SASI-ITAG *Invertebrates in Captivity Conference Proceedings*, pp. 140-151.

Overal, W.L. 1980. Observations on colony founding and migration of *Dinoponera gigantea*. *Journal Georgia Entomol. Soc.* 15(4):466-469.

Paiva, R.V.S. 1993. Another case of association between ants: *Dinoponera* and *Pheidole*. *Notes From Underground, A Myrmecological Newsletter*, No. 8. (Tobin, J.E, Chavarria, G., and Alpert, G.D., eds.), MCZ Labs., Harvard Univ., Cambridge, Massachusetts.

Peeters, C. 1993. Monogyny and polygyny in ponerine ants with or without queens. In: *Queen Number and Sociality in Insects*, Keller, L. (ed.), pp. 234-261. Oxford University. Press.

Schmidt, J.O. 1990. Hymenopteran Venoms: Striving Toward the Ultimate Defense against Vertebrates. In: *Insect Defenses, Adaptive Mechanisms and Strategies of Prey and Predators* (Evans, D.L. and J.O. Schmidt, eds.), pp. 387-419. State Univ. of New York Press, Albany.

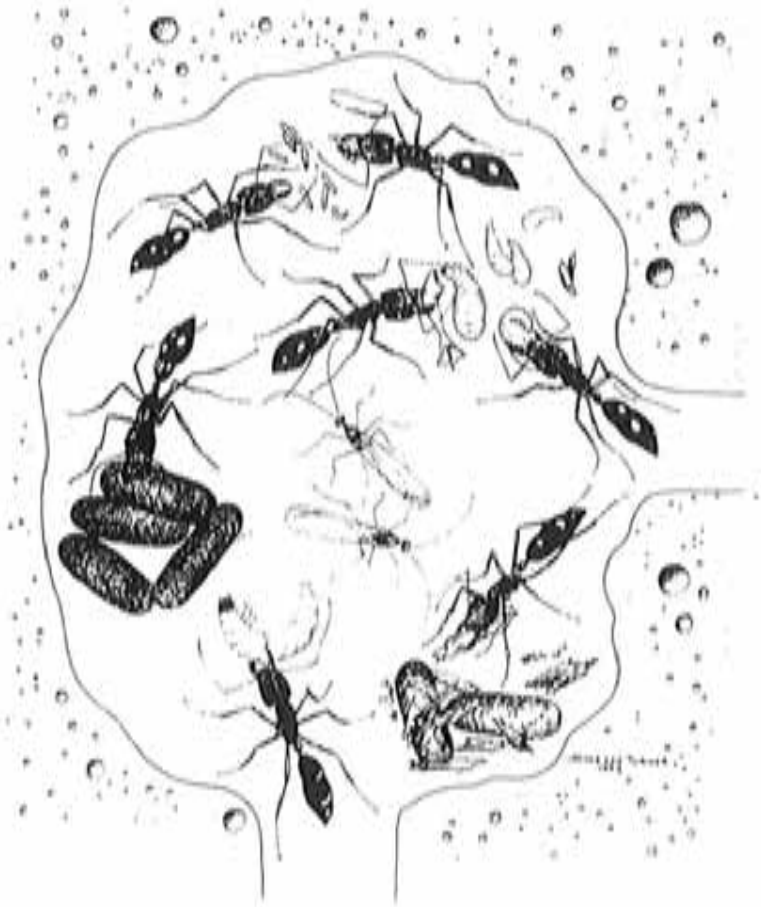

Figure 1: Overhead view of *Dinoponera longipes* observation nest chamber. Clockwise from top: females attending eggs, larva feeding on frog leg, female holding and regurgitating to larva, larvae spinning silk cocoons under debris framework, female entering chamber with mealworm prey, and cocoon pile. Center: winged males. Scale is about life size.

NATURAL HISTORY AND CAPTIVE MANAGEMENT OF LEAF-CUTTING ANTS IN THE GENUS ATTA (HYMENOPTERA:FORMICIDAE)

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The display potential and educational value of *Atta* was recognized as early as 1938, when the Bronx Zoo temporarily maintained a colony for public viewing (Ditmars, 1938). In 1978, the Cincinnati Zoo Insectarium began exhibiting *Atta*, and was then one of few institutions working with the ants. In recent years, there has been a dramatic increase in the number of zoos, museums and related educational organizations keeping *Atta*. Currently this includes at least 21 organizations in North America and Europe, with another five planning to acquire ants in the near future (Table 1). *Atta* colonies are now recognized as important and highly effective educational exhibits (Morgan, 1991).

Considering this interest in *Atta*, there is relatively little information available on its captive husbandry. This paper summarizes the relevant natural history of *Atta*, outlines the basic principles of captive management, and describes a simple system for keeping colonies. Field collection procedures and permit requirements are also noted.

NATURAL HISTORY OF ATTA

Ants in the genus *Atta* harvest plant material used to grow fungus gardens for food. The biology and behavior of *Atta* and other fungus growing ants has been the subject of detailed reviews (Wheeler, 1907; Wilson, 1971; Weber, 1972, 1982; Lofgren and Vander Meer, 1986; Holldobler and Wilson, 1990).

Biogeography: The genus *Atta*, containing 15 species, is native only to the New World and occurs primarily in moist tropical habitats in South and Central America, and Mexico. However, a few species have adapted to harsher climates, like *A. mexicana*, found in the hot deserts of Mexico and southern Arizona, and *A. texana*, occurring exclusively in Texas and Louisiana.

Social organization: *Atta* demonstrates one of the most complex social organizations known for any kind of ant. Its colonies typically consist of a single fertile queen and numerous sterile female workers. The massive queens, over 20 mm long, are specialized for egg production and give rise to worker populations as large as several million individuals. The workers are strongly polymorphic, varying in length from about 2-15 mm, permitting a high degree of task specialization. Generally, the smallest workers tend to remain in the nest and serve as nursemaids and gardeners, medium-sized workers gather plant material and maintain the nest, while the largest workers function as soldiers.

Nest structure and function: Established nests are large, extend several meters or more into the ground, and contain hundreds of fungus gardens. The nest architecture is complex and adapted to control the fungus gardens' environment. Subterranean garden chambers provide high humidity conditions required by the fungus. Central passageways above the gardens vent stale air and heat produced by fungal decomposition, while the nest is ventilated in turn with fresh air drawn in through peripheral tunnels. A lower system of passages drains the chambers to prevent

flooding. In dry periods the ants reduce nest openings, abandon gardens in the upper tiers, and move deeper into moist soil.

Colony reproduction: Mature colonies annually produce winged reproductive forms, or males and virgin queens; mass mating flights often occur at the start of the rainy season. The young queens carry a bit of fungus from their parental nest within their mouthparts. The males die shortly after mating, while the queens shed their wings and quickly excavate shallow burrows. Each queen rears her first brood (eggs, larvae, and pupae) and fungus garden in isolation. Developing workers assume domestic duties and soon begin to forage for plant material. Colony growth is slow at first, then proceeds rapidly, and maturity is attained in about five years.

Fungal substrate: The plant material used by the ants to grow their gardens is called fungal substrate. Since *Atta* is an agricultural pest, research has focused on substrate selection and foraging strategy (see Cherrett, 1968; Rockwood, 1976; Bowers and Porter, 1981; Waller, 1982). *Atta* naturally utilizes a wide variety of fungal substrate, but prefers introduced or agricultural cultivars over native plants, new leaves and flowers over mature leaves, and plant material with a relatively high water content. Plants with tough or distasteful leaves are generally avoided.

Gardening behavior: Fungal substrate is collected and manipulated assemblyline style. A worker straddles a leaf to be cut, measures a portion with her legspan, then rotates and shears the leaf with sharp mandibles. Columns of returning foragers carry small disks of plant material held over their heads. Plant fragments brought into the nest are processed by series of progressively smaller workers. The substrate is broken apart, macerated finely, treated with enzymes, and added to the upper and outer regions of the gardens. The ants fertilize their gardens with fecal droplets, meticulously weed out undesirable species of fungi, and harvest portions used for food. Old and exhausted pieces of the gardens are removed from basal regions and discarded as debris.

Fungus garden structure and function: The gardens look like globular masses of grey, sponge-like material, and are typically 10-25 cm in diameter. The ants' gardening behavior determines the appearance of a garden, which varies along its height. The upper and outer regions are formed into relatively large gray cells with thin granular walls. The base of the garden is compacted from the weight above and consists of smaller, yellow-brown cells. As a garden matures, it becomes peppered with light colored clusters of fungal mycelium. These nutrient-rich growths are the principal diet of the colony (workers also ingest sap from cut leaves). Both the queen and brood are held within the maze of fungal chambers.

Ant-fungus mutualism: The ants and fungus evolved in close association resulting in a mutualistic relationship where both species benefit and are completely interdependent. While the fungus provides the ants with food, the ants' behavior is directed principally toward sheltering the fungus and bringing it substrate, protecting it from competing fungi and other organisms, and helping it reproduce and disperse. Neither the ants nor the fungus can survive for long without the other.

CAPTIVE MANAGEMENT OF ATTA

Laboratory maintenance of research colonies has been detailed by Weber (1972, 1976, 1979, 1982) and summarized by Holldobler and Wilson (1990). Colony development by newly mated, wild-caught queens has been reported most recently by Weber (1972).

Mintzer and Vinson (1985), and Mintzer (1987). Also, the design and care of display colonies has been briefly described by Ditmars (1938) and Morgan (1991). The husbandry requirements of all species are virtually identical.

Standard housing and care: Weber's now conventional method of husbandry employs small containers, called garden chambers, to house the colony and its fungus gardens; clear plastic containers serve as observation nests. The shape and size of the garden chambers are relatively unimportant, as the ants are highly adaptable, and given an optimal environment, will readily grow their fungus in any small protective cavity.

To accommodate an expanding colony, garden chambers are linked together with tunnels made from clear tubing. Tunnels can be almost any length, but an optimal width is 2.5 cm in diameter. Wider passageways may be used by the ants as gardening sites, while much narrower tunnels restrict the free flow of workers carrying substrate.

Plant material is placed in a separate container, called the foraging area, also connected to the observation nest with tubing. Captive colonies are typically maintained on fresh and processed plant materials that are not available to the ants in nature. Foraging area debris, consisting of unused substrate, spent fungus, and dead ants, is periodically removed.

If the garden chambers and foraging area are not otherwise contained, it is crucial that all components be well constructed and fit precisely. The ants will eventually chew open and escape from any small space, and begin to forage outside of their enclosure. Aquarium sealant can be used to temporarily repair small cracks or holes used by escaping ants.

The moisture and temperature requirements of the fungus gardens are much stricter than those of the ants, thus the environment within the garden chambers is critical, while that of areas occupied only by the ants is of secondary significance.

Moisture requirements: The fungus gardens need a constant, highly humid atmosphere, preferably at or near the saturation point (100% RH). Weber placed clean moist sand in containers housing small colonies, which have less ability to regulate moisture levels, but noted that sand was unnecessary for most large colonies with established gardens. A related problem is the accumulation of water within garden chambers from condensation, which is detrimental to the fungus if left unchecked.

The ants, in contrast, tolerate a wide range of humidity levels. They will survive in a dry atmosphere as long as they have access to drinking water. Weber recommended that humidity levels in the foraging area be kept relatively dry (20-50% RH) to prevent the formation of molds. At the Insectarium, foraging areas are kept humid (>60% RH) and regular debris removal eliminates mold problems. In a humid atmosphere, plant material remains fresher and ants do not require drinking water.

Temperature and lighting: Room temperatures of 25-27°C are ideal for fungal growth, while temperatures of 20°C and 30°C are suboptimal for fungus grown in laboratory cultures (Weber, 1972).

The ants function well within a broader range of temperatures. Their metabolism slows at cooler temperatures; if briefly chilled they become torpid, but recover when warmed. Temperatures below freezing or above 35°C are lethal.

Colonies readily adapt to lighting at normal room intensities, and can have additional illumination for viewing provided the garden chambers are not overheated. Observation nests should never be exposed to direct sunlight.

A simple method of housing: At the Insectarium, surplus or reserve colonies are maintained as small populations. Each colony is housed in a single garden chamber held within a glass aquarium. The garden chamber is a clear plastic 19x14x10 cm specimen box (Table 2) with a 2.5 cm diameter hole in one end for the nest entrance.

The garden chambers are modified for moisture control. An important component is Hydrostone (Table 2), a material used like plaster-of-Paris but is more durable when cured. A 2 cm thick layer of Hydrostone is cast into the floor of each garden chamber. Since Hydrostone absorbs water, this base layer acts as a moisture reservoir and also wicks away any excess condensation. The plastic bottom of the garden chamber is drilled with four 6 mm holes, one near each corner. These holes extend part way into the Hydrostone and allow for drainage. While not essential, tan Mortar Color (Table 2) can be added to the Hydrostone during preparation to give it a natural color.

