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# ECOLOGY OF *CYRTODACTYLUS SUMONTHAI* BAUER, PAUWELS, & CHANHOME, 2002 (REPTILIA: SQUAMATA: GEKKONIDAE): A KARST DWELLING BENT-TOED GECKO FROM SOUTH-EASTERN THAILAND

**Nonn Panitvong**
*College of Environment, Kasetsart University, 50 Phaholyothin Rd. Chatuchak, Bangkok 10900, THAILAND*
*Email: npanitvong@gmail.com (Corresponding author)*

**Veerayuth Lauhachinda**
*College of Environment, Kasetsart University, 50 Phaholyothin Rd. Chatuchak, Bangkok 10900, THAILAND*
*Email: v.lauhachinda@hotmail.com*

**Soomet Saithong**
*Khao Chamao – Khao Wong National Park, P.O. Box 11, Amphoe Klaeng, Rayong, 21110,THAILAND*
*Email: sumet_hamed@hotmail.com*

**Thammanoon Temchai**
4 *National Park Research Center Region1,493/29 Phetchkasem Rd., Amphoe Chaam, Phetchaburi,76120, THAILAND*
*Email: dhamma57@gmail.com*

***ABSTRACT.*** — An ecological study of *Cyrtodactylus sumonthai*, a karst-dwelling species of gekkonid, was conducted in Khao Wong, a lime-stone karst of Southeastern Thailand, during a one-year period between Mar.2010 and Mar.2011. The mark and recapture method, using pattern and tubercles on the head region for individual animal recognition, was employed, along with general survey methods. Our results show that the population in Khao Wong consisted mainly of adults, with a small percentage of subadults and juveniles. The geckos were found to be active throughout the year, but lower activity was recorded during May–Oct (wet season), probably due to increased predator activity and interspecific competition from amphibians. Microhabitat partitioning among age groups was recorded as the adults preferred areas inside of the cave and the ecotone at the entrance of the cave; the subadults preferred the ecotone area and hill side; and the juveniles were found mostly on the hill side and at the base of the karst along an ephemeral stream. Females were found to be more active than males during the wet season, probably because they required more nutrients for developing eggs. We found the oviposition period to peak at the end of the wet season to the beginning of the dry season (Nov–Dec). Juvenile numbers peaked at the beginning of the dry season (Feb–Mar). Growth rates derived from recaptured individuals showed that females take two years to reach maturity. *C. sumonthai* females normally lay two eggs, but odd numbers were recorded in some eggs crevices, probably from female individuals that laid a second clutch in the same year. Egg crevices were found mostly inside the cave, with some being unused during the whole survey, evidence that these were not a limiting factor for this population. A low percentage of marked individuals were being re-captured, which is probably evidence for a large population size, high mortality and migration, or a low level of activity of this gecko in general. However, the majority of the re-captured individuals were mostly found in the same general area where they were previously captured, except for a few adult individuals that showed some short migratory behaviour and subadults that moved closer to the cave entrance as they grew.

***KEY WORDS.*** — *Cyrtodactylus sumonthai*, ecology, karst-dwelling, Thailand, cave

## INTRODUCTION

Gekkonoidea is a diverse group of reptiles, consisting of seven families, Gekkonidae, Carphodactylidae, Diplodactylidae, Eublepharidae, Phyllodactylidae, Sphaerodactylidae, and Pygopodidae. There are at least 1,400 species in this group, with *Cyrtodactylus* Gray, 1827 among one of the most diverse genera, containing at least 140 species (Uetz, 1995 onwards; David et al., 2011; Ngo, 2011). Of these species, at least 71 have been described since 2000, which shows that very little had been studied about this group of geckos. *Cyrtodactylus* are mostly nocturnal with diverse preferred types of habitat:

forest, karsts, intertidal, and some are known to occur in man-made plantation. (Bauer et al., 2002; Youmans & Grismer, 2006; Grismer, 2005). Among these preferred habitats, species found on habitats of various rock type: granite, limestone, and sand stone, naturally have small distributions due to limitations on the extent of suitable habitat and substrate. Meanwhile, these habitats are vulnerable to extraction of stone and mineral for human use, which can totally destroy the habitat. However, to our knowledge, apart from basic natural history given in taxonomic descriptions, no detailed ecological studies have been done on any species in this genus. In view of this situation, a study on the ecology of karst-dwelling *Cyrtodactylus* species is required to help better understand their ecology for further conservation planning.

