EAZA Best Practice Guidelines for the Giant Magnolia Snail (*Bertia cambojiensis*)

EAZA Terrestrial Invertebrate Taxon Advisory Group , Edition 1.0

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Preamble

Right from the very beginning it has been the concern of EAZA and the EEPs to encourage and promote the highest possible standards for husbandry of zoo and aquarium animals. For this reason, quite early on, EAZA developed the “Standards for the Accommodation and Care of Animals in Zoos and Aquaria”. These standards lay down general principles of animal keeping, to which the Members of EAZA feel themselves committed. Above and beyond this, some countries have defined regulatory minimum standards for the keeping of individual species regarding the size and furnishings of enclosures etc., which, according to the opinion of authors, should definitely be fulfilled before allowing such animals to be kept within the area of the jurisdiction of those countries.

These minimum standards are intended to determine the borderline of acceptable animal welfare. It is not permitted to fall short of these standards. How difficult it is to determine the standards, however, can be seen in the fact that minimum standards vary from country to country.

Above and beyond this, specialists of the EEPs and TAGs have undertaken the considerable task of laying down guidelines for keeping individual animal species. Whilst some aspects of husbandry reported in the guidelines will define minimum standards, in general, these guidelines are not to be understood as minimum requirements; they represent best practice. As such the EAZA Best Practice Guidelines for keeping animals intend rather to describe the desirable design of enclosures and prerequisites for animal keeping that are, according to the present state of knowledge, considered as being optimal for each species. They intend above all to indicate how enclosures should be designed and what conditions should be fulfilled for the optimal care of individual species.

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Summary

There is very little information available on this snail's natural history in the wild, mostly due to its extreme rarity. All published literature on the species to date is summarised and referenced herein, alongside the gathered knowledge of the few institutions currently keeping them. More information is almost certain to come to light in future, and this document will therefore likely go through regular updates and various versions.

This is the largest terrestrial mollusc in Southeast Asia, and its rediscovery in 2012 after more than a century with no records took the malacological community by surprise. It is restricted to primary lowland rainforest, and habitat loss and intense collection pressure continue to threaten the species.

The care of this Critically Endangered mollusc is more challenging than that of many other land snails, owing to its sensitivity to irregular substrate and food changes and pest invasions. This species requires very large quantities of fresh leaf litter, consistently high humidity & temperature, and a high protein diet to fuel its rapid growth. Colonies multiply slowly despite the large clutch sizes produced, due to the species' unusual biology of provisioning their young with infertile 'nurse eggs', and the young juveniles are very sensitive to disturbance. Despite this interested, collections are actively encouraged to take on the species, due to its beauty and extremely high conservation value.

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Section 1: Biology and FieldData

1.1 Taxonomy

- Order: Stylommatophora
- Family: Dyakiidae
- Genus: *Bertia*
- Species: *Bertia cambojiensis*
- Common name(s): Giant Magnolia Snail, Vietnamese Giant Magnolia Snail

1.2 Morphology

Bertia cambojiensis is a large species, having the largest shell of any land snail in Southeast Asia (Hun et al., 2019), measuring 70x60mm (length x height) in mature, captive bred adults (Chester Zoo, unpublished data). This makes them around six times large than the shell of a European garden snail *Cornu aspersum*. The shell is glossy, predominantly rich brown, patterned with cream and black bands (Fig. 2, Fig. 3). The head is dark with blackish reticulations and two long black tentacles. The body is lighter brown and reticulated, with an orange-brown base to the foot (Fig. 1) Juveniles do not hatch out with this colouration- see section 1.7.1 developmental stages to sexual maturity.

Figure 1. Adult *Bertia cambojiensis*, showing the distinctive markings and colouration of the species. Photo by T. Ziegler.

Figure 2. Four adult giant magnolia snails; lower-left individual is a wild-caught founder. Photo by T. Papp.

Figure 3. Shell of an adult giant magnolia snail, showing the distinctive & striking markings of the shell base. Photos by K. Kelton & S. Rawlins, Chester Zoo.

Well-established adults from the initial import from Vietnam weighed 110-165g (Fig. 5). healthy adults from 2018 and 2021 clutches were found to weigh 70-120g. Growth rate can be very rapid, as seen in the graph below (Fig. 4). A study of the wild population in Vietnam found individuals weighed up to 103g (Hoai Phong, 2019). This relatively low maximum weight, lower than the founders collected in 2012 and many captive-bred adults, could be due to harvesting from the wild targeting larger individuals, or simply due to very limited data sets inducing apparent differences, or other as yet unknown factors such as seasonal variation in weight.

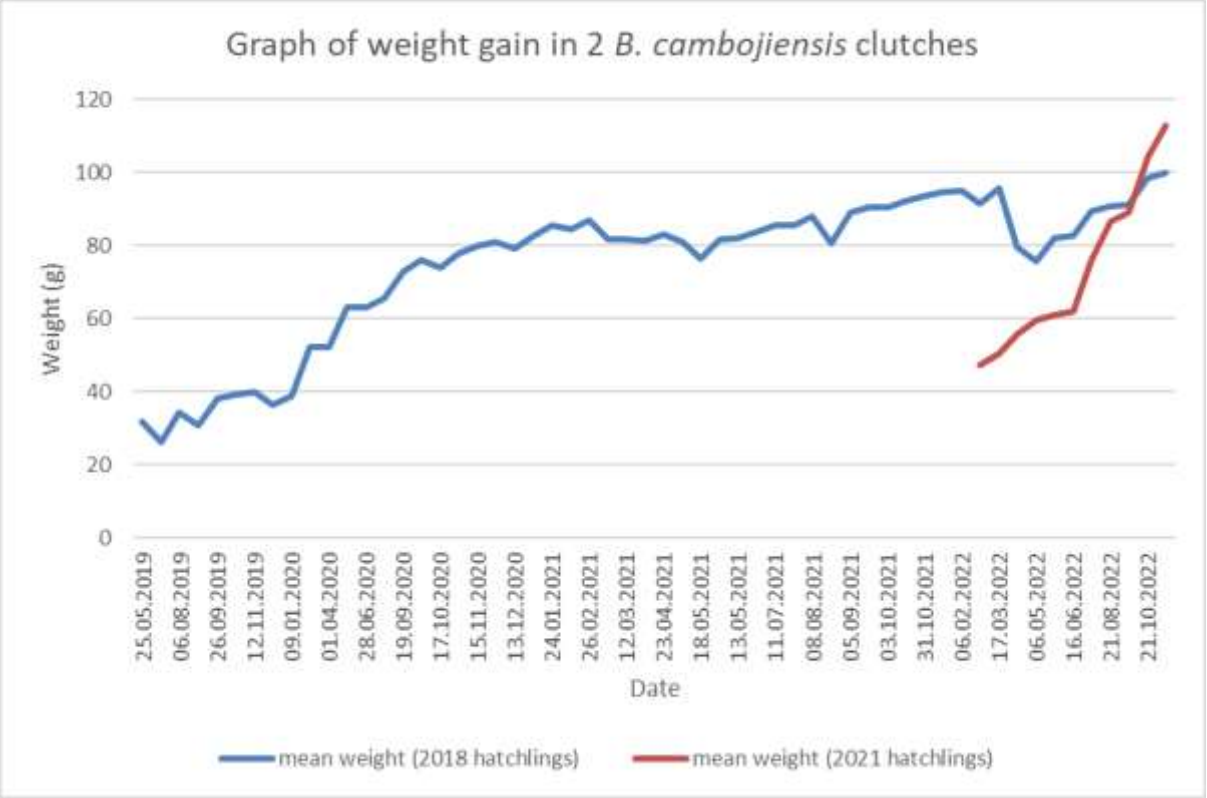

Figure 4: Graph of weight gain in two captive-bred clutches of *B. cambojiensis* at Chester Zoo. More rapid growth in 2021 clutch indicative of continuing improvements in husbandry and better understanding of requirements of juvenile snails. Dips in mean weight of 2018 clutch in May 2021 & April/May 2022 associated with egg-laying.

Figure 5: Weighing of a wild-collected founder *B. cambojiensis*. Photo by T. Papp.

1.3 Physiology

No physiological studies of *B. cambojiensis* have been published, and little literature is available on the physiology of its relatives within the genus *Bertia* and family Dyakiidae.

These large snails are sinistral (anticlockwise coiling) and have large, well-rounded, semi-globose shells (Jirapatrasilp et al., 2020). The genus *Bertia* is distinguished from other snails in the family Dyakiidae by the possession of an amatorial organ gland with four lobes, each lobe with a thick amatorial organ duct (Jirapatrasilp et al., 2020).