A standard 37.8 liter (10 gal.) aquarium provides a convenient foraging area for a small colony. If desired, larger tanks can be used for more populous colonies housed in several garden chambers. It is not necessary to interconnect garden chambers with tubing as the workers travel freely between boxes. To deter escape, sealant in the inner corners of the aquarium is removed with a razor, and about a 10 cm wide band of 3-in-One Household Oil (Table 2) is smeared on the glass around the upper inside perimeter. *Atta* workers are adept climbers, and the slippery barrier works best if the surface is wiped clean and the oil reapplied at weekly intervals.

Foraging area cleaning and ant population reduction, when needed, are accomplished simultaneously. The garden chamber is transferred to a clean aquarium and the old foraging area, containing debris and excess workers, is placed in the freezer.

Fungus garden management: Proper fungus garden management is the key to successfully keeping *Atta*. Fungus gardens are routinely monitored to distinguish healthy, actively growing gardens from ones that are shrinking or otherwise failing. Management practices are directed towards helping the ants maintain an optimal environment for fungal growth.

Seasonal variables have a profound affect on management strategy. Spring and summer bring high atmospheric humidity and moisture-laden plant material. Consequently, excess moisture typically condenses in the garden chambers and must be eliminated. Winter brings low atmospheric humidity and reduced plant moisture, and garden desiccation must be prevented.

Garden chamber moisture levels are controlled by regulating moisture input and output. Excess moisture is reduced by a combination of adequate drainage, increased ventilation, and dry substrate. Moisture levels are raised by providing moist substrate, adding water to the Hydrostone, and reducing ventilation.

Substrate source and utilization: Fungal substrate is obtained from several sources (Tables 3 & 4), and available choices include numerous plant species in about 40 genera and 25 families. Zoo landscape plants and weeds are used predominantly during the growing season. In the winter, the ants depend on plants that are winter-hardy,

grown in the greenhouse, or acquired as grocery produce. Substrate acceptability was determined by experimentation. Plant material offered to the ants is free of insecticides and fungicides.

The amount of substrate needed depends on colony size. Very young colonies benefit from continually available substrate, but several heavy offerings per week are sufficient for large established colonies. Plant species are routinely varied because the ants typically lose interest in the same material offered on several consecutive days.

GETTING STARTED WITH ATTA

New colonies cannot be started from captive colonies, which are normally maintained at population levels far below those of mature colonies, and are thus unlikely to develop winged reproductives. Further, the mating flights of most ants follow environmental conditions which are nearly impossible to duplicate (Holldobler and Wilson, 1990). Surplus colonies are sometimes obtainable from suppliers, but their availability ultimately depends on some method of field collection.

Field collection: Newly mated queens are easy to collect as they wander over the ground or excavate burrows. The principle difficulty is the need to be in the field following the mating flights, which occur infrequently and are not easy to predict. Colony excavation is the most consistently reliable means of acquiring livestock.

Collecting a mature colony, deeply entrenched and well-defended, is a formidable task. However, colonies less than are year old are easily collected and can often be found near mature colonies. Young nests of some species can be identified by their characteristic turret-like opening, which later disappears (Weber, 1972), and relatively small foraging processions.

The single garden, containing the queen, attendant workers and brood, can be exposed near the surface and gently scooped into a small container; it is unnecessary to collect foraging workers. The gardens are fragile and should be handled carefully during collection and transit, although workers quickly repair damaged gardens.

Importation permits and pest potential: Leaf-cutting ants are agricultural pests and should be treated responsibly. U.S. Department of Agriculture - Animal & Plant Health Inspection Service (USDA-APHIS) Plant Protection Quarantine (PPQ) Form 526 must be approved by both your state entomologist and federal officials before non-native species can be obtained from a supplier or imported into the United States; other countries may have similar regulations.

The pest potential of a captive colony is negligible since the queen is the only reproductive individual, and given the opportunity to escape, is unlikely to abandon the security of the gardens. It is also improbable that tropical species could establish in temperate regions.

Acknowledgments

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REFERENCES:

BOWERS, M.A. and PORTER, S.D. (1981): Effect of foraging distance on water content of substrates harvested by *Atta columbica* (Guerin). Ecology 62:273-275.

CHERRETT, J.M. (1968): The foraging behaviour of *Atta cephalotes* L. (Hymenoptera, Formicidae). I. Foraging patterns and plant species attacked in tropical rain forest. J. Anim. Ecol. 37:387-403.

HOLLDOBLER, B. & WILSON, E.O. (1990): The ants. Belknapp Press of Harvard University Press, Cambridge. 732 pp.

LOFGREN, C.S. & VANDER MEER, R.L. (eds) (1986): Fire ants and leaf-cutting ants, biology and management. Westview Press, Boulder and London. 435 pp.

MINTZER, A.C. (1987): Primary polygyny in the ant *Atta texana*: number and weight of females and colony foundation success in the laboratory. Insectes Sociaux 34(2):108-117.

MINTZER, A.C. and VINSON S.B. (1985): Cooperative colony foundation by females of the leafcutting ant *Atta texana* in the laboratory. J. New York Entomol. Soc. 93(3):1047-1051.

MORGAN, R.C. (1991): Leaf-cutting ants on parade. Backyard Bugwatching No. 13.

ROCKWOOD, L.L. (1976): Plant selection and foraging patterns in two species of leaf-cutting ants (*Atta*). Ecology 57:48-61.

WALLER, D.A. (1982): Leaf-cutting ants and avoided plants: defences against *Atta texana* attack. Oecologia 52:400-403.

WEBER, N.A. (1972): Gardening ants, the Attines. Memoirs of the American Philosophical Society, Philadelphia, Vol. 92, 146 pp.

WEBER, N.A. (1976): A ten-year laboratory colony of *Atta cephalotes*. Ann. Ent. Soc. Amer. 69(5):825-829.

WEBER, N.A. (1979): Fungus-culturing by ants. In: Insect-fungus symbiosis, mutualism and commensalism. Batra, L.R. (ed). Halsted Press, New York.

WEBER, N.A. (1982): Fungus ants. In Social insects, Vol. IV, H.R. Hermann (ed.). Academic Press, New York and London. pp:255-363.

WHEELER, W.M. (1907): The fungus growing ants of North America. Bulletin of the American Museum of Natural History 23:669-807. Reprinted in 1973 by Dover Publications Inc., New York. 136+ pp.

WILSON, E.O. (1971): The insect societies. Belknapp Press of Harvard University Press, Cambridge, Mass. 548 pp.

Table 1. Known zoos and museums keeping Atta; most organizations maintain display colonies. University research colonies are not listed.

Status Key:	C = Currently keeping Atta P = Plan to acquire Atta in the near future T = Temporary exhibit or no longer keeping Atta ? = Unknown

Country	State or Province	City	Organization	*Atta* species	Status
Belgium		Brussels	Belgian Institute of Natural History	cephalotes	P
Canada	Ontario	Toronto	Metropolitan Toronto Zoo	cephalotes	C
	Quebec	Quebec	Museum of Civilization	cephalotes	T
	Ontario	Sudbury	Science North	cephalotes	T
Germany		Koln	Koln Zoo	cephalotes	C
		Heidelburg	Heidelburg Museum	?	?
		Frankfurt	Frankfurt Zoo	cephalotes	T
				mexicana	P
		Berlin	Berlin Zoo	cephalotes	T
				sexdens	T
		Stuttgart	Stuttgart Zoo	cephalotes	C
Mexico		Guadalajara	Guadalajara Zoo	?	P
Netherlands		Amsterdam	Artis Zoo	cephalotes	C
		Emmen	Emmen Zoo	cephalotes	C
				sexdens	C
U.K., England		London	The Royal Botanic Gardens (Kew)	cephalotes	C
			Zoological Society of London	cephalotes	C
		Windsor	Windsor Safari Park	cephalotes	T
		Bristol	Bristol Zoo	sexdens	T
		Paignton	Paignton Zoo	cephalotes	T
U.K., Scotland		Edinburgh	Edinburgh Butterfly & Insect World	mexicana	C
		Glasgow	Glasgow Zoo	mexicana	T
United States	Alabama	Birmingham	Birmingham Zoo	cephalotes	C
	Arizona	Phoenix	The Phoenix Zoo	mexicana	P
	Arizona	Tucson	Arizona-Sonora Desert Museum	mexicana	C
	Arizona	Tucson	Soronan Arthropod Studies Inc.	mexicana	C
	D.C.	Washington	National Zoological Park	cephalotes	C
	D.C.	Washington	Smithsonian Insect Zoo	texana	C
	Florida	St. Petersburg	Great Explorations	cephalotes	T
	Massachusetts	Boston	Museum of Science	cephalotes	C
	Mississippi	Jackson	Jackson Zoological Park	mexicana	P
	Missouri	St. Louis	St. Louis Zoological Park	mexicana	C
	Nebraska	Omaha	Henry Doorley Zoo	mexicana	C
				cephalotes	C
	New York	Bronx	New York Zoological Society	cephalotes	T
	New York	New York	Central Park Zoo	cephalotes	C
	Ohio	Cincinnati	Cincinnati Zoo & Botanical Garden	columbica	T
				cephalotes	C
	Ohio	Cleveland	Cleveland Metroparks Zoo	?	P
	Oklahoma	Tulsa	Tulsa Zoological Park	cephalotes	C
	Vermont	Norwich	Montshire Museum of Science	cephalotes	C
	Washington	Seattle	Woodland Park Zoo	cephalotes	C

Table 2. Products mentioned in the text.

Hydrostone:	gypsum cement, manufactured by United States Gypsum, Chicago, IL 60606
Mortar Color:	concentrated dye, manufactured by Solomon Grind-Chem Service Inc., Springfield, IL 62705
Specimen boxes:	clear plastic containers (about 19x14x10 cm) with friction fitting lids, manufactured by Tri State Molded Plastics, Inc., Dixon, KY 42409
3-in-One Household Oil:	light lubricant, manufactured by Boyle-Midway Inc., New York, NY 10017

Table 3. Cincinnati Zoo landscape and greenhouse plants used by Atta.

Comments Key: WH = Winter hardy; GR = Greenhouse grown

Family	Genus species:	Common name	Comments
Aceraceae	*Acer negundo*	Boxelder	
Anacardiaceae	Rhus species	Sumac	
Aquilifoliaceae	*Ilex opaca*	American Holly	WH
	Mahonia aquifolium	Grape-Holly	WH
Araliaceae	*Hedera helix*	English Ivy	WH
Bignoniaceae	*Campsis radicans*	Trumpetvine	
	Catalpa speciosa	Northern Catalpa	
Buxaceae	*Pachysandra terminalis*	Japanese Pachysandra	WH
Caprifoliaceae	*Lonicera japonica*	Japanese Honeysuckle	WH
	Viburnum rhytidophylloides	Leatherleaf Viburnum	WH
Celanstraceae	*Euonymous kiautchovicus*	Manhattan Euonymous	WH
Chenopodiaceae	*Chenopodium album*	Lamb's-quarters	
Compositae	*Taraxacum officinale*	Dandelion	
Ericaceae	*Rhododendron* species	Rhododendron	
Euphorbiaceae	*Codiaeum variegatum*	Croton	GR
Leguminoseae	*Coronillia varia*	Crown Vetch	
	Gleditsia triacanthos	Honeylocust	
Malvaceae	*Hibiscus rosa-sinensis*	Chinese Hibiscus	GR
Musaceae	*Musa* hybrids	Banana (leaves)	GR
Nyctaginaceae	*Bougainvillea x buttuana*	Bougainvillea	GR
Oleaceae	*Forsythia x intermedia* / hybrids	Forsythia (flowers)	
	Ligustrum obtusifolium	Border Privet	
Polygonaeceae	*Polygonum* species	Smartweed	
Rosaceae	*Crataegus* species	Hawthorn	
	Rubus species	Brambles	
	Malus species / hybrids	Crabapple	
	Rosa species / hybrids	Rose	
	Prunus cerasifera	Purpleleaf Plum	
	Pyracantha angustifolia	Firethorn	WH
Rutaceae	*Citrus x paradisi*	Grapefruit (leaves)	GR
Salicaceae	*Populus deltoides*	Cottonwood	
	Salix babylonica	Weeping Willow	
Simaroubaceae	*Ailanthus altissima*	Tree-of-Heaven	
Tiliaceae	*Tilia cordata*	Littleleaf Linden	
Ulmaceae	*Celtis occidentalis*	Hackberry	
Vitaceae	*Parthenocissus quinquefolia*	Virginia Creeper	
	Vitis labrusca	Foxgrape	

Table 4. Grocery produce used by Atta at the Cincinnati Zoo Insectarium.

Leaves:	Fruit:	Grain:
Lettuce	Apple	Oatmeal
Kale	Banana	Rice (dry & cooked)
	Grapes / Raisins	
	Orange	

NATURAL HISTORY, CAPTIVE MANAGEMENT AND DISPLAY OF THE SUNBURST DIVING BEETLE

Thermonectus marmoratus (Coleoptera: Dytiscidae).