In Thailand, there are at least 60 species of Gekkonidae belonging to nine genera (Nabhitabhata et al., 2000). Among these geckos, the nocturnal *Cyrtodactylus* species represent the most diverse genus, comprising 20 species, of which nine are cave-dwelling species, all with small distribution ranges. *Cyrtodactylus sumonthai* was discovered as recently as 2002. It was recorded as the first cave-dwelling species found in Thailand. Its distribution is limited to a few lime-stone karsts in and around Khao Chamao–Khao Wong National Park, Southeastern Thailand. We have investigated a population of this species in Khao Wong area, using general survey and mark and recapture methods. Based on the data collected, we examined their foraging behaviour, growth pattern, habitat use, reproductive cycle, population demography, and the predator and prey diversity of *C. sumonthai* in its natural habitat.

No subject animals were harmed in anyway during our study period, except for a few incidences of tail autotomy during captures.

## MATERIAL AND METHODS

***Duration***. — Complete field surveys were conducted from Mar.2010 – Mar.2011. An additional survey was done during Apr.2011 to monitor unhatched eggs, during which time no other data apart from status of the eggs were recorded.

***Study area***. — Field surveys were conducted in Khao Chamao–Khao Wong National Park which lies at the border between Rayong and Chantaburi provinces in Southeastern Thailand,(12°53'N, 101°49'E). The park consists of two parts. Khao Chamao is a large granitic mountain, 8,368 ha, with its highest peak at 1,024 m with tropical monsoon forest cover and several large perennial streams. Khao Wong is a small lime-stone karst approximately 3,000 × 550 m, its highest peak is at 162 m with a sink hole of about 500-m diameter in the middle. Its vegetation is dry evergreen forest, with such trees as *Mitrephora tomentosa*, *Saraca indica*, *Calamus* spp., *Dracaena* sp., and *Lagerstroemia* sp. Ground cover on the hill-side is mostly ferns, annuals and tuber plants, such as *Amorphophallus* sp., *Alocasia* sp., *Globba* sp., *Impatiens* sp., and *Begonia* sp., that emerges only during wetter months of the year (May–Oct). Our study area consisted of five types of habitats. The first type, H1, is inside the caves (always dark), and this consisted of three caves: the largest (Lakorn Cave) has a very large entrance of about 30 m wide and 40 m high, and is about 150 m deep; the second (Singto Cave) is medium sized with entrance about 5 m wide and 15 m high, and about 30 m deep; the third cave (Wat Khao Wong Cave) has entrance of about 7 m wide and average 35 m high, and 15 m deep. The second type, H2, is an ecotone area around cave entrances (with light during day time and is dry in some parts during rain), and this consisted of half-dome-shaped karst with one side open to the hill side, a high ceiling of at least 40 m, and a total distance of about 120 m. H3 is the hill side with large rock boulders and some large loose rocks; H4, base of the karst along an ephemeral stream; and H5, the inside wall of a sinkhole. The whole study area path was about 760 m (Figs. 1, 2).

Climate in the area is that of tropical monsoon. The wet season runs from May–Oct, and the dry season from Nov–Apr. The 30-year average annual rainfall, calculating from the average of the two adjacent provinces (Rayong and Chantaburi) is 2,106.7 mm, with 17–21 days of rain per month in the wet season, and average year-round minimum and maximum temperatures of 23.9 and 30.3°C respectively (see Graphs 1, 2; Thai Meteorological Department, 2007 onwards).

***Survey frequency, effort, and protocols***. — Three researchers visited the study area twice each month (average gap between each visit = 15 days) during the 12-month period. Two surveys were conducted on each visit, once during the day and once at night (always after 1900 hours). Each survey lasted about 2–6 hours. Data from the same day were pooled together, then data from the same months were pooled together, unless otherwise stated. Upon finding a gecko, we captured it by hand, and the following data were recorded: type of habitat it was found (H1–H5 as stated above); type of perch site used, categorised as Rock (e.g., cliff or cave wall), Tree & Shrub, and Others (mostly man-made structures such as concrete bridge or wooden stairs); snout to vent length (SVL), measured with a digital vernier caliper (Suntech), which was then categorised into Juveniles <40 mm (S1), Sub-adults 40–60 mm (S2), and Adults>60 mm (S3); tail length (total length and regenerated length, if applicable); condition of tail (original tail or regenerated tail, tail recently autotomized or fully grown); sex (determined by postcloacal swelling present in males and absent in females); presence or absence of oviductal egg(s) in female, which can be seen through translucent ventral skin. Each animal was released immediately at the site where it had been captured. In the