One of the most interesting physiological features of land snails is the 'love dart', the calcareous structure containing the sperm which is used by a snail to pierce the partner's body and transfer sperm during mating (Lodi & Koene, 2015). These structures vary greatly across snail taxa but have been little-studied in most species. It has been observed that in snails of the family Dyakiidae the love dart is not coated externally in sperm-containing mucous as in many land snail species, but based on the structure of perforations and channels, Dyakiid love darts may function more like a hypodermic needle, injecting mucous straight into a partner's haemolymph (Lodi & Koene, 2015).

This species also has a physiological defence mechanism; upon detecting a perceived threat, a giant magnolia snail will withdraw into its shell and may produce copious amounts of a yellow mucous, which bubbles from around the aperture of the shell. This mucous is extremely slippery (Papp, pers. obs.) and may additionally act to prevent a predator from gripping the snail or its shell (Fig. 6) Nothing is known about the toxicity of this secretion, making handling without gloves unwise.

Figure 6: An adult *B. cambojiensis*, having just been handled, showing the thick yellow mucous this species produces as a defensive mechanism. Photo by T. Papp.

1.4 Longevity

One specimen, which was bred at ZSL London Zoo in spring 2015, passed away in December 2022 at Chester Zoo (ZIMS, 2023). This was the last survivor from the import from ZSL and gives a longevity record of 7.5 years. Wild longevity is not known, as no long-term capture-mark-recapture study has been undertaken on this species (see recommended research, section 2.8), but it assumed that due to predation and other risks wild longevity may be shorter. Conversely, as knowledge on the husbandry of the species improves, longevity of held individuals may continue to increase.

Field data

1.5 Conservation status/Zoogeography/Ecology

1.5.1 Distribution

The giant magnolia snail was first described in 1860, on the basis of a large & distinctive sinistral (anticlockwise coiling) specimen believed to be from Cambodia, initially under the name *Helix cambojiensis* Reeve, 1860. Ancey (1887) split it into the new genus *Bertia.* For the next 152 years after its initial description, no more data or observations of the species were published (Sutjarit et al., 2019), leading to the widespread assumption that the species was extinct (Coney, 2001). In 2012, a few living specimens of this species were found in Cat Tien National Park, in southern Vietnam (Sutjarit et al., 2019) and some were collected and brought into human care. It is from this collection that the held stock derives. There is a historical record of the species from Ba Vì National Park in northern Vietnam (Schileyko, 2011), but this is considered highly doubtful (Sutjarit et al., 2019). The species was assessed as Critically Endangered in 2013 due to its very limited range, presumed low population size due to few specimens being recorded, and the threat of collection both for food and for the shell trade (Naggs, 2014). In 2018 the species was discovered to be also living in eastern Cambodia, in the Keo Seima Wildlife Sanctuary (Fig. 7), very close to the border with Vietnam (Hun et al., 2019).

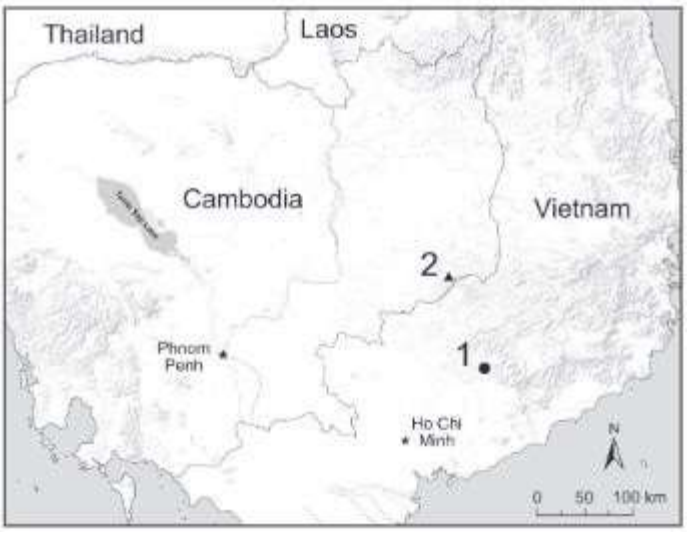

Figure 7. Map of Cambodia & southern Vietnam, showing elevation and country borders, and indicating (1) Cat Tien National Park and (2) Keo Seima Wildlife Sanctuary, the two known locations for *Bertia cambojiensis*. From Hun et al., 2019.

1.5.2 Habitat

Very little is known of the species' ecology in the wild. Snails have been observed in leaf litter, on rotten fallen trunks and branches, and on rocks (Hoai Phong, 2019). Most observations have been made in the rainy season. It has been observed in several forest types; bamboo forests, mixed forests, and evergreen forests, and locations of observations have acidic soil pH, high soil moisture (30%), high humidity, and average soil temperatures of 25.5°C (Hoai Phong, 2019).

1.5.3 Population

The number of wild individuals is not known with any certainty but is presumed to be very low due to the extreme scarcity of sightings and long time between records. A survey of wild populations in Vietnam found a population density of 0.001 snails per m^2 (Hoai Phong, 2019). Following its rediscovery, *B. cambojiensis* was first bred in captivity at ZSL in 2014 (Fig. 8). Chester Zoo first received this species from ZSL London Zoo in 2017, and the founder group consisted of two specimens from Vietnam and three bred at ZSL in 2015. The species first reproduced at Chester Zoo in 2018, and has bred almost every year since, apart from 2020. As of February 2024, Chester houses 51 individuals of this species, roughly 60% of the European *ex-situ* population, all of which were bred at the zoo.

Figure 8: The world's first captive-bred *B. cambojiensis*, in 2014. Please not that it is now recommended to always wear gloves when handling this species. Photo by P. Pearce-Kelly, ZSL.

1.5.4 Conservation Status

Not long after its rediscovery, the species was assessed as Critically Endangered (CR) on the IUCN red list (Naggs, 2014). This was due to its very restricted range and presumed small population size, as well as the immediate threat posed by the risk of overcollection due to the high price fetched by the shells of this species (Naggs, 2014). The species has not been re-evaluated since this initial 2014 assessment, however despite its rediscovery across the border in Cambodia the species' known range has not increased significantly, nor have the threats decreased sufficiently to presume the species no longer qualifies for CR listing. When it was rediscovered in Cambodia, habitat loss was additionally noted as a potential threat, and empty shells of this species discarded after cooking were observed in Keo Seima Wildlife Sanctuary, demonstrating the risk posed by collection for local consumption (Hun et al., 2019).

1.6 Diet and FeedingBehaviour

As with all aspects of this species' ecology, its feeding habits are very little known. Wild diet has been observed to include fallen fruit, fungi, and land crabs (Hoai Phong, 2019), with the latter presumably being scavenged dead individuals. This may provide an important source of both protein and calcium in the wild. See section 2.2 below for details of diet offered in zoological institutions.

1.7 Reproduction

Nothing is known of the species' reproduction in the wild, due to a lack of observations. All knowledge of the species' reproductive biology and behaviour has been gleaned from observations in holdings (Fig. 9).

Figure 9: Adult *B. cambojiensis* in the process of laying an egg. Photos by K. Kelton.

1.7.1 Developmental Stages to Sexual Maturity

This species undergoes extremely rapid growth for a land snail, doubling in size within the first week of hatching and continuing a very rapid rate of growth for the first few months (Fig. 10). Hatchlings measure 8-9mm in shell diameter. Fresh hatchlings start off translucent, darkening to brown once they begin feeding, and the distinctive colouration of the adults develops after approximately one month.

Figure 10: Juvenile giant magnolia snails, at two weeks old (left) and one month old (right). Photo by S. Rawlins, Chester Zoo.

1.7.2 Age of Sexual Maturity

Individuals can reach sexual maturity at 2-2.5 years of age with good quality husbandry (see section 2.4.4 for further discussion of growth & maturity). Wild age of first breeding is not known (see recommended research, section 2.8).

1.7.3 Seasonality of Cycling

Fertile clutches have been found *ex-situ* in both spring (March-May) and autumn (September). Other collections have reported spring breeding only. These breeding successes have been achieved without seasonal variation in temperature & humidity.
Climatic data from Cat Tien National Park shows a wet season lasting from April to November, with the wettest month being September, with mean relative humidity of 88.9% and mean rainfall of 442mm. January and February are the driest months. April is the hottest month, coinciding with the arrival of the rains, with a mean temperature of 28.3°C. there is not much season temperature fluctuation, with the coolest month, December, having an average temperature of 24.7°C (Deshcherevskaya et al., 2013). It has been suggested that atmospheric changes in spring may trigger reproduction in this species (Pearce-Kelly, pers. comm.), but this has not been proven, and requires further investigation (see recommended research, section 2.8).