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Introduction: Predaceous diving beetles (family Dytiscidae) comprise a large and diverse, globally distributed insect group adapted to live in freshwater habitats. Dytiscids are common and easy to collect in many localities, and are simple to maintain in captivity. The beetles make outstanding live educational displays because they are long-lived, frequently active, and demonstrate fascinating structural and behavioral adaptations for moving, feeding, breathing and reproducing in water (Morgan & Thoms, 1982).

While most Dytiscids are darkly colored or drably patterned, *Thermonectus marmoratus* is noteworthy: its dorsal surface is shiny black and conspicuously marked with about two dozen, variously sized, bright yellow spots (**Figure 1**; for photos see Milne & Milne, 1980; Arnett & Jacques, 1981; Arnett, 1985; Morgan, 1992). *Thermonectus marmoratus* is an eye-catching and entertaining exhibit animal, easily captive-reared, and is an effective teaching tool. All stages of its specialized life cycle can be manipulated and observed in close detail permitting demonstration of insect development and metamorphosis, aquatic insect behavior and ecology, and predator-prey relationships. Further, this species appears to be an exceptional example of an aquatic beetle that is both aposematic and gregarious (Morgan, 1992), and may prove to be a useful model for testing current theories pertaining to the evolution of these traits (for reviews see Evans & Schmidt, 1990).

Various field guides ambiguously call *T. marmoratus* the yellow-spotted water beetle (Powell & Hogue, 1979), the marbled water beetle (Milne & Milne, 1980), or the spotted water beetle (Arnett & Jacques, 1981). The name "sunburst diving beetle" was recently proposed (Morgan, 1992) to popularize this species and is used here. This paper reviews sunburst diving beetle natural history and describes captive management and display techniques used at the Insectarium.

Methods & Materials: Field observations were made mid-summer 1989-92 during week-long expeditions to southern Arizona. A group of nine (3 male: 6 female) beetles was collected from a small pool in 1991 and served as founding livestock. These were supplemented with seven (3 male: 4 female) beetles collected early November 1991 by an Arizona naturalist. Beetles' body lengths were measured to the nearest 0.5 mm with a hand rule. Live material was held and observed in both indoor and outdoor rearing containers. Indoor rearing utilized standard-sized aquaria exposed to artificial lighting on a 16-hour day cycle and room temperatures maintained at 24-27°C. Outdoor rearing containers consisted of large plastic garbage cans placed in direct sunlight, nearly filled with water, inoculated with various organic materials to stimulate microbial decomposition, and naturally colonized by immature mosquitoes and other aquatic fly larvae. Semi-aquatic tanks containing emergent gravel littered with sphagnum moss, cork bark or other shore debris provided terrestrial areas for oviposition and pupation. The entire adult population was later consolidated in the public exhibit described below (see Insectarium Display Tank).

NATURAL HISTORY

Dytiscid biology has been the subject of several detailed reviews (Leech & Chandler, 1956; Pennak, 1978; White et al., 1984). A popularized account of sunburst diving beetle biology and behavior is available (Morgan, 1992). Scanning electron micrographs of *T. marmoratus* show details of head and sensory organs and specialized appendages (Salvatore & Morgan, 1992).

Biogeography: The genus *Thermonectus* is restricted to the New World and contains about a dozen described species. *Thermonectus marmoratus* occurs in extreme southern California and Arizona (Powell & Hodge, 1979; Arnett & Jacques, 1981), New Mexico (Tomberlin, pers. comm.), and southwestern Texas (Roche, pers. comm.). University of Arizona preserved specimens have been collected in the Mexican states of Jalisco, Hidalgo and as far south as Oaxaca near Guatemala. Therefore, *T. marmoratus* ranges from about 33° N. latitude southward to at least 18° N. latitude.

In southern Arizona, populations occur in mountain valleys and canyons, and thus are separated by vast stretches of arid lowlands. Beetles typically occur in rocky creeks and streams at moderate elevations (roughly 900-1200 m) where relatively permanent moisture supports adjacent deciduous woodlands. Field observations made during late dry season when waterflow is reduced indicate that the beetles tend to be gregarious. Often several and sometimes dozens of beetles were found in quiet pools or narrow stretches of slowly flowing water, while apparently absent from similar adjacent sites. Palting (pers. comm.) once observed about 50 beetles active in a small pool at night. The beetles are more difficult to find after the start of the rainy season and concomitant increase in waterflow, especially if their waterways have been scoured by flooding.

External Morphology: Dytiscids are smooth, oval and elliptical in profile, and thus effectively streamlined. Membranous hind (flying) wings are normally folded and hidden under the hard wing covers. The rear (swimming) legs are stout, flattened like paddles and fringed with hair. Sunburst diving beetles' front and middle legs can be mostly retracted into a ventral groove between the head and thorax; the rear legs each bear a pair of large tibial spines. The species is sexually dimorphic: males have specialized suction disks on their front legs (like many Dytiscids) and also tend to be smaller than females. Wildcaught males averaged 13.1 mm in overall body length (n=6, R=13-13.5 mm) compared to females, which averaged 13.9 mm in length (n=10, R=13-14.5 mm). Captive raised males averaged 12.2 mm in length (n=28, R=11-12.5 mm) compared to females, which averaged 12.9 mm in length (n=32, R=12-13.5). Thus, captive raised beetles of both sexes tended to be about 1 mm shorter than wildcaught beetles.

Sensory Organs: Sunburst diving beetles possess large, finely faceted compound eyes suggesting well-developed vision. The tips of the antennae apparently bear basiconic and coeloconic pegs which would function to detect waterborne chemicals. The tips of the maxillary palps seem to bear a cluster of sensory pits, another form of contact chemoreceptor. Maxillary palp tips also exhibit a ring of whip-like flagella, possibly mechanoreceptors for providing information concerning the beetles' movements and orientation within the waterflow.

Feeding Behavior: Captive sunburst diving beetles behave as generalized predator-scavengers and readily feed on a wide variety of live and freshly dead organisms. Natural prey probably include most small soft-bodied aquatic invertebrates. A group of nine recently captured beetles held in a community tank were observed to consume several hundred Corixid (water boatmen) eggs overnight and eliminated further Corixid oviposition. Beetles possessing small food items typically flee from competing beetles, but will feed *en masse* on larger food items like an adult cricket, creating an engrossing visual display. The beetles are adept at capturing mosquito larvae and pupae and seem to prefer these over other prey (pers. obs.). Other *Thermonectus* species are also believed to be important natural predators of immature mosquitoes (Miura & Takahashi, 1974; Apgar et al., 1985).

Locomotion: Propelled by strong hind legs stroking in unison, Dytiscids are among the fastest and most agile swimmers of all aquatic insects. The hair fringing *T. marmoratus'* swimming legs apparently folds during the frontstroke to reduce drag, and then spreads on the backstroke to maximize surface area and thrust (pers. obs.). The beetles have a positive buoyancy, probably due to their self-contained air reserve (see Respiration below), and when not clinging or swimming float upward. Extreme modification of the hind legs impedes terrestrial locomotion, causing the beetles to flounder on smooth surfaces; however, the long tibial spines on the rear legs are used like tree-climbing spikes helping the beetles crawl from water onto rough surfaces (pers. obs.). Beetles typically leave the water to oviposit or when preparing to fly. Flight probably occurs either during dispersal or escape from deteriorating habitat. *Thermonectus marmoratus* commonly flies to blacklight lures placed near their

typical haunts (Palting, pers. comm.). Long-range flight seems infrequent; more than ten years of extensive blacklight trapping in several arid lowland regions have yielded only one specimen (Prchal; Palting, pers. comm.).

Respiration: Like terrestrial insects, Dytiscids respire through spiracles, breathing air either directly at the surface or from a reservoir held under their wing covers when submerged. To replenish their air supply, the beetles float bottoms-up with their abdominal tips piercing the surface film. Once submerged they have a limited ability to extend their bottom time by extruding a portion of their air supply, held on the abdominal tip as a small silvery bubble (**Figure 1**). The exposed bubble, or physical gill, extracts dissolved oxygen from water by diffusion. The physical gill's efficacy improves at lower temperatures, allowing Dytiscids to remain submerged for significantly longer periods in cold water.

Reproduction and life cycle: Dytiscids undergo complete metamorphosis involving four distinct life stages: eggs, larvae, pupae, and adult beetles (**Figure 2**). Captive *T. marmoratus* reproduce opportunistically given optimal conditions of abundant food and warmth. Mating and egg production continue year round while development from oviposition to adult can be completed in as little as 28 days. To mate, males use their tarsal suction disks to grasp the females piggyback from above; mounting and copulation last anywhere from a few seconds to a minute. Coupled pairs may lodge in aquatic vegetation but often continue swimming. Females crawl from the water at night to oviposit nearby.

Eggs: Eggs are hidden just above the waterline in moist sites like crevices between rocks, under bark or debris, or buried in loose gravel. Individual eggs are oblong (about 1x3 mm), adhere to one another, and are deposited in groups or clutches. One group of 62 eggs apparently resulted from several females using the same oviposition site. Excluding this group, clutch size averaged about 19 eggs (n=11, R=5-30 eggs). During a 13 week period, at least 18 clutches were produced by six females for an average of three clutches per female, or about one clutch per female per month. Egg production probably continues throughout adult life under optimal conditions. Newly laid eggs are pearly white, but larval eyespots and body markings are visible from the third day through hatching (for photo see Morgan, 1992). Egg clutches had an average hatch time of about 6 days (n=5 clutches, R=4-8 days). The tiny hatchlings (about 7 mm long) quickly worm their way back into the water, probably to avoid desiccation and shoreline predators. One recently laid clutch was eaten by a common isopod (pillbug) accidentally placed in the tank with a piece of bark.

Larvae: Dytiscid larvae also rise to the surface to breathe through a large specialized terminal spiracle, but do not carry an air reservoir. They are called water tigers because they aggressively prey upon a variety of small aquatic animals, including one another. Captive *T. marmoratus* larvae have been observed feeding on immature Belostomatids (giant water bugs), Notonectids (backswimmers), Gerrids (water striders), and Culicids (mosquitoes), all occurring in the beetles' natural habitat (pers. obs.). Larvae often hunt at or near the surface, and like the adult beetles show preference for immature mosquitoes.

Larvae have large dark eyespots and seem to track their prey visually. Slowly dog-paddling, they glide toward intended victims then spurt forward to strike. Their heads are flattened and bear channeled, sickle-like pincers used to pierce their prey and drain its body fluid. Their elongated bodies are soft and membranous and swell with consumed food (for photo see Morgan, 1992). Pale colored (teneral) larvae and shed membranous skins in the water indicate molting. There are three larval instars best recognized by head capsule size (about 1.0, 1.5, & 2.2 mm wide, respectively). Larval development can be rapid, often reaching the third stage in less than a week. Fully grown, third-instar larvae (about 25 mm long) stop feeding for at least a day and then crawl from the water to pupate nearby.

Pupae: Captive *T. marmoratus* larvae readily adapt to differing pupation sites. Those offered moist sphagnum moss burrow inward and rearrange bits of material, but pupate without building distinct puparia or cocoons. Larvae given moist sand and debris construct fragile, spherical shells (about 17-20 mm diam.) usually under and often adhering to an overlying object, like a piece of bark. Once secure, the larvae shorten and thicken to become swollen pre-pupae, and remain in this phase for a couple of days. Pre-pupae eventually shed their larval skins, transforming into stubby, cream-colored pupae. Large dark eyespots, embryonic wings, legs, and other adult

structures are visible on the pupae (for photo see Morgan, 1992). Pupae are helpless and immobile, other than squirming within their cells, and drown if their chambers flood. Pupal stage duration averages about 6 days (n=5, R=5-8 days).

Adults: Newly eclosed adult sunburst diving beetles are pale and soft. They delay leaving their pupal cells for a few days until their exoskeletons fully color and harden, and then enter the water. Young adult beetles hunt prey almost immediately and begin to mate a few weeks later. Adults may be active both diurnally and nocturnally. Sixty captive raised beetles consisted of 28 males and 32 females, probably indicating an even adult sex ratio. Several beetles collected in 1991 and held in an observation tank were alive one year later (Prchal, pers. comm.); most adult Dytiscids live for at least one and sometimes several years.

Defensive strategy: Dytiscid beetles have hard exoskeletons and make rapid evasive maneuvers when threatened. The beetles possess paired abdominal pygidial glands that produce volatile defensive compounds, and prothoracic glands that secrete steroids and other chemicals highly toxic to fish and amphibian predators (for review see Whitman et al., 1990). When captured or irritated, most species secrete milky-colored fluid and bite (pers. obs.). Trapped *T. marmoratus* release milky fluid from openings between the head and thorax and in the anal region, and taste bitter if touched with the tongue-tip.