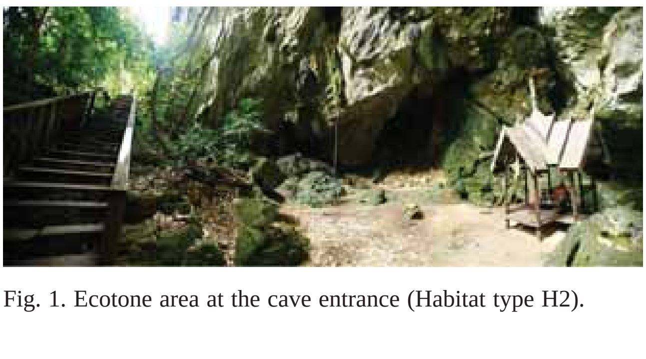


Fig. 1. Ecotone area at the cave entrance (Habitat type H2).

case of geckos that were sighted but not captured, length was estimated by the first author and recorded as one of three size categories above. Other information such as location, sex, tail condition, etc., if possible to determine, were recorded.

*Cyrtodactylus sumonthai* lay one or two hard-shelled, non-adhesive eggs in small, dry lime-stone crevices. These crevices can be identified by the presence of eggs or hatched shells. We monitored six such crevices in our study area throughout our survey period, and two additional crevices were discovered during the 7th and 10th months of the survey period, respectively. Two were found in the 9th month of the survey period. All these latter crevices were found with egg(s) already present. We assumed that the eggs had successfully hatched if matching numbers of empty shells were found in the spot where eggs were earlier found. Eggs that disappeared were assumed to have been eaten or removed by predator(s) and were recorded as having failed to hatch.


Graph 1. 30-year average temperature of the study area (Thai Meteorological Department, 2007).


Graph 2. 30-year average rainfall in the study area (in mm) (Thai Meteorological Department, 2007).

Potential competitors, predators, and prey found during the surveys were counted (if possible) and identified to their smallest taxonomic unit. However, amphibians, which we regarded as competitors, can be very numerous in the study area at a certain time, and given their cryptic behaviour, are extremely difficult or impossible to count. We, therefore, recorded only species of amphibians found in the different habitats, which can, to a certain extent, show how strong or weak the competition in the different habitats is.

***Mark and recapture method.*** — Toe clipping is normally used to mark small species of reptile. Its effect to the animal is controversial, from no effect at all to greatly reduced performance of the subject animal (Borges-Landaez & Shine, 2003; Bloch & Irschich, 2004). With the welfare of our studied animals in mind, we adopted a mark and recapture technique used in many animal species with unique individual patterns, such as whales (Katona & Whitehead, 1981) and tigers (Karanth & Nichols, 1998). In *C. sumonthai*, pattern and distribution of tubercles on the head region was unique among individuals and changed little over time. Therefore, upon capture, the head region of each individual was photographed for later comparison with images in our database. Other data from each individual, such as its sex and state of its tail, can also be used to help confirm each individual. We also used nail polish to mark each individual that we captured on their thighs. The paint lasted for at least 45 days, thus, to a certain extent, it allowed us to recognise re-captured individuals. Growth rate per month was determined by dividing the difference in SVL between each re-capture by the number of days between each capture then multiplying by 30. In individuals that we captured more than twice, only the first and last data points were used. Measuring live animals in the field represented some challenges since they do not stay still or perfectly straight all the time, which resulted in error


Fig. 2. Images showing the same area during the dry season (A) and the wet season (B). Note the profusion of herbaceous plants during the wet season.

in our SVL measurement, with some individuals appearing to have shorter SVLs when recaptured. We realised that this error should result in both underestimated and overestimated growth, therefore all the numbers were pooled together (both negative and positive growth) to determine the growth rate of each size group.