Table 1: Climatic data per month from Cat Tien National Park. From Deshcherevskaya et al., 2013.

Parameter*	Month											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Temperature, °C	25.0	26.2	27.6	28.3	27.8	26.9	26.4	26.2	26.0	25.9	25.5	24.7
Standard temperature deviation, °C	1.1	0.7	0.5	0.7	0.7	0.6	0.5	0.5	0.4	0.5	0.6	0.9
Maximum temperature, °C	35.4	37.0	38.3	38.5	38.0	35.9	34.6	34.2	34.1	35.0	34.7	34.1
Minimum temperature, °C	13.0	14.6	15.0	19.6	20.1	20.8	20.4	19.9	20.5	16.5	13.2	13.0
Precipitation, mm	8.2	15.5	51.1	145.2	268.4	328.6	328.6	397.7	442.2	354.4	136.5	41.4
Standard deviation, mm	16.2	25.1	52.6	92.3	105.0	121.9	110.1	115.1	134.2	98.2	82.4	48.8
Number of days with precipitation	1.5	1.7	4.5	10.4	17.9	21.3	23.4	23.9	25.5	22.6	12.2	4.5
Relative humidity*, %	70.9	70.1	70.2	74.7	81.1	85.5	87.2	88.8	88.9	86.4	80.1	74.1
Wind velocity**, m/s	1.5	1.4	1.6	1.4	1.5	1.5	1.6	1.5	1.3	1.2	1.3	1.7
Duration of sunshine**, h	275.4	255.8	267.3	243.1	224.2	181.8	178.8	154.9	150.8	185.8	214.2	245.2

* Monthly mean values are given for all parameters except for minimum and maximum temperatures. The recorded absolute maximum and absolute minimum are given for the maximum and minimum temperatures (instantaneous values between the observation times).
** The values are based on the data of the Phuoc Long meteorological station because they are not available from the Đồng Xoài station.

1.7.4 Gestation period/Incubation

Observations at Chester Zoo have consistently shown an incubation time of 14-20 days for this species, based on individuals directly observed laying eggs. This is at the optimum conditions for the species described in section 2.1.4; deviation from this may impact hatching times.

1.7.5 Clutch Size/Number

Although clutch sizes in this species are large (100+), very few of these eggs seem to be fertile, with generally >20 hatchlings successfully emerging per clutch. This is thought to be due to the majority of the clutch being infertile 'nurse eggs', left by the adult as a food source for the hatchlings, and possibly laid at a separate time (Pearce-Kelly, pers. obs.). See section 2.4 below for more details of breeding this species in captivity.

1.8 Behaviour

1.8.1 Activity

Based on observations of individuals in captivity, the species is predominantly nocturnal and crepuscular, with highest levels of activity observed in the evening (Fig. 11). Mating is very rarely observed and is presumed to take place overnight.
In Cambodia in the early dry season, live specimens were only located within 20m of a stream on dry ground in leaf litter, or in shade under logs and fallen trees. Empty shells but no live snails were found in the forest away from stream (Hun et al., 2019), suggesting that individuals may disperse away from the permanent water sources during the wet season.

In surveys in Vietnam, very few specimens were found in the dry season, with only three found, in leaf litter; these were in more concealed locations than in the wet season, such as under rock niches (Hoai Phong, 2019). The same report also states that the species aestivates in the dry season but will emerge from its shell following occasional rain. Surveys in the wet season found many more snails at the same sites, and these were recorded on the ground, under leaf litter, on rocks, rotten fallen trees and on fallen branches (Hoai Phong, 2019).

Figure 11: This species is most active during periods of low light levels. Photo by G. Garcia.

1.8.2 Locomotion

As with other land snails, giant magnolia snails move using their single large muscular foot. All observations from the wild suggest the species is completely terrestrial, with individuals being recorded on the ground, under leaf litter, or on low objects such as fallen tree trunks and rocks (Hoai Phong, 2019; Hun et al., 2019). Observations in *ex-situ* populations suggest a wider range of movement, with snails found hanging from top of enclosures, and a layer of slime present on the top even on mesh-topped tanks (Papp, pers. obs.).

1.8.3 Predation

Nothing is known of predation on this species in the wild. The snail's defensive secretion of slippery yellow slime (see section 1.3) may put off many potential predators. It is assumed, as such a large-bodied mollusc, it is valuable prey to various predators, but wild predators of the species are not known (see section 2.8). It is known to be consumed by people in Cambodia (Hun et al., 2019).

1.8.4 Social Behaviour

No social interactions have been noted in this species. Although individuals may sometimes be seen crawling over each other's shells (Fig. 12), there are not at present thought to be any social bonds in this species outside of mating. Such clustering behaviour is thought to simply be snails seeking out the same environmental conditions and has been shown in other species to be driven by olfactory cues (Chase et al., 1980).

Mating has not been observed in this species and based upon other land snails is thought to take place overnight. This species is hermaphroditic, and co-fertilisation may occur, as in other land snails, with both mating partners simultaneously injecting each other with sperm-containing mucous (Lodi & Koene, 2015).

Figure 12: Although they sometimes climb over each other's shells, social interaction is not known in giant magnolia snails. Photo by K. Kelton.

1.8.5 Courtship and Mating

Like much of the species' behaviour, courtship and mating is only known from observations in captivity. Observations at Cologne Zoo suggest that mating may occur, as in many terrestrial gastropods, face-to-face and is preluded by one individual everting its penis for an extended duration (Fig. 13).

Figure 13: *B. cambojiensis* courtship filmed at Cologne Zoo, showing **A.** snail with penis everted and **B.** individuals facing each other prior to mating. Photos by P. Klaas.

Section 2: Management in Zoos and Aquaria

2.1 Enclosure

2.1.1 Boundary

Glass vivaria (Fig. 15) or plastic tubs (Fig. 16) can both be used to house this species. While vivaria with hinged doors are not recommended for many snail species due to the risk of crushing snails sheltering near the door when opening the vivarium, this is rarely an issue for this species due to the large body size (Fig. 14) and tendency to spend the majority of their time spent in the leaf litter rather than on the glass. Regardless, juveniles are best housed in plastic tubs, both to prevent the small risk of getting crushed by hinged vivarium doors and to more easily achieve and maintain the very high humidity required by the juveniles.

Figure 14: Unlike many other snails, hinge-door terraria do not pose issues for adult *B. cambojiensis*. Photo by T. Papp.

Due to the high sensitivity of these snails to a number of pest invertebrates (e.g. isopods, cockroaches, ants) barrier management is important to prevent unwanted infestations. This can easily be achieved through the use of water baths (trays of water containing a small amount of washing up liquid, at a concentration of around 10ml per litre) which pest invertebrates are unable or unwilling to cross. These can be placed under individual enclosures or under whole shelving units housing multiple enclosures, or both, ensuring there is nothing bridging the moat and allowing colonisation, and that the moat is wide enough to prevent colonisation by larger pests (e.g. cockroaches). .

Figure 15: Enclosure for six adult *B. cambojiensis* at Chester Zoo. Photo by K. Richardson.

Figure 16: Despite being predominantly terrestrial, *B. cambojiensis* will utilise the full height of any tank or tub they are housed in. Photo by I. Newens-Hill.

2.1.2 Substrate

The substrate used for giant magnolia snails must be moisture-retaining to allow the maintenance of humidity and the successful deposition and incubation of eggs. Snails will spend much of their time on the top of this substrate, buried in the leaf litter above it. Materials such as a mix of coir and sand are best, and while peat-containing composts may be suitable they should be avoided due to the detrimental environmental impacts of peat extraction (Alexander et al., 2008).

2.1.3 Furnishings and Maintenance

Items such as logs (preferably oak or other similar hardwoods; avoid pine or other conifers due to potential impacts of their resin), or hides can be provided to these snails but are not considered essential as the snails will spend most of their time within the leaf litter. Care must be taken to ensure any such décor is unable to be moved or dislodged by snails moving in the leaf litter, as this may cause injuries. Live or artificial plants can be used within on-display exhibits to improve the aesthetics of the enclosure for visitors (Fig. 17) but are not necessary for the species' husbandry. The best plants to use are tough species like *Scindapsus pictus* that can tolerate damage well, as these large, omnivorous snails may nibble at foliage or break it simply by moving across the plant. If provided with a large source of calcium carbonate such as pure limestone rocks or whole cuttlefish bone, the snails will crawl over the surface of it while consuming the calcium.

Figure 17: On-display enclosure for four adult giant magnolia snails at Chester Zoo. Featured plants are *Aglaonema* 'Cutlass' (left) and *Scindapsus pictus* (right). Photo by T. Papp.