Thermonectus marmoratus' conspicuous black and yellow markings suggest aposematic or warning coloration used to reinforce predator learning and avoidance. In support of this argument, the beetles often are active diurnally in clear shallow water, where they would be visible to predators with well-developed vision. Further, *T. marmoratus* is gregarious, a behavior often associated with aposematism. In theory, gregariousness can evolve if individuals' odds of survival and reproduction improve in the presence of aposematic conspecifics. The brightly colored pattern's dorsal position suggests that it may be directed upward at predators attracted to the water. In arid regions, water is a resource that is not always abundant, even at higher elevations. Aposematic coloration and gregariousness in *T. marmoratus* may be adaptations permitting exploitation of shallow or decreasing water resources while limiting predation by shoreline vertebrates.

CAPTIVE MANAGEMENT

Aquatic insect husbandry and rearing have been reviewed in detail by Merrit et al. (1984) and briefly described by Morgan (1988). An overview of sunburst diving beetle captive management was provided by Morgan (1992).

Adults: Sunburst diving beetles are tough insects that can be handled and manipulated without harm. Long-stemmed, standard aquarium dip-nets are ideal for working small rocky pools. The beetles transport well in small plastic containers lined with moist toweling for padding, and can be readily carried or mailed. Water is not necessary and may complicate travel. Too many beetles crowded together and agitated may damage or remove one another's legs; providing several crumbled paper towels or field material for perches and hiding areas helps eliminate this damage. The beetles can be maintained and displayed in almost any standard aquarium and fed common prey items. Some method of filtration or cleaning is required to limit organic waste build up. Terrestrial oviposition sites are needed only if breeding is desired.

Eggs: The eggs are thin-skinned, very fragile, and easily ruptured. Physical disturbance seems to increase chances of eggs succumbing to bacterial or fungal attack. Female beetles will wedge eggs in viewable positions if oviposition sites are limited to crevices just above the water line next to glass tank sides. Eggs in the display tank are usually inserted into thin spaces between rocks and water-soaked wood, but have also been found clumped within moist moss growing on the shoreline. Eggs are typically allowed to hatch *in situ*, but those in hidden sites can be exposed and viewed. Eggs can be gingerly picked-up with a damp, fine-point artist's brush and transferred to a moist sponge, permitting direct macro and microscopic examination of development and hatching. Eggs containing mature embryos have been induced to hatch by gentle probing with an artist's brush.

Larvae: For rearing purposes, hatchling water tigers are removed from the display tank to avoid predation by adult beetles. Small, easily injured larvae are transferred by net, although larger individuals can be picked up by hand if necessary. Water tigers can be mass-reared in any standard aquarium or water container given abundant food and the absence of other large predators. They are reared indoors in winter and outside in summer with the latter method preferred for ease. Nearly grown larvae are netted from rearing containers and transferred to a pupation tank where they finish feeding and then leave the water to pupate. Mature larvae unable to escape the water drown.

Pupae: Specimens buried in moss can be carefully exposed then covered by a removable object, allowing repeated and detailed observation of pre-pupal and pupal development, and adult eclosion. Specimens in sand-walled puparia can be viewed by gently probing open a small window in one side of their cocoons. Young, recently emerged adult beetles found swimming in the pupation tank are netted and transferred to the public display tank housing the breeding population.

Adult Food: For convenience, frozen crickets (either immatures or adults) are sprinkled on the water surface and provide the staple diet. Live crickets are not used since they climb from the water becoming unavailable as food. Nightcrawlers are sometimes sectioned, rinsed and fed to the beetles. Dry flake fish food is eaten by hungry beetles but left untouched if prey is available. During warm weather, live mosquito larvae and pupae found in outdoor water containers have been used as food, although developing adult mosquitoes readily escaped in the rearing area and sometimes bit keepers. A preliminary trial with blackworms held submerged within a clear glass bowl appeared to be an effective method for continually providing fresh live food. The bowl prevented blackworms from burrowing into gravel and hiding from beetles. (**Table 1** lists commercially available live food sources).

Larval food: Small actively swimming crustaceans, *Daphnia* or water fleas, are cultured year-round in large plastic garbage containers (*Daphnia* can often be acquired from local tropical fish hobbyists). Mosquito larvae and pupae developing naturally in outdoor water containers are used extensively during warm weather. Larger water tigers also take live apterous (flightless) fruit flies (**Table 1**) and small frozen crickets sprinkled on the water surface.

INSECTARIUM DISPLAY TANK

The public display tank is freestanding (for photo see Morgan, 1992). Its 1 m sq. enclosed base stands about 0.9 m high and supports a slightly narrower, 1 m tall glass tank. Thus, the tank's volume is about 0.8 cubic meters. The tank is covered by a 56 cm high enclosed cap making the entire structure about 2.4 meters tall.

The enclosed base hides structural supports, electrical outlets, water hoses and a canister filter-pump (**Table 1**) for water circulation and mechanical filtration. The enclosed cap hides electrical outlets and overhead lighting. The tank is primarily illuminated by nine 90 watt halogen floodlights (**Table 1**). These simulate natural sunlight and permit live display plants.

Display tank substrate is a 7 cm deep pea gravel bed supported by an undergravel filter-plate for biological filtration. Water is pulled through the gravel bed and into four inlets spaced below the filter plate; these join before entering the filter-pump. Water is returned to the display pool through a single, central upwelling. The gravel bed's large surface area (about 0.8 m sq.) facilitates efficient biological filtration. The tank's biological load is heavy given numerous live beetles and daily feeding, yet major cleaning (gravel bed siphon-cleaned, water changed, and filter-pump cleaned) needs to be done only about every three or four months. Daily care mostly consists of feeding and removing old uneaten prey and other decomposing matter found in the water. The tank is serviced via a hinged, plexiglass door on the side away from visitor flow.

Display tank water level is maintained at 18-22 cm deep, for a total volume of about 160 liters. The water's large surface area (about 0.8 m sq.) and lighting heat cause significant evaporation; additional water must

be added weekly. Both aquatic and semi-aquatic plants grow within and above the water, while vines and taller plants fill the upper reaches of the tank. Several large orb-weaving spiders, *Argiope* sp., maintain webs among the emergent vegetation, feeding on flies released into the diorama.

A breeding population of about 100 sunburst diving beetles is currently exhibited. These are the centerpiece of a community display entitled "Water Beetles" also showing other Dytiscids, Hydrophilids (water scavenger beetles) and Gyrinids (whirligig beetles). The display tank can be viewed on all sides, providing visitors with an intimate look at life both above and below the waterline. The diorama depicts a natural habitat of sunburst diving beetles: a shallow sunlit pool strewn with gravel, rocks, driftwood and plantlife. It provides Zoo visitors with a wonderful opportunity to closely observe colorful sunburst diving beetles as they move, feed, breathe and reproduce in their world.

Acknowledgments

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REFERENCES

APGAR, L.A.; MEEK, C.L.; & GEACHAN,J.P. (1985): Toxicity of Riceland Agrichemicals on *Thermonectus basillaris*, a Predator of Mosquito Larvae. *Southwest. Entomol.* 10(3):222-227.

ARNETT JR, R.H. (1985): *American Insects: A Handbook of the Insects of America North of Mexico.* Van Nostrand Reinhold Co. Inc., New York & Ontario, 850 pp.

ARNETT JR, R.H. & JACQUES JR., R.L. (1981): *Thermonectus marmoratus.* In: *Simon & Schuster's Guide to Insects.* Simon & Schuster Inc., New York, Toronto & London, pp. 86-87.

EVANS, D.L. & SCHMIDT, J.O.; eds. (1990): *Insect Defenses: Adaptive Mechanisms and Strategies of Prey and Predators.* State Univ. of New York Press, Albany, 482 pp.

LEECH H.B. & CHANDLER, H.G. (1956): Family Dytiscidae, Predaceous Diving Beetles. In: *Aquatic Insects of California.*, Usinger, R.L., ed. Univ. of Calif. Press, Berkeley & Los Angeles, pp. 305-324.

MERRIT, R.W.; CUMMINS, K.W.; & RESH, V.H. (1984): Collecting, Sampling, and Rearing Methods for Aquatic Insects. In: *An Introduction to the Aquatic Insects of North America*, 2nd Ed., Merritt, R.W. & Cummins, K.W.; eds. Kendall/Hunt Publishing Co., Dubuque, pp. 11-26.

MILNE, L. & MILNE, M., (1980): Marbled Diving Beetle (*Thermonectus marmoratus*). In: *The Audubon Society Field Guide to North American Insects and Spiders.* Alfred A. Knopf, New York, p. 542 + plate 96.

MIURA, T. & TAKAHASHI, R.M. (1974): Insect Developmental Inhibitors Effects of Candidate Mosquito Control Agents on Nontarget Organisms. *Environ. Entomol.* 3(4):631-636.

MORGAN, R.C. (1988): Windows on the Water World. *Backyard BUGwatching* 5:4-6.

MORGAN, R.C. (1992): Sunburst Diving Beetles: Living Jewels Brighten Rippling Waters. *Backyard BUGwatching* 14:4-8.

MORGAN, R.C. & THOMS, E. (1982): Insects: Diving, Swimming, Snorkeling, Floating. *Cincinnati Zoo News*, Fall: 6-9.

PALTING, J. (pers. comm.): Member Sonoran Arthropod Studies, Inc., Tucson.

PENNAK, R.W. (1978): Dytiscidae (Predaceous Diving Beetles). In: *Fresh-water Invertebrates of the United States*, 2nd Ed. John Wiley & Sons, New York & Toronto, pp. 628-637.

POWELL, J.A. & HOGUE, C.H. (1979): Predaceous Water Beetles. In: *California Insects*. Univ. of Calif. Press, Berkeley & Los Angeles, pp. 264-266.

PRCHAL, S. (pers. comm.): Director Sonoran Arthropod Studies, Inc., Tucson.

ROCHE, R. (pers. comm.): Department of Entomology, Univ. of Ariz., Tucson.

SALVATORE, D. & MORGAN, R.C. (1992): Take a Closer Look: A Sunburst Diving Beetle. *Backyard BUGwatching* 14:8-10.

TOMBERLIN, B. (pers. comm.): Hatari Invertebrates, Portal.

WHITE, D.S.; BRIGHAM, W.H.; & DOYEN, J.T. (1984): Dytiscidae (Predaceous Diving Beetles). In: *An Introduction to the Aquatic Insects of North America*, 2nd Ed., Merritt, R.W. & Cummins, K.W.; ed's. Kendall/Hunt Publishing Co., Dubuque, pp. 377-388.

WHITMAN, D.W.; BLUM, M.S.; & ALSOP, D.W. (1990): Allomones: Chemicals for Defense. In: *Insect Defenses: Adaptive Mechanisms and Strategies of Prey and Predators*, Evans, D.L., & Schmidt, J.O.; eds. State Univ. of New York Press, Albany, pp. 289-351.

Table 1: Products mentioned in the text.

Apterous fruit flies: Carolina Biological Supply Co., Burlington, NC 27215.
Blackworms: Small freshwater annelids (segmented) worms. California Aquatics, Fresno, CA 93726.
Crickets: Fluker Farms, P.O. Box 378, Baton Rouge, LA 70821.
Halogen Floodlight: 90 watt Sylvania Natural Light. GTE Products Corporation, Winchester, KY 40391.
Canister filter-pump: Magnum 330 (capacity=330 gal or 1250 liter/hr). Marineland Aquarium Products, Aquaria Inc., Simi Valley, CA 93065.
Nightcrawlers: Large earthworms. Wholesale Bait Co. Inc., Hamilton, OH 45015

FIGURE 1. Submerged sunburst diving beetle attacking an aquatic worm. The conspicuous, bright yellow and black markings probably serve to warn predators that the beetle tastes bad. The exposed bubble, or physical gill, extracts oxygen from the water by diffusion.

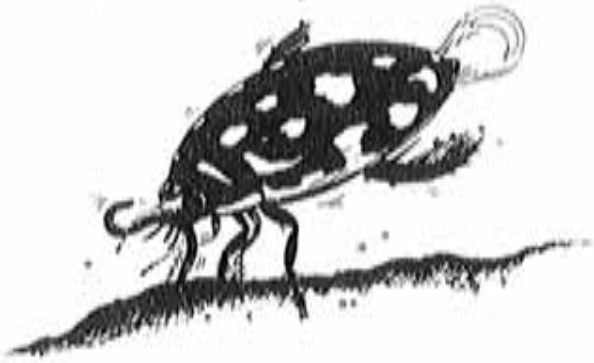

FIGURE 2. Life cycle of the sunburst diving beetle *Thermonectus marmoratus*.
Clockwise from top: female beetle hiding eggs on land, hatchlings crawling into water, first and second instar larvae swimming, third instar larva impaling mosquito pupa, mature larva exiting water to construct pupal chamber, swollen larva or pre-pupa, cream-colored pupa, pale newly eclosed adult, young beetle entering water, beetles mating while swimming, and gravid female beetle leaving water to oviposit.

The Captive Husbandry of Passionvine Butterflies (Genus: *Heliconius*)

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Introduction

Within the zoo community, the plight of the Golden-Lion Tamarin is well known. This splendid animal has been the subject of countless studies and captive breeding programs. With this rare primate being released back into the wild, it looks like zoos have the potential to rewrite the previously dismal last chapter on this animal's chances of survival in the wild. Conversely, little is known of the rare Brazilian passionvine butterfly *Heliconius nattereri* a potential SSP candidate. In 1972, Brown declared this species on the verge of extinction. If ever deemed necessary, the successful proposal and subsequent administration of a *Heliconius nattereri* SSP hinges on the cooperation of several institutions equipped to rear these butterflies. At the present time, it would be difficult to assemble this coalition in the United States.

Many of the *Heliconius* butterflies share a common plight with other rainforest denizens: loss of suitable habitat. Although there has been considerable interest in breeding and displaying these extraordinary animals, few zoos have butterfly displays or breeding programs. I suspect this reluctance to take the plunge and actively promote the display and captive breeding of *Heliconius* butterflies is the result of a knowledge gap. The paucity of literature outlining rearing and display techniques makes a difficult gap to bridge. There is also an underlying assumption that butterflies are difficult to breed and require specialized, expensive displays. Butterflies do have requisite environmental needs related to light intensity, temperature and humidity, but they are certainly less stringent than the needs of coral reef inhabitants.

One of the biggest stumbling blocks in initiating a Heliconius breeding program is obtaining founding stock. Founding members can be wild collected or obtained from institutions already breeding the butterflies. Presently, reliable commercial sources of *Heliconius* are not available. The material that is

available is often of unknown genetic stock resulting from the intentional hybridization of subspecies and even closely related species. The production of hybrids for taxonomic or genetic research is a critical element in sorting out the often puzzling Heliconius evolutionary tree. The production of hybrids for the sole purpose of creating new color forms is unacceptable and should be discouraged. We should strive to maintain genetically pure species and subspecies.

Once in culture, many species can be maintained for extended periods of time without the introduction of fresh blood lines. The senior author has maintained one species of *Heliconius* in continuous culture for over seven years. This translates to approximately 114 captive bred generations. Two other species have been in culture for over two years. Breeding most *Heliconius* is surely easier than hand feeding pigeons!

This is the third in an on going series of papers on aspects of butterfly display and rearing (Elia, 1989 and Elia, 1991). It is hoped that these papers will help provide some of the information needed to fill the knowledge gap. The breeding program outlined below is one of several used at Callaway Gardens. It is a clinical approach to butterfly breeding suitable for an SSP program. It is possible to successfully raise *Heliconius* butterflies using other less critical methods, but this program minimizes the chance of disease and maximizes success (see Turner, 1974 for a less clinical, greenhouse based rearing program).

Basic Husbandry

Like all butterflies, the *Heliconius* have four distinct life stages: egg, larva, pupa and adult. Each of these life stages has it's own husbandry requirements. Table 1 summarizes the developmental time of each stage for several species. Before breeding populations of *Heliconius* butterflies can be established, suitable host plants in sufficient quantity must first be grown. The *Heliconius* use plants in the genus *Passiflora*, commonly known as passionvines. Fortunately, there are many species of passionvine available commercially or through private collectors (see Elia,1991 for a list of recommended species).

Adults

The adult butterflies are housed in temperature controlled greenhouses. Daytime temperatures range from 26°C - 35°C. Nighttime temperatures may drop unaided to 18°C. The *Heliconius* are rainforest animals and require a high humidity. We try and

maintain humidities above 70%. Humidity is increased by mist nozzles and the frequent hosing of the walks and gravel. Ideally, a humidistatically activated fog system would be utilized to control humidity. The greenhouse is covered with 50% shade cloth to reduce heat and light levels to more closely simulate the butterfly's forest habitat. We have found no need to manipulate photoperiod.

Breeding colonies consisting of 15 to 20 butterflies are maintained in 16ft x 16ft x 8ft flight cages. Casual observation suggests a sex ratio of approximately 50/50. Because one male can inseminate several females, we tend to keep more females than males in the population. Additionally, the male passes a package of sperm which stays viable for an extended period of time. An inseminated females will continue to lay fertile eggs in the absence of males. Subspecies and species that are known to produce interspecific hybrids are maintained in separate flights to ensure genetically true cultures.

The adult butterflies will live in excess of three months in captivity with proper food and environmental conditions. Several hanging baskets of *Lantana camera* variety "Radiation" are provided as nectar sources for the butterflies. During periods of reduced flowering, sugar water in artificial feeders is used as a supplemental diet (see Elia, 1989). To promote long life and increased fecundity, *Heliconius* require pollen in addition to nectar . Our main pollen source is *Psiguria umbrosa*, a neotropical curcurbit, that serves as an important pollen source in the wild. This vine grows easily from seed or cuttings. The pollen is collected by the butterflies on their tongue and dissolved for ingestion.

Eggs

The natural occurrence of a tiny wasp ,*Trichogramma* sp., that parasitizes the *Heliconius* eggs, prevents us from keeping host plants in the cage for extended periods of time. The wasps are less than a millimeter long and are difficult to detect. When eggs are left in the flight the percentage of parasitized eggs can exceed the percentage of eggs hatching seriously debilitating the culture. To circumvent this problem, host plants are introduced as cuttings in a water filled flask.

When a predetermined number of eggs have been oviposited, the flask is removed from the flight and brought into the laboratory building. The laboratory building has a central heating and cooling system. Temperatures range from 23°C to 26°C. No growth chambers are available or needed to raise *Heliconius* butterflies. Any clean, well lit, pesticide free space can be

adapted to a laboratory.

We have found that collecting the eggs on cuttings allows us to keep better track of the culture's health and vigor. Since we know how many eggs are on hand at all times, it is easy to prevent overpopulation (more mouths to feed than host plant to feed them!) and also to detect depressions in culture vigor at an early stage.

The eggs and a small portion of the vegetative material they are attached to is transferred to a 2 ounce, Solo P200 souffle cup with lid and monitored for hatching.

CATERPILLARS

The caterpillars are raised singularly in 1/6 size (2.5 quart) Cambro storage containers. Several small holes are drilled into the container and the lid for ventilation. The bottom of the container is lined with paper towels to absorb excess moisture and help facilitate cleaning. A 25cm, or suitable length, cutting of the proper *Passiflora* species is inserted into a small hole punched in the lid of a 2 ounce, Solo P200 souffle cup filled with water. The hole in the lid should be just large enough for the stem of the cutting. Caterpillars have a propensity for crawling down the stem and drowning if the hole is too large. A newly hatched caterpillar is then transferred to the tip of the cutting using a paint brush.

A caterpillar will be able to go several days without feeding or cleaning the container, reaching third instar. If the cutting is kept off the floor of the container, the caterpillar will not contact it's frass eliminating the need for daily cleaning. When the food is replenished, the old food and frass is removed and the paper towels are replaced. Caterpillars should always have sufficient fresh food to ensure large, healthy pupae.

When the caterpillar is finished feeding, the normally white caterpillar will turn a light pink or purple color. At this time feeding is halted and the container is not disturbed. In a day, the caterpillar will affix its caudal end to the stem or lid and hang upside down in a "J" shape. Within 24 hours it will molt it's skin revealing the pupa.

PUPAE

The newly molted pupa's exoskeleton is shiny and soft. It should not be touched for at least 24 hours. Once fully hardened,

the exoskeleton will be darker, without a sheen. The pupa is then transferred to a 1/2 size (9 quart) Cambro storage container. The lid has two strips of high density insect pinning foam attached to it with hot caulk (the hot caulk produces a longer lasting bond then hot glue). A row of small holes is drilled in each side of the lid to allow some air movement. The bottom of the container is lined with nine C-fold paper towels and moistened with 1.5 ounces of water.

Pupae are attached to the lid with stainless steel insect pins inserted through the stem they are attached to or the silk button attached to their caudal end and into the pinning foam. Pupae without silk buttons are affixed by the cremaster to a piece of index card using hot glue. We allow the glue to cool down before affixing the pupa. Caution should be exercised to ensure only the cremaster is glued to the card and not any of the abdominal segments. The pupae are held in this container until the adult butterflies emerge and are ready to fly. The new butterflies are then released into the Day Butterfly Center or used to balance attrition in the breeding colony.

Conclusions

The breeding and display of tropical butterflies requires learning new skills. Unfortunately, the paucity of literature on the subject makes this a daunting task. Callaway Gardens is committed to sharing the techniques and procedures we develop for rearing and displaying tropical butterflies. We are actively seeking other institutions interested in establishing *Heliconius* breeding programs. Our goal is to be able to maintain a greater degree of genetic diversity in captive cultures and to have back up supplies in the event a colony loses it's vigor. As stated earlier, any successful SSP will require the contributions of several institutions.

Bibliography

Brown, K. S. Jr. 1972. The Heliconians of Brazil. Part III. Ecology and Biology of *Heliconius nattereri*, a key primitive species near extinction, and comments on the evolutionary development of *Heliconius* and *Eueides*. *Zoologica NY* 57:41-69

Elia, Frank C. 1989. Feeding Butterflies in the Butterfly Display. *AAZPA Regional Conference Proceedings* 543-545

Elia, Frank C. 1991. Selecting Passionvines for a Heliconius Breeding Program. *AAZPA Regional Conference Proceedings* 178-179

Turner, John R. G. 1974. Breeding Heliconius in a Temperate Climate. *J. Lepid. Soc.* 28:26-33

Table 1: Duration of Developmental Stages (in days) *

Species	Egg - Hatch	Hatch - Pupa	Pupa - Adult
H. charitonius	4	15	8
H. melpomene plesseni	4	14	9
H. m. intergrade	4	13	9
H. hecale	4	14	10

* Data were collected under laboratory conditions outlined above.

The feasibility and value of invertebrate captive breeding programmes, with special reference to the British field cricket *Gryllus campestris*.

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Few people in the conservation world are unaware of the tremendous role that invertebrates play in maintaining the earth's ecosystems, as well as constituting the submerged bulk of the "bio-diversity iceberg". In addition to their major position on most of the food chains and indispensable role as recyclers, and pollinators, many invertebrate species have an important economic, cultural and aesthetic value for mankind (Wells et al 1984). Indeed some of the planets most beautiful and fascinating animal species happen to be invertebrates.

As is the case for threatened species of vertebrates, the need to augment the prime species conservation measure of habitat protection with captive-breeding programmes is increasingly being recognised as being necessary for a growing number of threatened species of invertebrate. As again is the case with vertebrates, the onus is very much on zoos and aquaria to provide the mainstay of such *ex situ* conservation efforts.

It has been demonstrated that, with the correct management protocols, a diverse range of invertebrate groups can be cultured in captivity. By virtue of their small size, and consequent modest accommodation requirements, together with an often spectacular reproductive potential, invertebrates can often be maintained as large populations ensuring the retention of healthy levels of genetic variation, over time. Furthermore, experience suggests that many invertebrate groups are well adapted to contend with periodic population drops, greatly enhancing the chances of maintaining healthy populations, over successive generations (Morton, 1991).

Another strong incentive for conservation bodies, such as zoos and aquaria, becoming involved with invertebrate breeding programmes is the often high chance of effecting successful reestablishment. It would be fair to say that there are many instances where the habitat problems effecting invertebrate species are well understood. Although it may take some time and financial outlay, effective solutions to many habitat problems (certainly in temperate regions) can usually be found and put into effect. Such habitat management considerations are of course very pertinent when evaluating the likely chances of successfully reestablishing a species.

A further consideration for zoos and aquaria to take on board is that invertebrate captive breeding programmes, in addition to being the cheapest and most technically feasible to establish and maintain, have proved themselves to be of strong interest to the public and media alike. All of these factors combined make many invertebrate groups (such as the Orthoptera and lepidoptera) excellent candidates for being incorporated into mainstream captive-breeding programme work.

A good illustration of the value and feasibility of zoo based invertebrate conservation work is London Zoo's captive breeding programme for the British field cricket *Gryllus campestris* .

Although a common species on the Continent, the British population of the field cricket is now confined to a single colony, numbering between 200-300 individuals, in West Sussex.

The reason for the decline of the field cricket in England is essentially loss of its selective close-growing turf sites which need to be situated on porous sandy or chalky soil and enjoy a sheltered and sunny aspect. A prime reason for this habitat loss has been the overgrowth of vegetation as a result of changes in grazing practices (Whitten, 1990).

In a effort to safeguard the existing field cricket population, and expand the number of colonies, the Governmental conservation body English Nature has placed the field cricket onto its Species Recovery Programme. This conservation initiative is directed at recreating the field crickets habitat requirements over areas of its former range and identifying existing alternative sites that already provide suitable habitat requirements.

However, such site management is of little use if the animals are not available to establish new colonies. To this end, London Zoo's Invertebrate Conservation Centre was approached by English Nature in the Spring of 1992 and asked to participate in its conservation initiative by establishing a captive-breeding programme for the field cricket with the intention of building up sufficient numbers of animals for release into sites identified by English Nature.

In late Spring of 1992, 6.6 sub adult field crickets were collected from the remaining wild colony in West Sussex and taken to the Invertebrate Conservation Centre. The crickets were housed separately in ventilated plastic tanks under carefully controlled lighting, heating and humidity levels, reflecting as closely as possible the natural environmental conditions, and fed on a semi natural diet of wild grasses, nettle, dandelion leaves and flowers, root vegetables and bran.