2.1.4 Environment

In line with observed temperatures in the wild (see section 1.7.3), enclosures should be maintained at 23-27°C. This can be achieved by fitting a heat mat on a thermostat to the back of the vivarium, or by heating the whole room; heating should not be provided from underneath the enclosure as this will lead to desiccation. Any heat mats and thermostats used should be reputable reptile specific products, such as Exo-Terra (Exo Terra, 2024) or HabiStat (HabiStat, 2024). Short drops below this e.g. overnight can be tolerated by these snails, however longer exposure to temperatures below this range, especially those below 20°C, are detrimental and lead to a sharp decline in activity levels. Temperatures above this range likewise can be tolerated for short periods but again are not recommended long-term. At Chester Zoo lighting for adult tanks is provided by 1150mm 54W T5 2.4% UV tubes (Arcadia Reptile, 2023), however this is predominantly for the benefit of the keeper while servicing the enclosures, to provide illumination and visibility. Studies in other land snail species suggest photoperiod has an impact on breeding

behaviour (Benbellil-Tafoughalt et al., 2009).

Enclosures should feature a drainage layer of hydroleca (Fig. 18A) or a similar material, which is necessary due to the high humidity and heavy spraying requirements of this species. Drainage can further be improved by adding a plastic drain within the substrate, allowing excess water to flow down more easily into the drainage layer (Fig. 18B). Above this, a thin membrane is placed, and then a layer of coir and sand (ratio of 3:1 coir: sand) around 5-10cm deep.

Figure 18: Setting up a *Bertia* enclosure. A good drainage layer of hydroleca prevents waterlogging of substrate (left) and a drain lined with coir matting further improves drainage (right). Photos by T. Papp.

Above that, large quantities of dead leaf litter are piled. The species seems highly dependent upon leaf litter and is much less active when less leaf litter is used. When first placed into the enclosure, the leaf litter should be most of the height of the vivarium above the substrate, meaning a depth of at least 20cm is recommended (Fig. 18). The species of leaves does not seem critical, except that the snails seem to do better with locally collected native leaf litter (e.g. oak *Quercus* sp*.,* beech *Fagus sylvatica,* field maple *Acer campestre* and poplar *Populus* sp. have all proved successful) rather than tropical species (e.g. *Ficus sp.*), which do not seem to have the same impact upon activity levels. Walnut (*Juglans* sp.*)* leaf litter is to be avoided due to toxins. Leaf litter is frozen for at least 48 hours at -18°C to remove any potential pathogens or other unwanted pests, and then washed in boiling water prior to being placed in enclosures. It is also vital to ensure the leaf litter has cooled down after the boiling wash before the snails are returned to the enclosure to avoid harming them. Leaf litter can subsequently be rinsed with cooler, filtered water prior to being placed in the enclosure to remove further soil and detritus, if necessary. The exact significance of the leaf litter is not yet understood; although the snails do sometimes feed on it, in those cases it apparently passes through their gut undigested and is excreted, suggesting it is not a nutritional requirement.

Figure 19: Enclosure for adult snails with freshly changed leaf litter, showing the desirable depth of leaf litter for this species. Vivarium is 45cm tall in total. Photo by K. Richardson.

Also of importance for this species is the frequent changing of this leaf litter. The activity level of the snails is high upon fresh leaf litter being initially added, but after a couple of weeks, once it starts decaying, activity levels begin to decline, feeding decreases, and weight loss can be observed. Less frequent changing of leaf litter has been linked to periods of lower activity and weight loss and periods of slower growth in immature snails, leading to snails developing less-smooth shells due to inconsistent growth rate. It is therefore important to not delay routine maintenance activities and ensure the leaf litter within the enclosure is replaced within a maximum of 3 weeks, although more frequently than this is preferred.

Humidity in the enclosures should be kept constantly high, ideally above 80% (Fig. 20). This can be achieved through twice daily spraying with around 50ml of water per tank, although an automated misting system, such as MistKing (MistKing Ltd., 2023) or similar could be used, as long as the reservoir is checked regularly. All water involved in the husbandry of these snails, both for spraying enclosures and for the washing of leaf litter, should be filtered water; the use of tap water is linked to a sharp drop in activity levels. Both Heavy Metal Axe (HMA) and Reverse Osmosis (RO) systems produce suitable filtered water for this species. Drops in humidity are associated with reduced activity and feeding in these snails.

The presence of mould is basically guaranteed in the enclosures due to the combination of warm temperatures, high humidity, and plant matter (both the snail food and the leaf litter); however, it does not seem to affect the snails, and the regular changing of leaf litter should prevent mould growth becoming extensive.

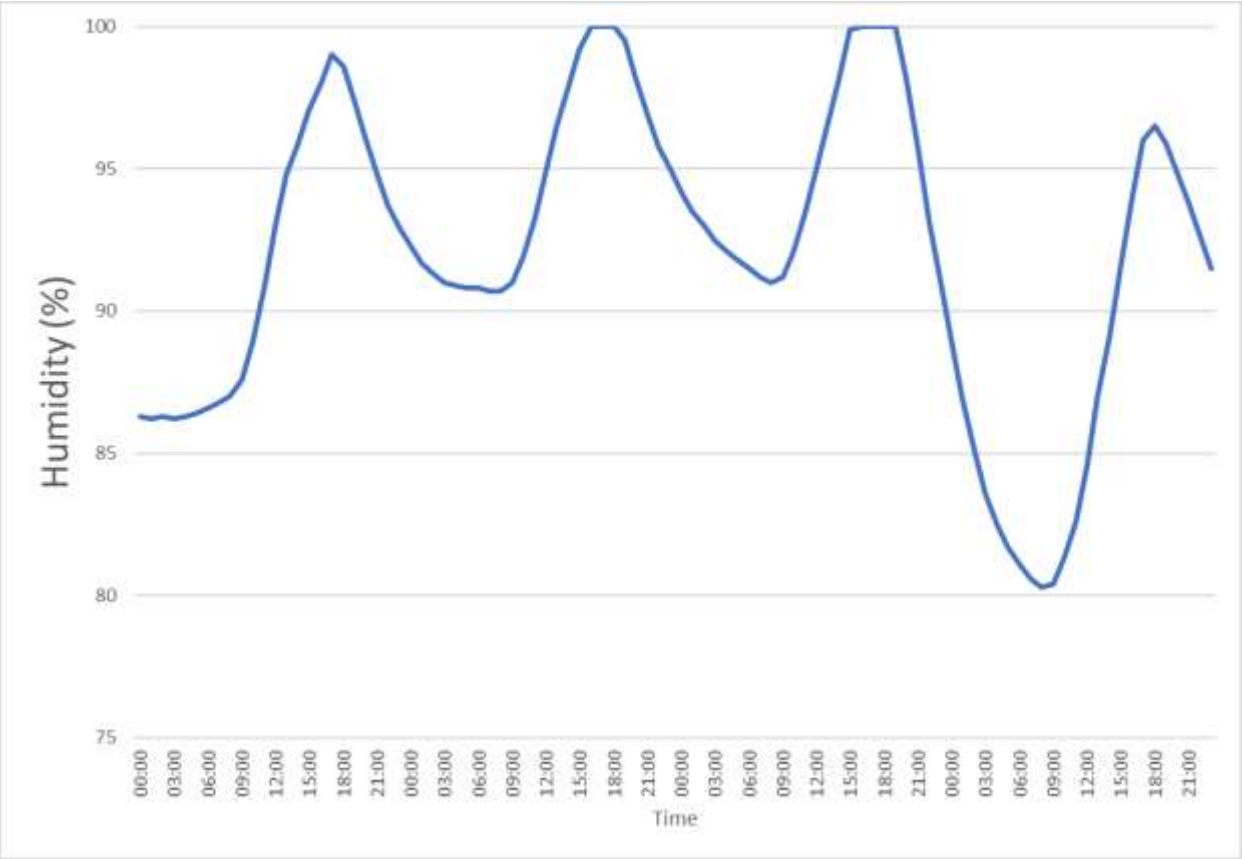

Figure 20: Humidity readings for a *Bertia* enclosure at Chester Zoo over a 3-day period.

2.1.5 Dimensions

Adult giant magnolia snails are best housed in glass vivaria, widely available from companies such as Exo Terra (Exo Terra, 2023). Requiring more space than most snails due to their large size, a minimum of a 60x45x45cm (width x depth x height) vivarium is recommended for a group of 6 adults, with larger enclosures than this possibly being beneficial (Fig. 14). Slightly smaller enclosures than this can be used if housing fewer snails, e.g. a 45x45x45cm vivarium may be suitable for just a pair of adults.