Following a series of successful matings, a thousand or so hatchings were obtained. The resultant nymphs were reared up in nursery colonies (one such colony being established for each of the five progeny lines) until they were considered large enough (3rd - 4th instar) to be released into the field. In a collaborative exercise with English Nature, 700 of the captive bred nymphs were released into two selected West Sussex sites in early August 1992. The remaining 300 nymphs are to remain at the Zoo where they will be taken through their winter dormancy period to establish a second, and much larger, captive population in the Spring of 1993.

In addition to providing English Nature with a large F2 population, which will be used to establish further fresh colonies in the field, the retention of the 300 F1 crickets shall enable us to answer some important biological questions. By retaining statistically meaningful numbers of offspring it should be possible to clarify the natural sex ratio for this species, which is currently unknown. Genetic fingerprinting studies will determine the degree of variation within the captive reared F1 generation and allow subsequent comparisons with the F2 generation and with the original parent colony, the 12 members of which have been deep frozen until the analysis can be carried out at the Society's Institute of Zoology.

Conclusion

As has already been discussed, invertebrate captive breeding programmes represent a highly feasible and cost effective area of programme work for conservation bodies, such as zoos, to become involved in. Much is in place to allow a dramatic conservation success of unparalleled portions. Many deserving species have been identified, much technical expertise is available to be drawn upon, as is the public interest. By further developing the captive-breeding option for endangered species of high profile invertebrates, zoos and aquaria have an opportunity to play an indispensable role in preserving many of the earths most fascinating species.

Acknowledgements

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References

Morton, A.C. (1991) Captive breeding of butterflies and moths: 11. Conserving genetic variation and managing bio-diversity. International Zoo Yearbook. (1991) 30: 89-97 Zoological Society of London.

Wells. S, Pyle. R, and Collins. M, (1984) The IUCN Invertebrate Red Data Book. IUCN, Gland, Switzerland.

Whitten, A. (1990) Recovery: A proposed programme for Britain's protected species. Chief Scientist Directorate, Nature Conservancy Council, Peterborough, UK.

THE EVOLUTION OF A PLANKTON-COLLECTING TANK AND ITS USE TO FEED PLANKTIVORES AT THE SEATTLE AQUARIUM

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The Seattle Aquarium (Seattle, WA.) has 29 small tanks (40-280 gallons) devoted to local marine invertebrates, many of which are planktivores, suspension feeders, or detritus feeders. The animals are held in open-system tanks, fed by water from Elliott Bay, Seattle's harbor. Raw sea water is pumped at the rate of 2500 gpm from the end of a pier and filtered for clarity before passing to exhibit tanks. The sand and gravel filters were designed to remove particles as small as 10-20 micrometers. Feeding these animals presents a distinct challenge to the aquarist.

For the first ten years of the Aquarium's existence, we ran unfiltered water through the system at night, after closing, in order to feed the filter feeders. Filtering began again soon enough in the morning for tanks to clear by opening to the public. In addition to the nightly addition of unfiltered water, various home-made, pureed concoctions were added to the invertebrate tanks in an effort to supplement feeding (see Table 1). Although the invertebrates clearly were not surviving as well as they would in the wild, survival was good enough to maintain the exhibits with minimal collecting efforts to replace those animals that didn't survive well, notably bivalves, barnacles, sabellid worms, sea cucumbers, and tunicates.

The large header pipes feeding the Aquarium's systems maintain a fast enough flow rate so that settling by fouling organisms is inhibited. Sergy and Evans (1975) state that settling in pipes of marine bio-fouling organisms is impeded at water speeds of 40 meters per minute or higher. We have found that some fouling organisms tend to settle in these pipes where there are water eddies or calm spots, such as pipe joints, elbows, or valves (see Anderson, 1991). Smaller water distribution pipes feeding individual tanks have slower flows, and continually become clogged with organisms such as barnacles, mussels, and scallops or their shells. Such fouling reduced water flow and frequently shut it off, as shells broke off the pipes and became wedged in tees, elbows, joints or throttled valves just prior to tank inlets. Occasional loss of animals resulted, even with frequent "snakings" of the pipes. A new systems engineer suggested that we eliminate the running of unfiltered water to reduce the bio-fouling in the smaller pipes. Such action

would require that I feed the planktivores by other means.

It is very labor intensive to tow plankton nets off the pier, due to the physical lay-out of the Aquarium. At certain times of the year it was also un-productive. A device for collecting wild plankton, developed during an octopus-rearing project (see Eddy, 1984), was effective, but awkward and time-consuming, needing about two hours a day for set-up and take-down. Another method of getting plankton was sought.

The engineer suggested that we obtain plankton that was being filtered out of the sea water onto the filters. We could obtain it during the backwash cycle of the filters. We could then manually feed it to the plankton feeders, and eliminate the unfiltered water at night. While this would also eliminate the nano-plankton that filter feeders such as bivalves benefit from, it was decided to try this method.

Our first attempt at collecting plankton from the filters was to install a 3/4" hose onto an air bleed valve located on top of the filters. The valve was opened while the filters were being backwashed, and the filter effluent ran through the hose into a plankton net hung on the wall (located above a floor drain). The results were encouraging. It was expected that much of the plankton would survive the pumping process, based on the settlement of fouling organisms within the filters, but few were expected to survive the backwash process. In this process, water is directed into the filters opposite the normal direction, so that anything caught on top of the filters is washed up and away from the filter bed. Many plankters were found to survive both the pumping and backwash processes. Live plankton collected by this process were mostly amphipods, copepods, conchostracans, and ostracods.

The disadvantage of this system was that we were not able to filter enough of the backwash effluent. The 3/4" hose carried only a small portion of the effluent, and the plankton net we used to capture it readily clogged and overflowed. We decided to design and implement a Mark II version.

Our criteria for the design of the plankton tank were to locate it near the filters and above a floor drain (we all know that tanks leak, break, overflow, etc.). The tank had to accept as much flow as possible from the backwash cycle of the filters. It must collect plankton automatically into the plankton tank, as the filters backwash automatically. It must allow for holding the plankton throughout the day. It must be simple and easy for multiple users at different times. It must have adequate drainage for the backwash effluent. It must fit into a crowded work-space. Perhaps most importantly, it had to cost practically nothing, since nothing was budgeted for this project.

A surplus glass aquarium tank (sixty inches high by sixteen inches square) was used that would fit into the narrow space

selected. A cylindrical plankton net (140 micrometers mesh size) was made by Research Nets (P.O.Box 249, Bothell, WA.98041) to fit into the tank. A framework was constructed for the net, to keep it from collapsing. The framework consisted of a piece of 12" fume duct PVC pipe with holes drilled into it. To keep the plankton from clogging the net, an air bubbler was designed into the base of the framework. The air bubbler was a piece of perforated 3/4" PVC pipe encircling the bottom of the screened pipe, connected to a compressed air line. When the plankton was being collected, the air bubbler acted effectively to continually clear the net of plankton, allowing water to pass through. The framework for the net connected to a drain in the bottom of the tank, which connected to an existing drain line about half way up the tank. This drain functioned as an external stand-pipe that kept the tank about half full of water. The plankton net cylinder was open at the top so that if clogged, it would over-flow down the drain. A faucet was installed in the side of the tank near its bottom for draining off the plankton and to drain the tank for occasional cleaning. A 1-1/2" pipe was installed to the plankton tank to bring in backwash effluent. A salt-water line was installed into the tank, for keeping the plankton alive.

The results from the use of this tank were very encouraging, but still not perfect. The plankton net still consistently clogged and the tank overflowed. The drain could only handle a very small portion of our backwash effluent; the inlet valve had to be well-throttled. The plankton net, while very good at capturing zooplankton, effectively let most phytoplankton (which are smaller) pass through, although many diatoms were detected in the filtrate. Due to the height of the plankton tank, the net was difficult to remove for cleaning.

Since much of the plankton was composed of marine larvae, there was considerable settlement of bio-fouling animals in the plankton tank, particularly of barnacles. In the spring, barnacle larvae (nauplii) were very evident in the plankton collected. Barnacles effectively coated the inside of the tank and had to be scraped off periodically, as they were eating the very plankton we wanted to collect.

Further modifications were obviously in order, and conveniently came about when the tank was accidentally broken.

Mark III modifications (besides fixing the broken tank) included installing a larger drain (3") and drilling a new drain hole through the side of the building for it to go out. By examination, since we were getting mostly zooplankton, it was decided to target these and go for copepod-sized plankton. The mesh size was increased to 250 micrometers. The larger drain will now take all that the 1-1/2 inch inlet can deliver. After backwashing, and after the plankton has been collected, the tank and plankton net are washed down with high-pressure freshwater and allowed to drain and dry. This cleans the net and prevents settlement of bio-fouling organisms inside the tank. Plankton is

collected from the faucet with a fine mesh net. The larger (amphipods) and smaller (copepods) plankters are separated by straining through different mesh sizes. Frequently, un-sieved backwash effluent is collected in a bucket and fed to filter feeders. Backwash effluent allowed to settle to the bottom of a bucket is fed to detritus feeders such as sea cucumbers.

A typical backwash cycle of the five main filters will produce about one cup of unconsolidated material. Although many of the plankters are dead, a large number are alive and swimming. A close examination of the plankton collected by this method reveals a large number of copepods, amphipods (gammarid, caprellid, and hyperiid), conchostracans, ostracods, and mysids, along with many crustacean and other larvae, particularly barnacle nauplii. Identifiable non-living material includes dead zooplankton and barnacle molts. An analysis of the material obtained in different seasons was performed by the University of Washington School of Oceanography, indicating a very high nutritive value (see Table 2).

Surprisingly, many soft-bodied and delicate animals survive the backwash cycle and are caught in the plankton tank. Some of these are undoubtedly coming from the filters themselves, rather than being pumped from the water. The filters support a rather amazing fauna (see Anderson, 1991). Some of the more delicate animals that have been collected from the backwash effluent include the opalescent nudibranch (Phidiana crassicornis), the pteropod Gastropteron pacificum, flatworms, arrow worms, and even the sea spider Nymphon sp.

Suspension feeders and zooplanktivores particularly respond well to the addition of this plankton broth to their tanks, as expected. Tube worms emerge from their tubes. Sea cucumbers expand their tentacles and begin their "finger-licking" form of feeding. Parastichopus californicus, the giant red sea cucumber, mops up the material off the bottom with its tentacles. Brittle stars, normally quiescent, thrash all over the bottom searching for food particles, which they evidently smell or taste; they will even eat barnacle molts. Basket stars expand to their full width to receive as much food as possible. Sea anemones expand as much as possible, particularly Metridium, Corynactis, other small anemone species, and cup corals. Gorgonians and soft corals expand their polyps.

While the plankton collected will not feed filter feeders needing smaller food size (<250 micrometers), some smaller plankton is obviously getting through the filters, as it still supports a decreased bio-fouling population in pipes and tanks. Supplementary diets for desired filter feeders in exhibit tanks include feeding of bottled filter feeder food (commercially available in different formulas for different animals), pureed mixtures of raw sea food, and herring blood. Most filter feeders seem to be surviving well on this diet (note: some filter feeders do not seem to respond to various bottled foods).

This plankton diet is fed only once a day and is supplemented with occasional feedings of brine shrimp nauplii. Of course, a single heavy daily feeding does not duplicate the condition in the wild, where feeding occurs continually as plankton is washed over filter feeders in currents and tides. Ideally, we should be feeding plankton to our tanks in a slow feeder (see Wong, 1989) or with the use of small diaphragm pumps. Our present budgetary constraints prevent the implementation of these systems, but I anticipate their use in the future.

Obviously, this system can only work with aquariums located on seashores, which use and filter raw sea water. I would expect that such aquaria would benefit from obtaining plankton such as we do.

Acknowledgements

I especially thank Bob Kiel for all the ideas, time, and effort he put into the plankton tank development. I also thank Katherine A. Krogslund and the University of Washington School of Oceanography for performing chemical analyses of the plankton.

References:

Anderson, R.C. 1991. Marine bio-fouling at the Seattle Aquarium. Of Sea and Shore. 14(3):147-152.

Eddy, J.W. 1984. An inexpensive plankton trap. Drum and Croaker. 21(1):10-18.

Hedges, J.I. and J.H. Stern. 1984. Carbon and nitrogen determinations of carbonate-containing solids. Limnol. Oceanogr. 29(3):657-663.

Sergy, G.A. and J. W. Evans. 1975. The settlement and distribution of marine organisms fouling a seawater pipe system. Veliger. 18(1):87-92.

Wong, K. 1989. A slow feed device for keeping soft corals. AAZPA 1989 Regional Proceedings. 418-419pp.