2.2 Feeding

2.2.1 Basic Diet

Adult *B. cambojiensis* should be fed three times a week. They are fed a variety of different food items, as this was found to promote higher activity levels than the regular feeding of a more limited range of foods (Fig. 21). Mushrooms are featured in every feed as these seem to be favoured by the species, but the other represented types of fruit and vegetables are varied (Table 2). Several types of mushrooms have been tried (e.g. button, chestnut, oyster mushrooms) and all are readily accepted by this species. Fish flake is included in the diet to provide a source of animal protein, which is crucial to the maintenance of these snails, especially the juveniles as it helps fuel their rapid growth. At Chester, Vitalis tropical flakes (Vitalis, 2023) are used, although other manufacturers produce other similar products with a high percentage of constituent protein. Fish flake can be offered by itself, or as part of 'Bermuda snail powder', a diet developed at Chester Zoo originally for the Bermuda snail programme, which consists of calcium powder, crushed fish flake and spirulina mixed together in a 1:1:1 ratio. Other protein sources that have been well-accepted by *Bertia* include gecko diet powders (e.g. Repashy, 2023) and dry cat food soaked in water to soften it. Any brand of good quality dry cat food with high protein content would be suitable. If fruit flies or fungus gnats are present in the enclosure, feeds of particular wet items such as soaked cat food or gecko diet should be avoided and substituted with other food items, to prevent a

proliferation of such pests.

Figure 21: Offering a varied diet encourages stronger feeding response. Photo by T. Ziegler.

The species also seems to have a high calcium requirement; if offered a petri dish half-filled with calcium powder slurry daily, they will have consumed it all by the next day. However, it is not recommended to provide this much calcium due to concerns of potential negative impacts of excess consumption (Ireland & Marigómez, 1992); therefore, snails should be offered calcium powder once a week. This is offered in a petri dish, where it is mixed in a 1:1 ratio with filtered water to make a fine slurry. Use a product with a high calcium: phosphorous ratio, such as Nutrobal (Vetark, 2023) or pure calcium carbonate. Other sources of calcium, such as cuttlefish bone or pure calcium rocks, are also readily accepted if offered, and cuttlebone should be left in the enclosures to allow constant access and replaced if it goes mouldy.

Monday		Wednesday		Friday	
Mango	1 quarter per tank	**Banana**	1 quarter per tank	**Apple**	1-2 halves per tank
Papaya	1 slice per tank	**Cucumber**	1 thick slice per tank	**Sweet potato**	1-2 slices per tank
Mushrooms	2 halves per tank	**Mushrooms**	2 halves per tank	**Mushrooms**	2 halves per tank
Honey Melon	1 slice per tank	**Pak Choi**	1 leaf per tank	**Courgette**	1 thick slice per tank
Fish flake/ Bermuda powder	Thin layer in petri dish	**Soaked cat biscuits**	Half a petri dish (90mm)	**Calcium powder**	1 petri dish per tank

Table 2: Feeding schedule for *Bertia cambojiensis* at Chester Zoo. Each of these tanks housed 5-6 adults.

2.2.2 Special Dietary Requirements

Young juveniles of this species seem to have a higher protein requirement than adults, presumably to fuel their rapid growth. This means that several sources of animal protein generally ignored by the adults are readily consumed by the juveniles, such as hard-boiled eggs. The juveniles also have a higher calcium requirement and will need more regular provisioning of calcium powder and/or cuttlebone. The long-term consequences of insufficient calcium provisioning in this species are severe (see section 2.7, Veterinary considerations).

2.2.3 Method of Feeding

Fruits, vegetables, and fungi are best presented simply by slicing and laying on the surface of the leaf litter (Figs. 22-23). Wet foodstuffs such as calcium paste slurry, or a fish flake & banana mix can be made up in a petri dish to the desired consistency using filtered water and this can then be placed on the surface of the leaf litter (Fig. 24).

Figure 22: Adult *B. cambojiensis* feeding on sweet potato (left) and apple (right). Photos by K. Richardson & I. Newens-Hill.

Figure 23: Adult *B. cambojiensis* feeding on a section of banana. Photo by T. Ziegler.

Figure 24: Giant magnolia snail feeding from a petri dish of calcium paste. Photo by K. Kelton.

2.2.4 Water

The snails receive all the water they need from their humid surroundings, their food, and regular spraying. Provision of an additional water source is not recommended as it would simply get soiled and filled with substrate very quickly by the movements of the snails and may pose a risk of drowning if too proportionally large for the individual snails.

2.3 Social structure

2.3.1 Basic Social Structure

Nothing is known of the social structure of this species in the wild. Given the extremely low population densities reported from field surveys in Vietnam (Hoai Phong, 2019), the species is perhaps best thought of as solitary.

2.3.2 Changing Group Structure

The main limiting factor for group size in these snails is enclosure size- they are large invertebrates that must be kept at relatively low densities to do well. There is no evidence of territoriality or intraspecific aggression in giant magnolia snails (Fig. 25). If a group of snails needs splitting, for example a group of growing juveniles whose waste production is making them unmanageable at present densities, individual snails can simply be picked out and transferred to a suitable new enclosure. It is not recommended to move juveniles until they are over a week old, as previous instances of juveniles being moved earlier than this have been associated with subsequent high mortality rates.

Figure 25: These snails do not display territorial or antagonistic behaviours towards conspecifics. Photo by T. Papp.

2.3.3 Sharing Enclosure with OtherSpecies

These snails are large, heavy omnivores, limiting the number of species they can be mixed with. Delicate species may be injured simply by the snails' movement around the enclosure, and any species that moult their exoskeleton would be at risk of predation by the snails in the immediate aftermath of their moulting, while they are still soft. The best potential mixes may be small, arboreal South-East Asian lizards that are predominantly diurnal and able to steer clear of the snails.

For reasons that are currently unknown, this species struggles to thrive and becomes less active if there are significant numbers of isopods (woodlice) present in the enclosure. Therefore, it is important to prevent accidentally introducing any isopods on décor, substrate, or food etc. As with other snail species, phorid flies, also known as scuttle flies, can be a major pest in *B. cambojiensis* enclosures, as the larvae of various phorid species feed on snails (Coupland & Barker, 2004). Serious infestations will cause the death of snails and they should be controlled if present. The species does not seem to be affected by springtails in their enclosures, remaining active and feeding even alongside high densities.

2.4 Breeding

2.4.1 Mating

This species breeds predominantly in spring, although autumn breeding has been observed. Mating behaviour has only rarely been observed at Cologne Zoo, and presumably occurs predominantly during the night. In general, the species seems most active in the evening following their afternoon spray, and while not truly nocturnal they certainly seem to be more active overnight. Observations from ZSL London Zoo suggest that breeding behaviour is triggered by changes in day length or air pressure in spring (Pearce-Kelly, pers. comm.); however, instances of September breeding at Chester Zoo draw this into question. Due to the relative lack of mating observations, it is also uncertain how long the duration between mating and egg-laying is.

2.4.2 Egg Laying and Incubation

Egg laying can take anywhere from 2-11 days. The individual should be disturbed as little as possible during this time. Eggs are typically laid under the leaf litter, but near the surface of the substrate below

(Fig. 26). Clutch sizes in this species are very large, with a typical clutch consisting of 120-150 eggs, but occasionally up to 290 eggs. Despite this, the hatch rate is very low, with only around 5-10% of the clutch being fertile. This could be the provisioning of 'nurse eggs' as a source of calcium and nutrients for the hatchlings, as has been recorded in other land snail species (Baur, 1994). Certainly, it is vital that the unfertilised eggs are not removed, as the new hatchlings will eat them as their first meal upon emergence, adding further evidence to the hypothesis that this is the deliberate provisioning of nurse eggs. Eggs can appear sunken-in and shrivelled when initially laid (Fig. 27) but will fill out if left in the substrate. Eggs will also fill out if eggs are removed from the tank and placed in a tub of damp vermiculite (Pearce-Kelly pers. obs.), but this is not necessary for successful incubation.

Figure 26: Clutch of *B. cambojiensis* eggs. Note the variation in size, probably due to the presence of both developing fertile eggs and infertile nurse eggs. Photo by G. Garcia.

Figure 27: It is normal for *B. cambojiensis* eggs to appear shrivelled and collapsed when initially laid. Photo by T. Ziegler.

2.4.3 Birth/Hatching

Egg clutches typically take between 2 and 3 weeks to hatch, if kept at optimum temperatures (same ambient air temperature as the adults). Eggs should be kept for at least 40 days before discarding to be on the safe side. Hatchlings are translucent pinkish when they first emerge from the egg (Fig. 28). One clutch of hatchlings measured in 2019 had an average shell size of 9mm upon discovery; however, due to subsequent high mortality possibly associated with disturbance, it is not advised to measure hatchlings until they are at least a week old.

Figure 28: A fresh hatchling of *B. cambojiensis,* surrounded by clutch mates and empty eggshells. Photo by G. Garcia.

2.4.4 Development and Care of Young

Within 2 days of hatching, juveniles will have consumed their own eggshell and any infertile eggs in the clutch (Fig. 29) and will begin feeding on other food, darkening to a brownish colour at this stage. The species' distinctive shell pattern begins to develop after approximately 1 month. These young snails grow very rapidly, doubling in size (to 16-20mm shell diameter) by the end of their first week (Fig. 30), and within two months are larger than an adult Roman snail (*Helix pomatia*). At this stage, the growth rate does slow down, but snails can still reach 100g in as little as 16 months from hatching.

Figure 29: Fresh hatchling giant magnolia snails feeding on empty eggshells/ infertile eggs in their nest chamber. Photo by G. Garcia.

Figure 30: A one-week-old hatchling *B. cambojiensis*. This will already have roughly doubled in size since hatching. Photo by K. Kelton.

Enclosures for juvenile snails need to be maintained at a consistently very high humidity above 80%, and the young juveniles seem more sensitive to pest insects such as phorid flies and fungus gnats. Due to this more delicate nature, hatchlings should be housed separately from the adult snails. Therefore, it is recommended to set up the juvenile enclosures in a similar manner to the adults, but with plastic sheeting or wrapping over the top and/or doors to prevent insects from entering (Fig. 31). This can be removed after a month, once the snails are at a less vulnerable size.

Figure 31: Plastic faunarium covered by black plastic to prevent pest incursion and keeping very high humidity, suitable for housing juvenile giant magnolia snails. Photos by K. Kelton.

Like the adults, the hatchlings will readily consume any sources of calcium available to them and should be provided constant access to cuttlebone as well as calcium powder feeds once a week. Calcium can be provided as a slurry made from calcium powder and HMA/RO water, presented in a petri dish. Juvenile *B. cambojiensis* also seem to have a higher demand for animal protein than the adults, feeding on some food sources largely ignored by the adults, such as hard-boiled eggs. It would appear that this high rate of consumption of both calcium and protein helps fuel the rapid growth of the baby snails. Another food item generally ignored by the adult snails, but readily accepted by the juveniles, is romaine lettuce; the reasons for this are less clear.

As stated above, juveniles grow very rapidly in the first couple of months, and after around 2 months will be larger than most terrestrial snail species. It is at this stage that upgrades to larger enclosures are recommended, and the young can then be kept as described above for the adults.

In April 2021, four snails which had hatched in October 2018 laid fertile egg clutches (Fig. 32), therefore time to reproductive maturity is estimated at 2.5 years. However, with further improvements in the husbandry of this species, some of those 2021 young have reached the same body weights as reproductive adults in as little as 16 months (see Fig. 4 in section 1.2), suggesting that shorter time until first breeding of perhaps 2 years may occur.

Figure 32: F2 baby giant magnolia snails with F1 2.5-year-old parent. Photo by G. Garcia.

2.4.5 Hand-Rearing

No hand rearing is necessary or possible for this or any other snail species.

2.4.6 Population Management

This Critically Endangered species is at present (February 2024) held in only three EAZA collections. It is not currently subject to any formal population management, though is a candidate species for a future EEP. No target population size has been set, though a larger population held at a larger number of institutions would be beneficial to minimise the risk of losing this important *ex-situ* insurance population. While it is not envisaged to be a problem at any time in the near future, if the *ex-situ* population does reach a size large enough that free breeding and population growth need to be curtailed, this could be easily achieved through the removal of egg clutches from the adult enclosures and freezing them, as is accepted and routinely practiced with other land snail species.

2.5 Behavioural Enrichment

No specific behavioural enrichment is required beyond provisioning of suitable refugia and food items (see section 2.1.3 and 2.2). Cover items can be regularly rearranged to introduce dynamism into the snails' environment.

2.6 Handling

2.6.1 Individual Identification andSexing

Sexing of this species is unnecessary, as, like with many molluscs, it is hermaphroditic. Individual identification within groups is best achieved through the marking of individuals' shells. This can be as simple as a laminated piece of paper, although products such as the VI alpha tag from Northwest Marine Technologies (NMT, 2023) are likely to be longer-lasting and less likely to be lost. VI alpha tags have the added advantage of being fluorescent under a VI light (Fig. 33), allowing visibility from further away, highly useful for studies in the wild (see recommended research section 2.8). The VI tags used for this species at Chester Zoo are 2mmx5mm in size, and this size and above are recommended to ensure visibility on such a large snail. The tag could feasibly measure upwards of 10mmx15mm without causing disruption to the snails.

Figure 33: VI Alpha tag (NMT, 2023) on the shell of a giant magnolia snail, fluorescing under UV light. Photo by S. Rawlins, Chester Zoo.

When applying a new tag to a snail, it is important to prepare the area, by first cleaning and polishing a section of shell (Flewitt, 2020) to prevent any debris from preventing or reducing the adhesion. Then apply a small dab of superglue to the prepared area of shell before placing the tag on top of the glue. It is then recommended to apply another small dab of superglue on top of the tag, sealing it and reducing the chances of the tag being removed through the snail's day-to-day movement (Fig. 34). On occasion this may cause the numbers on the tag to become obscured if trapped air bubbles cloud the superglue. Once it has been determined that the tag is flat and legible, the snail should be placed in an empty tub with no substrate and no other snails for 15 minutes to ensure the glue has time to dry without any risk of material becoming adhered to it, or ingestion of the tag or glue by other snails.

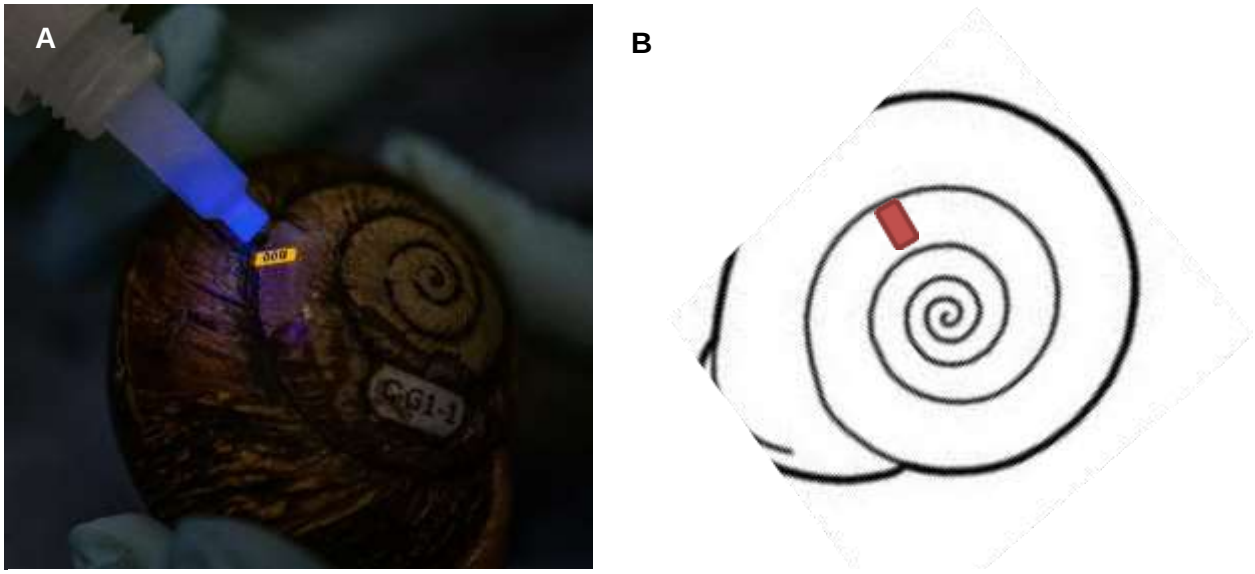

Figure 34: **A.** Application of a VI Alpha tag (NMT, 2023) to the shell of a giant magnolia snail. Note the old, laminated paper tag also present. Photo by S. Rawlins, Chester Zoo. **B.** diagram showing ideal placement of Alpha tag on a *Bertia* shell. Figure modified from Oesch et al., 2019.

2.6.2 General Handling

To avoid undue stress to these sensitive invertebrates, it is recommended to keep the handling of *B. cambojiensis* to a minimum. If animals must be handled and lifted for weighing, health checks etc., make sure you have a firm grip of the shell (be prepared for secretions making the shell slippery and difficult to hold, see section 1.3). If the snail does not retreat fully back into its shell, place your other hand under the extended foot to support it. Due to these secretions and to reduce the risk of any disease transfer, powder free soft nitrile gloves should always be worn when handling these snails (Figs. 35-36).