TABLE 1

FILTER FEEDER DIETS FOR MARINE INVERTEBRATES AT THE SEATTLE AQUARIUM

Food	Composition	Comments
Puree I	beef heart algae or kelp brewer's yeast	potential for fouling tank, dubious efficacy
Puree II	beef heart, diatoms, brewer's yeast, fish flake food, live clams fresh sea food	potential for fouling tank, dubious efficacy
Raw plankton	from unfiltered water overnight	produced bio-fouling in pipes
Raw plankton	dipped from bay	labor intensive, sporadic
Raw plankton	from filters	size-selective, easy, readily available
Bottled planktivore diet	store-bought, various formulae	easy, species-specific, some won't respond, some respond negatively

TABLE 2

PERCENT ORGANIC CARBON OF SAMPLES FROM THE PLANKTON TANK

Material	% Organic Carbon
Plankton Sample (winter)	26.79%
Plankton Sample (spring):	19.64%
Plankton Sample (summer):	24.29%
Spruce Wood*	47.80%
A Sediment Core*	2.19%
Oceanic Sample of Suspended Matter*	9.43%

*from Hedges and Stearn, 1984

SINGLE CELL ALGAE CULTURES AS A NUTRITIONAL SUPPLEMENT FOR INVERTEBRATE DIETS

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As the popularity of aquariums has increased over the past decade, so has the realization that conservation must be an important part of any aquarium's agenda. In most cases this means establishing a captive breeding program for fish and invertebrates, often within existing budgetary and staffing constraints and adding workloads to current personnel. A husbandry program aimed at raising marine fish and invertebrates requires large scale production of marine microalgae and rotifers, which are required by invertebrates and fish larvae as food sources. The culturing of the algae and rotifers can be very time consuming and cost prohibitive. In 1990, the National Aquarium in Baltimore began a collaboration with Martek Biosciences Corporation, located nearby in Columbia, Maryland. Martek is a biotechnology company specializing in applications of microalgae. They have over one thousand freshwater and marine microalgae in their culture collection, enabling the evaluation of a broad range of algae as food sources for various organisms. Additionally, Martek Biosciences has a unique, patented photobioreactor, designed specifically for the culture of microalgae. With these photobioreactors, Martek can produce more than two kilograms of algae in a single batch.

The initial work involved the Aquarium's neon goby breeding program. The newly hatched neon goby larvae are fed a diet of rotifers, which are raised on Nannochloris. The Aquarium had been growing Nannochloris in Sunlight tanks illuminated by fluorescent bulbs. Production was limited by space and low cell densities. Martek, however, was able to provide an algal paste containing 500 grams of Nannochloris on an as needed basis for the Aquarium. This paste could be stored in the refrigerator for up to six weeks. To culture the rotifers, 4 cc of algal paste was resuspended in 800 cc of artificial sea water. 200 cc of algal suspension was added to each of four 30 liter rotifer culture tanks. Rotifers were harvested daily to feed the fish larvae. Make-up water and algae were added as needed to the rotifer culture tanks to maintain the continued production of the rotifers.

Since the establishment of the neon goby breeding program, which has produced over 1,000 post larval gobies to F4 generation, other uses for the Nannochloris paste have been developed. These include using the algae both as a primary and secondary food source for marine invertebrates.

As a primary food source, Nannochloris was tested on the upside down jellyfish, Cassiopeia xanachana. Adult jellyfish were purchased for the Aquarium and placed in a twenty-gallon tank with a water depth of 30 cm and an undergravel filter illuminated by 3 50-watt flourescent light bulbs. For the first two months the jellyfish were fed newly hatched brine shrimp (Artemia salina) two times a day. After the two month period a daily 5 cc of the diluted algal paste was added directly to the tank. Although the algae did not seem to have a significant effect on growth rates, the development of jellyfish planula or larvae did not occur until after the introduction of algae to the tank. The exact relationship between Nannochloris and the symbiotic algae that occurs in the jellyfish is not yet known, although since the use of Nannochloris the first group of planula have developed into the adult stage and measure 55 mm. In addition to this the jellyfish exhibit tank has had a continual population of jellyfish planula developing on the tank wall. As we continue to work with the jellyfish we will try to improve ways to measure how much Nannochloris is being used by the jellyfish, Cassiopeia xanachana.

The secondary method of using Nannochloris as a nutritional supplement is similar to the method of using the algae for rotifers. The main difference is using adult brine shrimp instead of rotifers. Live adult brine shrimp are delivered to the Aquarium on a weekly basis. The adult brine shrimp are rinsed and then put into 20 gallon tanks with air stones for circulation. At first the adult brine shrimp were soaked in a solution of Nannochloris for one half hour before feeding; since then approximately 25 cc of Nannochloris has been added directly into the 20 gallon barrels. The end result is the increased nutritional value of the adult brine shrimp as demonstrated through the research done by Wantanabe 1989. This has been most evident in the Aquarium's attempt to establish a breeding program with the sea horse, Hippocampus erectus.
For the past nine months, the Aquarium has developed a relationship with local pet stores. They agreed to notify the Aquarium when a pregnant male would come in. After birth, the Aquarium would then pick up the juvenile sea horses which would not otherwise survive in the hobbyist trade. Until the use of Nannochloris as a nutritional food supplement, the juvenile sea horses did not readily survive to sexual maturity on adult brine shrimp alone. Since that time the Aquarium has been able to consistently raise juvenile sea horses up to 10 cm in height on adult brine shrimp and Nannochloris algae. Although the final goal of raising sea horses from birth to sexual maturity has not been perfected, the use of Nannochloris

as a nutritional enhancer appears to be a key factor in the rate of survival in the juvenile phase of growth. In the future, with more research, we hope to provide exact development requirements of sea horses and how Nannochloris affects growth rates.

Another secondary use of Nannochloris as a nutritional source for invertebrates is the growth of macroalgae in tanks that have had Nannochloris added directly into the tank. This has been observed in the Aquarium's cold water anemone tank where Nannochloris was used as a phytoplankton food source for many of the tanks' filter feeders. Before using Nannochloris, the tank had only a brown, stringy algae that would grow. Since using the Nannochloris, several species of red, green and brown macroalgae have started to grow, such as Ulva and the brown kelp, Laminaria sp. The exact relationship between the Nannochloris and the growth of various species of other macroalgae is not yet known, but the overall increased vitality in filter feeders and algae grazers has been observed. Only with more research on the inter-relationship between algae and growth and the reproductive requirements of closed system invertebrates and plants will the Aquarium begin to come to more conclusive answers.

Since the use of Nannochloris as a nutritional supplement for invertebrates there have been more questions raised than answers found, but the initial results have been promising. The fact that the time to culture rotifers by using the Nannochloris paste is cut in half is a significant advancement in the Aquarium's aquaculture program.

BIBLIOGRAPHY

Barnes, Robert. Invertebrate Zoology, Fourth Edition, 1980.

Brune, D., Tomasso, Joseph. Aquaculture and Water Quality. The World Aquaculture Society, 1991.

Fulks, W., Main, Kevan., Rotifer and Microalgae Culture Systems. Proceedings of a U.S. - Asia Workshop, Honolulu, Hawaii, January 28-31, 1991. The Oceanic Institute.

Watanabe. T., Enrichment of Live Foods. March 4, 1989. Advances in Tropical Aquaculture. Tahiti, February 20 - March 4, 1989.

THE USE OF ARTHROPODS IN EDUCATION

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I appreciate this opportunity to address my colleagues on the use of Arthropods in Education. Education departments are always looking for new ways to teach biological principles. Arthropods are well adapted for this role with their different modes of locomotion, use of defensive secretions, feeding structures, courtship behaviors, social structures, use of protective coloration, near global distribution, methods of communication and sensitivity to environmental changes. They comprise a large percentage of the invertebrate species found worldwide and invertebrates represent ninety-nine percent of all animal species. One can quickly see they offer an endless array of educational opportunities.

At present there are only a few institutions which have very large displays of invertebrates but this not to say that most all institutions can not use Arthropods in their educational programs. We all are familiar with some of the arthropods that surround us, such as: ants, spiders, cockroaches, honey bees, scorpions, butterflies, beetles, crayfish and a multitude of others. As educators we must take this familiarity, and misunderstanding, and use them as building blocks to educate people about exactly how important these animals are to our future.

Arthropods can be used as exhibits or used in more formal education programs. Such places as Cincinnati's Insect World, San Francisco's Insect Zoo, Bronx Zoo's Jungle World and the St. Louis Zoos Living World have put this often forgotten world on exhibit to the public. Within these exhibits a variety of techniques are used to enlighten the public. One of the best methods is to put a variety of species on display within a natural habitat. This is, however, not always enough. Many insects are so small that even though they are displayed in large groups it is just not enough to keep our guests interest peaked unless other methods are employed. Using techniques such as photo enlargements or drawings to highlight features like mouth parts, stingers and the methods used to deploy them, insect eggs and how they differ from other animal eggs, leg structures and how they are used in different modes of locomotion, all add to the experience.

Magnifiers and microscopes can both be used to bring these interesting and often forgotten creatures to our guests. Students, of all ages, can scan butterfly wing scales, look at a flies halteres, gaze upon the multitude of insect egg sizes and shapes,

see the multifaceted eyes of any number of insects or simply discover some tiny insect about which they have never heard. Electronic cameras can be used to highlight the same materials as the manual types but offer a larger screen so more people can view it at the same time. However, electronics can be cost prohibitive to those institutions with smaller budgets.

Use of pinned or preserved specimens can enhance the whole experience since it allows one to display a larger cross section of invertebrate life. A particular species may be easily reared in captivity. Other members of the family or genus may not lend themselves to captive propagation, but can be preserved and displayed to show the variety of specimens found in the group. In addition to pinned specimens, but artifacts like shed scorpion, tarantula or cicada skins embedded in plastic, abandoned nests of wasps lacquered to delay breakdown, cocoons sealed in plastic boxes after the adult has emerged, branches of trees with tunnels of boring insects and spider webs caught on black paper which is sprayed with shellac can be used to highlight the wonders of the invertebrate world. A method to display pinned specimens or artifacts is the Riker mount, a box with cotton backing which presses specimens to protect them against breakage. Next to these other methods, one could incorporate a station with pencil and paper which would allow the visitor to sketch what they have just seen. Throughout all of our educational programs we should use and teach sound scientific methods.

By planting native plant species or leaving pockets of native flora one can set up an area conducive to butterflies and other insect species with a minimum of work or cost. To make these exhibits more educational, signs describing and depicting the common species found in your region and identifying the plant material should be erected. Coupled with these graphics, a brochure detailing the species, both plant and animal, that can be used or expected to come to the insect garden. Information about how to set up their own " butterfly garden" along with a bibliography of references would hopefully give them the impetus to start their own garden and thus make more habitat available for these wonderful creatures.

In addition to displaying arthropods, they may also be used in educational programs. I am aware that there is much discussion about the use of live animals in programs and I will leave that topic until another time. In using live specimens in your demonstrations you must be aware of state, federal and international regulations governing their status in the wild as many are now threatened or endangered. If you use an exotic species, the state and USDA regulations governing the keeping of these species and their use must be checked for their status as possible invader species. Another consideration is the requirements of the animal while it is being transported or waiting to be used in the program. Some guidelines are to have a supply of distilled water for the animal to drink, remove all exhibit furniture or design a unit just for transport with a retreat for

the specimen, use the transport unit for only a single specimen or don't use for other specimens unless it has been thoroughly cleaned, be aware of temperature requirements of the animal and the ambient temperature during transport in addition to where the presentation is to be given. All individuals that handle specimens should be cognizant of some of the possible hazards such as urticating hairs of tarantulas and some caterpillars, stings of scorpions or bites of centipedes, cuts from some stick insects, fluid release from millipedes and that beetles along with cockroaches could transmit disease.

When designing materials for the use of arthropods in an educational program (class), talk about the many important things they do for man. They serve as pollinators of most of our food crops, produce silk and are useful as indicators of how safe our environment actually is. Yes, I know that the control of some members of this group are why we spend millions of dollars to spray millions of gallons of pesticides into the air and onto our soil but we need to emphasize that there are many species that are predators or parasites of the other members of this group. Also select species that can be used to dispel myths or misconceptions such as tarantulas which many people believe if they are bitten they will die but in reality most tarantula bites would only get red and swell slightly like a bee sting. To peak their interest talk about how ants can carry fifty times their weight, monarch butterflies are twelve hundred times more sensitive to sweets than man, caterpillars have four thousand muscles compared to seven hundred ninety-two for humans, that dragonflies can see three hundred sixty degrees and how a flea can broad jump three hundred times their body length.