Figure 35: Gloves should always be worn when handling giant magnolia snails. Photo by K. Kelton.

Figure 36: Any brand of powder free, nitrile veterinary or medical gloves are suitable for handling snails. Photo by N. Bradley.

2.6.3 Catching/Restraining

If the snail is on a smooth surface such as glass while attempting capture, do not pull it off the surface, as this can cause internal injuries due to the surface tension; instead, place one hand on the shell and, without applying any force, wait for it to withdraw into its shell before lifting it. It may need gently encouraging to withdraw into its shell. Make sure you have a firm grasp of the shell as injuries through dropping a snail of this size and weight can be severe. If you feel it is necessary, support the shell from underneath with your other hand. Gently place the snail in a safe location. Do not leave a giant magnolia snail unattended unless it is in a tub with a well-secured lid; these are powerful molluscs and quite capable of pushing a loose-fitting lid off a tub.

2.6.4 Transportation

Transport for giant magnolia snails is similar to that for other land snails, except for lower number of individuals due to this species' much larger size; a standard Braplast tub (1.3l; 185x125x75mm; Figs. 37-38) is ideal for packing a single adult *Bertia*. It is important the snail is kept moist during transit – the tub should be packed with *Sphagnum* moss to ensure humidity is maintained throughout the journey (Fig. 38). For international transport where live plant material may cause customs issues, damp paper towel can be used. All tubs should always be clearly labelled with species name and number of individuals, and lids must be secured at both ends with tape, to prevent the snail from pushing the lid off during transit.

Figure 37: A giant magnolia snail being prepared for transport in a tub with damp paper towel. Note the tape and clearly-labelled lid. Photos by T. Papp.

Figure 38: A giant magnolia snail being prepared for transport in a tub with live sphagnum moss. This is the preferred method, if the presence of live plant material does not cause customs issues with the journey. Photos by T. Papp.

Plastic boxes should then be packed tightly into larger polystyrene boxes (Fig. 39a). If travelling by air, the polystyrene transport box should be sealed and then itself be packed within a larger wooden shipping crate (Fig. 39b). It is important to select an appropriate transport box that complies with IATA Live Animal Regulations (IATA, 2015). The polystyrene transport box should be surrounded by water bags to stabilise temperature and act as a cushion. Ventilation should be provided on both the wooden and polystyrene box by incorporating a fine mesh into the lids. Screws are the best option for sealing the wooden crate as this enables the crate to be opened for inspection etc. This methodology has been used many times for shipping other critically endangered land snail species at Chester Zoo.

Figure 39: **A**. Giant magnolia snails packed into polystyrene boxes, and **B.** a suitable crate for shipping giant magnolia snails internationally. Photos by K. Kelton, Chester Zoo & P. Pearce-Kelly, ZSL.

2.7 Veterinary: Considerations for Health and Welfare

The husbandry of the snails is very easily evaluated by the quality of their shells. If there is any kind of deficiency in your giant magnolia snails' diet, it may manifest as a disruption to the usual growth of the shell. Other husbandry changes can also lead to shell growth changes, including specimens being kept in leaf litter that is too old and hasn't been changed frequently enough (Fig. 40). Due to this species' rapid growth, it is important they receive enough calcium to support shell development, and a lack of calcium can lead to significant health problems and even death.

Figure 40: Abnormal shell growth in giant magnolia snails caused by missed substrate change, and subsequent correction of growth following husbandry improvement. Photos by T. Papp.

A number of *B. cambojiensis* were observed to stop feeding and lose body weight over a period of 2-3 months, eventually losing over 50% of their body condition before dying. Post-mortem examination revealed a change in the structure of their radulae, or feeding organs, visible under a microscope (Fig. 41). The cuticle (surface) of the radula is ordinarily covered in numerous rows of teeth which snails use to rasp at their food, composed mostly of calcium. These are worn down and replaced over time (Krings et al., 2019). The afflicted individuals were, due to a deficiency in calcium, unable to replace their radular teeth, leaving them with an unusually thickened cuticle with no teeth and rendering them incapable of feeding. Upon this discovery, one individual which had stopped feeding and had lost 50% of its body weight was offered pure calcium powder in a petri dish. This specimen quickly resumed normal feeding activity and regained the lost weight in two weeks (Papp, pers. obs.).

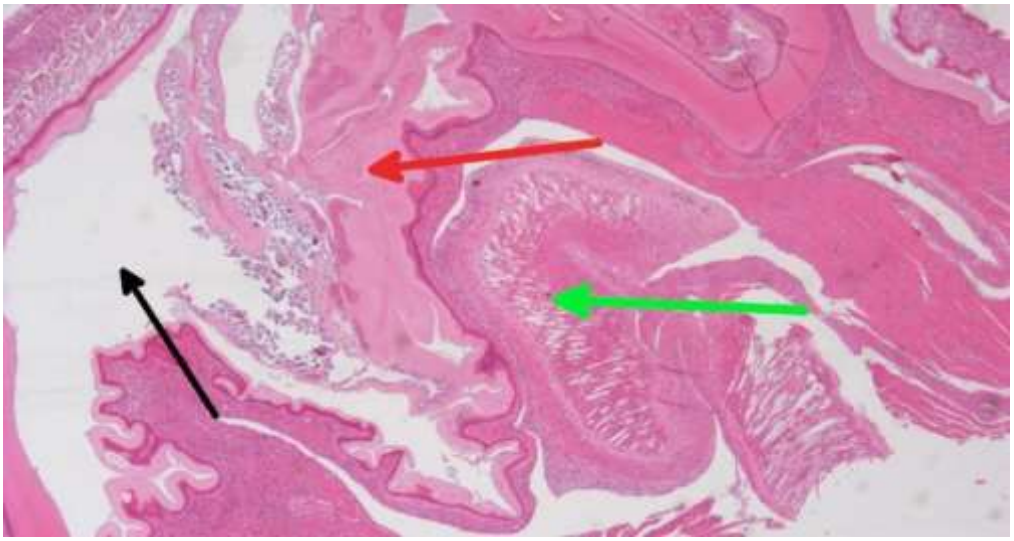

Figure 41: Microscope slide of a cross section of *B. cambojiensis* radula. Black arrow indicates the mouth cavity, red arrow indicates unusually thickened radular cuticle. Green arrow indicates odontophore, as a landmark. Compare this to the typical radula below in Figure 42. Photo by P. Richards, University of Liverpool.

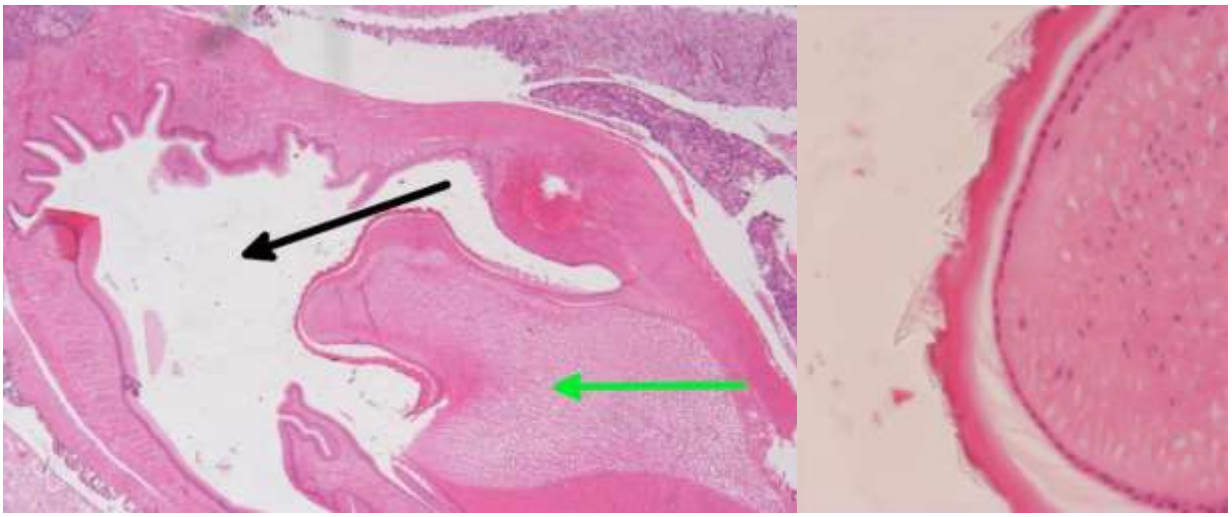

Figure 42: Microscope slide of a cross section of the radula of a garden slug (*Arion sp*.). Black arrow indicates mouth cavity, green arrow indicates odontophore as in previous figure. Note the much less-thickened surface. Close-up shows the presence of radular teeth on the cuticle, absent in the afflicted magnolia snail. Photo by P. Richards, University of Liverpool.