At Sunset Zoo we incorporate a variety of arthropods into our programs and training classes. In our Junior Zoo Keeper training we use arthropods as examples in addition to birds, mammals, reptiles and amphibians. How to handle Red-kneed Tarantulas (Brachypelma smithi) and Madagascan Hissing Cockroaches (Gromphodorhina portentosa) are part of our docent training program as we use them in our Live Animal programs. During the summer a class on insects is taught periodically where we take students to an outdoor learning facility on zoo grounds to collect specimens which are then brought back to the education building to be identified. Before the field trip a discussion of the general characteristics of insects such as they have a hard exoskeleton, jointed appendages, six legs, antennae, three body segments (head, thorax and abdomen) and the different feeding structures they use. Characteristics of other Arthropods such as spiders, scorpions, millipedes, centipedes and crustaceans are covered to show similarities and differences between the different arthropod classes. To illustrate these characteristics we use a live Red-kneed tarantula, preserved spiders, preserved centipedes, preserved millipedes, preserved crayfish and an insect collection. As a method to show complete metamorphosis a live set of eggs, larvae, pupae and adults of the Tobacco Hornworm (Manduca sexta) are borrowed from a local insect laboratory. Illustration of

incomplete metamorphosis is done using the different immatures of the Boxelder bug (Leptocoris trivittates) which are collected around the zoo. Response to this class has been excellent.

After you have begun using arthropods in your programs consider doing in-service for your local educators about the use of arthropods in the classroom. In doing so discuss the different common species that could be used in the classroom such as mealworms, crickets, ants, crayfish, cockroaches, millipedes and walking sticks. For in-service develop information sheets on how to rear and use these common species in the classroom where they can teach the students respect for animals, respect for the environment, life cycles, habitat design and construction, food requirements, responsibility and to get students interested in using the library to research related animals. All of these can be achieved because of the need to interact and discover which allows many to get past the "fear" factor related to many of the arthropod species.

As one presents programs on these animals or puts them on display they must be prepared to act as a clearing house for information and for identification of native species which the lay person can not identify. Don't let this scare you as it only reinforces what you know but also demonstrates what we need to teach our guests.

Arthropods are a large part of the animal kingdom, many are easily maintained, they have many diverse characteristics and lend themselves to a variety of methods of presentation. This paper is by no means a comprehensive look at how arthropods can be used to educate our guests but is meant to stimulate you to use this vast group of animals in your education programs.

Understanding the Big Picture: The Importance of Invertebrate Education

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Bugs.
Nobody likes them.
We swat them, spray them, step on them.
Beetles, ants, flies, mosquitoes, roaches. Especially roaches.

So begins the opening paragraph of a book by Dr. Arthur Henley entitled Phobias: The Crippling Fears. Entomophobia (fear of insects) is one among a list of medically recognized phobias involving animals. Other fears include Ailurophobia (fear of cats), Cynophobia (fear of dogs), Muriphobia (fear of mice), Ophidiophobia (fear of snakes), and the now notorious Arachnophobia (fear of spiders). While most people never develop a full-blown phobia involving insects and other invertebrates, it is clear that whether scorned, squashed or sprayed, this group of creatures has taken it on the chin ever since humans first noticed them (Pyle, 1989). Even Shakespeare had comments about invertebrates; "Hence you long-legged spinners, hence! Beetles black, approach not near; worm nor snail, do no offence". Saint Augustine once said that insects were creatures of the devil.

The truth is that we need invertebrates, but they don't need us. Professor E.O. Wilson has noted that if human beings were to disappear tomorrow, the world would go on with little change. But if invertebrates were to disappear, it is doubtful that the human species could last more than a few months. When people are questioned about their fear and loathing of certain invertebrates, typical responses include, "they bite", "they spread disease", "they're ugly". While there are numerous occasions when the lives of invertebrates impinge on the lives of humans (as in crop pests and invertebrate vectors of disease), even adults and children who cannot site any significant inconvenience related to invertebrates express strong feelings of hatred.

Anthropologists have documented that human beings have an innate fear of snakes, or more precisely, they have an innate propensity to learn such fear quickly and easily past the age of five. It seems that a similar propensity to learn fear and develop hatred exists regarding invertebrates. Fear and loathing are passed from generation to generation and are based largely on ignorance. Of all the bias, prejudice and anxiety we may pass on to children, fear and hatred of insects and other spineless creatures may seem unimportant. But in fact, it is this lack of understanding of natural systems, fueled by anthropocentrism that

distorts the human view of the world and may lie at the root of many political, social, economic and environmental problems. We need to be aware of the bias that exists in education, and as scientists and educators, promote creative change.

E.O. Wilson has called invertebrates "the little things that run the world". But in a survey of children's literature, it is more common than not to find reference books with titles such as Animal Encyclopedia for Children, The Animal Kingdom, Children's Atlas of World Wildlife and Animal World with hardly a mention of the over 990,000 known species of invertebrates. Several books also group animals in a misrepresentative manner. For example, in the Animal Atlas, published in 1992, a page showing animal "groups" pictures six divisions; one for fish, one for amphibians, one for reptiles, one for birds, one for mammals, and one for invertebrates. Besides being scientifically incorrect, this artificial grouping presents an inaccurate educational message which downplays the importance of invertebrates. Professor Wilson has described a scenario of life without the spineless ones:

"If invertebrates were to disappear, I doubt that the human species could last more than a few months. Most of the fishes, amphibians, birds, and mammals would crash to extinction about the same time. Next would go the bulk of the flowering plants and with them the physical structure of the majority of the forests and other terrestrial habitats of the world. The earth would rot. As dead vegetation piled up and dried out, narrowing and closing the channels of the nutrient cycles, other complex forms of vegetation would die off, and with them the last remnants of the vertebrates. The remaining fungi, after enjoying a population explosion of stupendous proportions, would also perish. Within a few decades the world would return to the state of a billion years ago, composed primarily of bacteria, algae, and a few other very simple multi-cellular plants" (Wilson, 1987).

Two children's books on tropical rainforests entitled, Animals of the Tropical Rainforests and Jungle Animals make no mention of invertebrates, not even insects. In a typical tropical rainforest, each hectare contains a few dozen birds and mammals, but well over one billion invertebrates! In the Amazon forest the ants alone have more than four times the biomass of all of the land vertebrates combined - amphibians, reptiles, birds and mammals (Wilson, 1987).

Children's books like The Icky Bug Counting Book and Creepy Crawlies exhibit bias in their titles as well as in their text. Statements such as "beetles eat big plants and little plants" misrepresent this fascinating group of insects, whose members comprise one out of every four species of animals. In the picture accompanying this text one type of beetle is shown, with no mention of the other 289,999 known species of beetles that represent a variety of lifestyles, including some beneficial to humans. Other biased statements found include, "Three Elegant Crab Spiders are walking on a branch. It is hard to believe anyone would name a

spider "Elegant"! "Kissing bugs do not kiss other bugs. They bite other bugs in the face. Kissing bugs are not very nice." "Moth larvae eat holes in your wool clothes." (reality: the larvae of less than one-tenth of one percent of moth species threaten your woolens; (Winter, 1989). "Blister beetles walk around on the desert sand. Blister beetles squirt a liquid that causes blisters on people. Yuck! Icky!" And then on the following page, "Actually, Blister Beetles are not that bad. Some are used to make medicines that help people." The biased message being that if an animal can be used by humans, it is elevated.

On average, children's non-fiction sections in Columbus libraries contain three-hundred books on various invertebrate species, as compared to eight-hundred on mammals, and six to seven-hundred on birds. Approximately one-third of the invertebrate selections are on butterflies. Not surprisingly, scores of books on "baby" animals rarely mention young invertebrates. When school children attending educational programs at the Columbus Zoo were asked the question, "are insects animals?", they routinely answered, "no". (Ironically, children also frequently answer "no" when asked if people are animals).

Expressions which ridicule invertebrates have become incorporated into our language. "Crabby" refers to an extremely ill-tempered person. "Slug" is defined as a lazy, indolent individual. "Worm" has come to describe a pitiable, contemptible, or weak-willed person. "Louse" describes a mean or contemptible person. A "leech" is a human being who ruthlessly sucks profit out of another. "Spineless" describes a person lacking courage or willpower.

Because species diversity was created prior to humanity, and because humans evolved within it, we have never fathomed its limits (Wilson, 1984). As the philosopher D.M. Templemore said, "all man's troubles may arise from the fact that we do not know what we are and do not agree on what we want to become". This crucial inadequacy is not likely to be remedied until we have a better grasp of the diversity of life that created and sustains us (Wilson, 1984). Children must grow up understanding the "big picture", or in other words, that "interdependency is all" (Myers, 1984). At the Earth Summit last June the planet's most pressing ills; drought, desertification, erosion, population growth, air and water pollution, destruction of forests and loss of biological diversity were confronted. The solution, in broad outline, is fairly clear. The nations of the world must abandon those practices that are self-destructive in favor of sustainable development. Balancing economic growth and ecological concerns will require creative problem solving by women and men that have a deep understanding of the interrelatedness of species.

If we eliminate just one kind of tree out of hundreds in a forest, some of its pollinators, leaf-eaters, and wood borers will disappear with it, then various of their parasites and key predators, and perhaps a species of bat or bird that depends on its

fruit. And when will the reverberations end? Perhaps not until a large part of the diversity of the forest collapses. The effects are beyond the power of present-day ecologists to predict (Wilson, 1984). Preserving species is necessary, but, we have found, insufficient. Greater attention will be given to conserving the full array of the earth's representative ecosystems.

As the indicators of ecosystem health, little things will have special importance (Beebe, 1990). Signs of ecosystem stress may first be observed in populations of microorganisms in lake and stream bottoms and soils. And nowhere are the critical roles of insects and other invertebrates more evident than in forest soils. Experiments have shown that insects and other microarthropods control the metabolic activity of fungi and bacteria, which liberate nutrients through litter decomposition and chemical transformation of the soil (Moldenke, 1990). Some scientists are using microarthropods to examine questions of "biological legacy": how long does the biochemical signature of an individual tree remain imprinted on the local soil ecosystem once it blows down or is cut? Do management practices such as slash-and-burn and the use of herbicides have long-lasting effects on the soil that can be detected years or even decades later? If we are to achieve sustainable development, we need to know the answers to these questions (Moldenke, 1990).

And this is where we, the zookeepers and zoo educators come in. We are in a unique position to influence children through programs we present at our facilities. These girls and boys will grow up to be economists, farmers, loggers, teachers, Secretaries of the Interior, and presidents. In the past few years we have seen the environment become the perceived "enemy" for many citizens. "Put People First" has become a battle cry of sorts for politicians who perceive the economic activities of people and preservation of biological diversity to be mutually exclusive. A U.S. delegate at the Rio summit was quoted as insisting that "the American life-style is not up for negotiation" (Dewitt, 1992). What a different world it would be if policy-makers understood that without sustainable development there will be no "life-style".

During the 1970's three insectariums opened to the public in the U.S. Many other zoos and museums soon followed suit, and invertebrates have become a big draw for children and adults. Interactive components in the exhibits, including "hands-on" sessions with some animals are doubtless reforming attitudes towards the spineless majority. Books which represent invertebrates as fascinating animals to be observed with wonder are appearing in children's literature. "Folktale" puppets (octopus, crab, spider, firefly, cricket, ladybug, bee, cockroach, fly, butterfly, scorpion) have brought invertebrates into the world of stuffed animals, and offer a wonderful opportunity to introduce children to these animals in an entertaining and non-threatening way.

Connecting with teachers should be the ultimate goal. Acquire

materials (books, puppets, instructional materials, biofacts, slides, photographs etc...) that can circulate in local classrooms. Organize an invertebrate workshop for teachers in your area (it is not necessary to have an invertebrate exhibit to do this). Work with your volunteers to develop an invertebrate outreach program. Write a children's book or article with an invertebrate topic. When it's time to give birthday or Christmas gifts to children in your life, forget the GameBoy, give them books, then sit down and read with them. Even with the mountains of toys children have, attention from adults is still their favorite. Become a crusader for holistic education. Help stamp out hierarchical thinking. In the natural world there is no top and bottom, there is only grand diversity.

Professor Wilson told Harvard magazine that what future generations would find hardest to forgive is the massive destruction of biological diversity. Our task, as Albert Einstein instructed us, is to "free ourselves...by widening our circle of compassion to embrace all living creatures and the whole of nature in its beauty."

REFERENCES

Beebe, Spencer B., 1990. Ecosystem Conservation in the Temperate Rainforest. Wings: Essays on Invertebrate Conservation (3-6).

Collins, Mark N., 1989. International Zoo News. Invertebrate Displays in Zoos of the Future (15-21).

Dodson, Elizabeth Gray, 1984. Green Paradise Lost.

d'Entreves, Passarin, 1975. The Secret Life of Insects.

Furth, David, 1991. Beetlemania. Wings: Essays on Invertebrate Conservation.

Lattin, John D., 1990. Arthropod Diversity in Northwest Old-Growth Forests. Wings: Essays on Invertebrate Conservation (7-10).

Moldenke, Andrew, 1990. One Hundred Twenty Thousand Little Legs. Wings: Essays on Invertebrate Conservation (7-10).

Pallotta, Jerry, 1992. The Icky Bug Counting Book.

Pyle, Michael, 1989. Spineless Wonders. International Wildlife.

Wilson, E.O., 1984. Biophilia: The Human Bond With Other Species.

Wilson, E.O., 1987, The Little Things That Run the World. Wings: Essays on Invertebrate Conservation (3-7).

Wilson, E.O., 1991. Ants. Wings: Essays on Invertebrate Conservation.