As discussed above, giant magnolia snails have negative interactions with a range of pest and parasitic invertebrates. Microscopy work during post-mortem examinations has revealed the presence of nematodes in this species (Fig. 43); however, these have not been associated with any specific health problems. Of greater concern are scuttle flies (family Phoridae), which may lay their eggs on a living snail and whose larvae, feeding on the snail's flesh, may kill an otherwise completely healthy snail but are particularly deadly to already weakened or sick individuals.

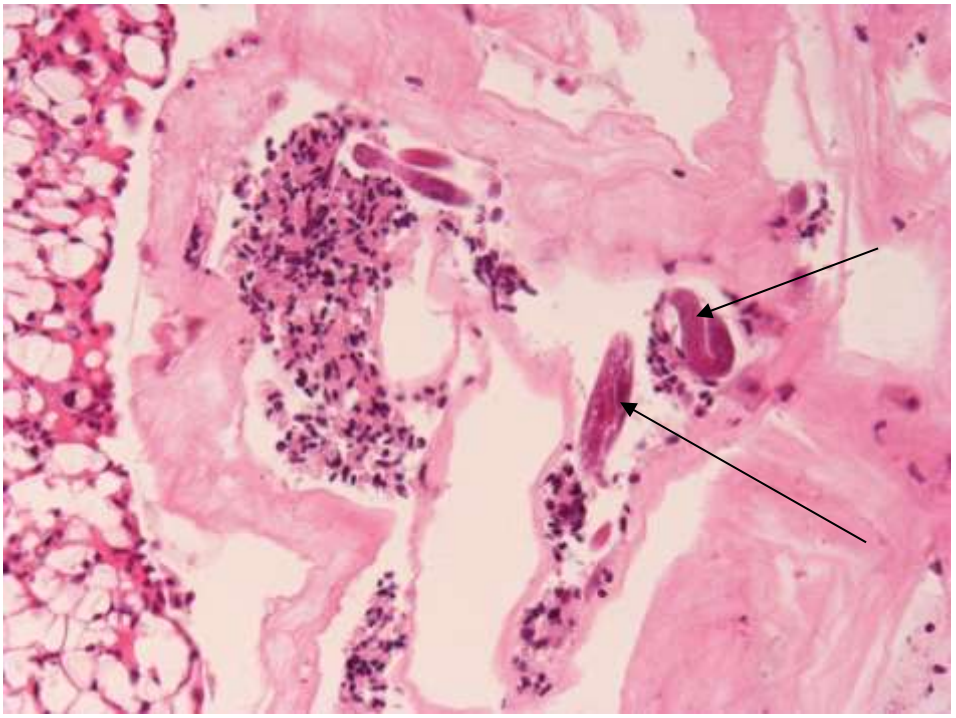

Figure 43: Nematodes (indicated by arrows) within the digestive tract of a *B. cambojiensis.* Photo by P. Richards, University of Liverpool.

Individuals with insufficient calcium in their diet, and/or negative interactions with pest species, e.g. cockroaches, may develop holes in their shell (Fig. 44). These cases are best identified and treated early as recovery can be a prolonged process, and care must be taken to avoid secondary infection or scuttle fly (*Phoridae*) infestation. If a secondary infection is suspected, treatments of marbofloxacin at a dose of 5mg/kg intramuscularly have shown some success in this species (C. Bentley, pers. comm.). Holes in the shell can also be treated by the application of bone wax (Fig. 45).

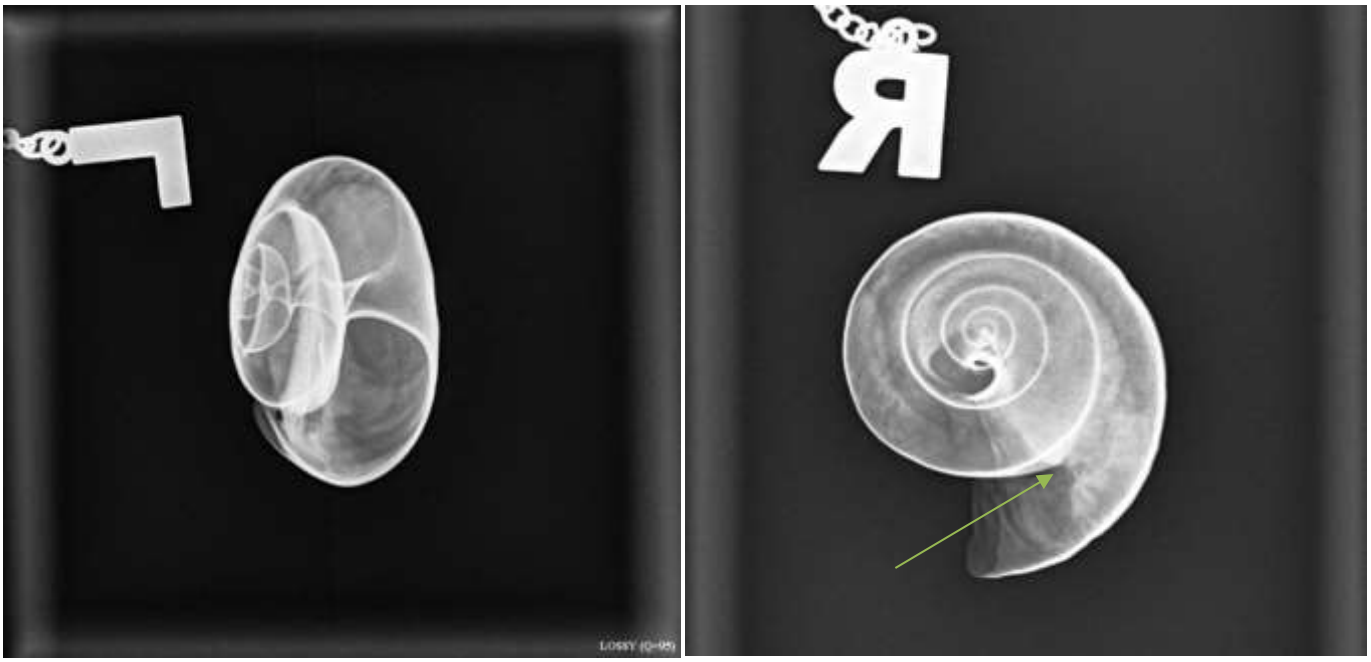

Figure 44: Radiograph images of a *Bertia* with a hole in its shell (visible on the right, lighter area indicated by an arrow). Photos by C. Bentley, Chester Zoo.

Figure 45: A *B. cambojiensis* that has had bone wax applied over a hole in its shell. Photo by K. Kelton.

2.8 Recommended Research

This species is critically understudied, and next to nothing is known of its natural life history or biology (Naggs, 2014). This makes any further information that can be collected on this species highly valuable. That being said, there are a number of key areas where further research is especially desirable:

- Research into the different microhabitats utilised by the species in the wild could be used to fine-tune husbandry.
- The wild diet, its nutritional composition and any seasonal variation is all unknown, apart from a handful of chance observations.
- Nocturnal behaviour, when most activity, including mating, is thought to occur could be

studied *ex-situ* in zoos, utilising remote camera technology.

- The seasonal cues that trigger breeding in wild *B. cambojiensis* need investigating, as both spring and autumn breeding have been recorded in the population held in human care. This can be investigated by inducing seasonal temperature shifts in *ex-situ* facilities.
- The provisioning of infertile 'nurse eggs' by this species is a fascinating behaviour, and it remains to be fully understood if these are deposited separately to viable eggs, or if there is any distinction between the two at time of laying.
- Population structure, growth rate and survivorship remain completely unknown in wild populations and could feasibly be studied by a mark-release-recapture study based on a methodology like that of Liew et al. (2021).
- Genetic study of the populations in Cambodia and Vietnam, assessing the level of divergence between the two locations and discerning if there are signs of a population bottleneck caused by rapid decline, and if the *ex-situ* population captures a good level of wider genetic diversity.
- Nothing is known of wild predators, parasites or pathogens of this species, crucial information to inform the conservation and future recovery of the giant magnolia snail.

Section 3: Acknowledgements and References

3.1 Acknowledgements

The authors would like to thank Peter Richards of the University of Liverpool, Paul Pearce-Kelly, Dave Clarke and the rest of the invertebrate team at ZSL, Dr. Javier Lopez and Charlotte Bentley from Chester Zoo's veterinary department, Iri Gill, Jay Redbond, and the rest of the Ectotherms team at Chester Zoo who have helped with the husbandry of *Bertia* over the years.

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