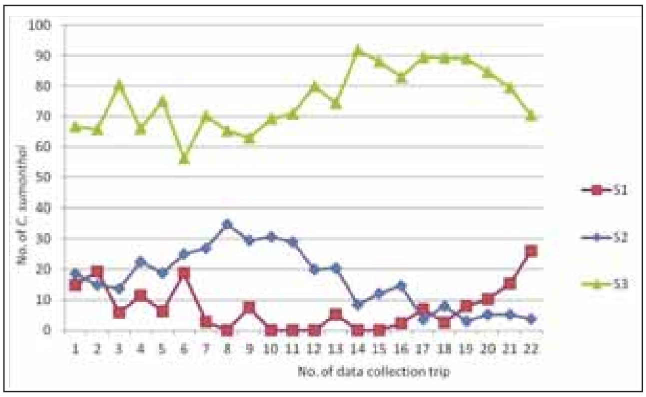
## RESULTS

***Population demographics***. — A total of 934 sightings and captures were recorded during our survey, of which 45.50% of animals were captured and 54.50% were not captured. 11.46% and 88.54% were found during day surveys and night surveys respectively. Most sightings and captures during the daylight hours were inside caves or dark crevices. 7.49%, 14.99% and 77.52% are from the S1, S2 and S3 size groups respectively. We were able to determine the sex in the majority of the S3 group and some of the S2 group. Males constituted 43.00%; females, 57.00%. The average sizes of the 10 largest males and females were 75.57 mm and 77.94 mm, respectively. In this regard, females were significantly larger than males (t-test: $t = 3.21$, $p < 0.01$, $df = 18$). The smallest and largest individuals recorded were 25.17 and 80.71 mm SVL respectively. Average size of the S1 and S3 groups declined over the period of our survey ($y = –0.2711x + 35.958$ and $y = –0.0684x + 69.013$, respectively), while those of S2 group increased ($y = 0.3828x + 50.62$) (see Graphs 3, 4).

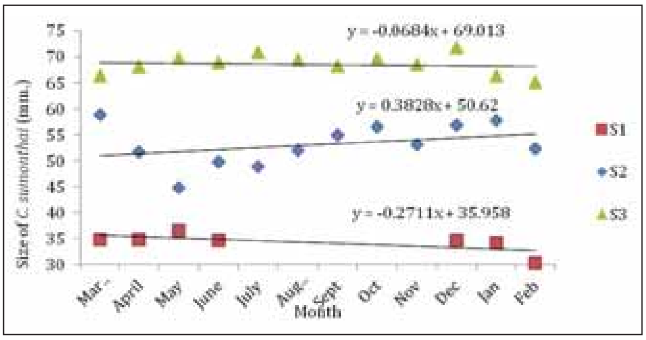
***Tail conditions***. — 66.00% of the geckos had regenerated tails while 34.00% had original tails. Between size groups, the S1 group showed the highest percentage of complete original tail (83.00%), while S2 and S3 were recorded at 48.39% and 14.56% respectively. There were no significant differences in tail condition between sexes, with 20.00% of males and 18.00% females retaining their original tail. Of those with complete tails, mean Body:Tail length ratios were 1:1.21, 1:1.38 and 1:1.36 for the S1, S2 and S3 size groups respectively. There was no statistical difference between mean Body:Tail length ratio of the S2 and S3 groups (t-test: $t = 0.732$, $df = 64$), however, the mean of S1 group is statistically different from those of the S2 and S3 groups (t-test: $t = 4.86$, $df = 40$, and $t = 5.74$, $df = 60$). Among the S3 group, mean Body:Tail length ratios were 1:1.38 for males and 1:1.34 for females. There was no statistical difference between means of the different sexes (t-test: $t = 1.586$, $df = 41$).

Our mark and recapture data show that one S3 individual, with a newly autotomized tail of total tail length 42.33 mm, regrew its tail to 80.04 mm within 43 days between its first and second captures. This may be translated to a regeneration rate of 26.31 mm $mth^{-1}$.

***Pattern***. — Newly hatched *C. sumonthai* started their life with solid bands of dark brown alternating with light yellowish brown. The light band starts to change into adult cross marks across the body at around the size of 40 mm SVL. They achieve the adult pattern at around 55–60 mm SVL. However, the head pattern changed very little overtime. We did not detect any difference in pattern between the sexes during our survey (Fig. 3).




Graph 3. Number of individuals from each age group S1–S3. (Note: Data from survey trip with lowest and highest count number of *C. sumonthai* is omitted.)



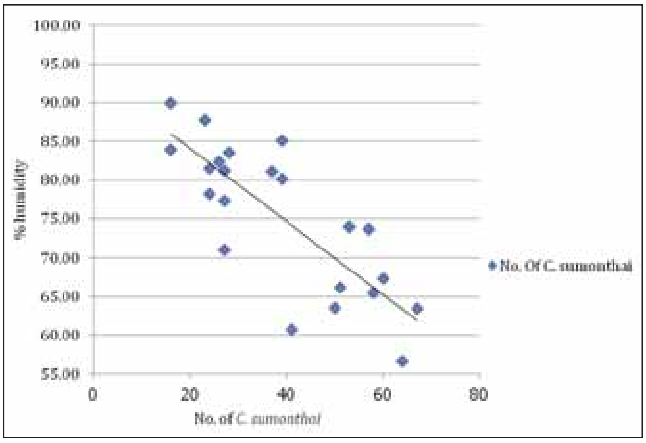

Graph 4. Size of different age groups.


Fig. 3. Images show how pattern of *Cyrtodactylus sumonthai* transforms at different size: A, juvenile with SVL ca. 25 mm; B, subadult with SVL ca. 40 mm; C, adult with SVL ca. 65 mm. These pictures also show unique head pattern in each individuals of this species.

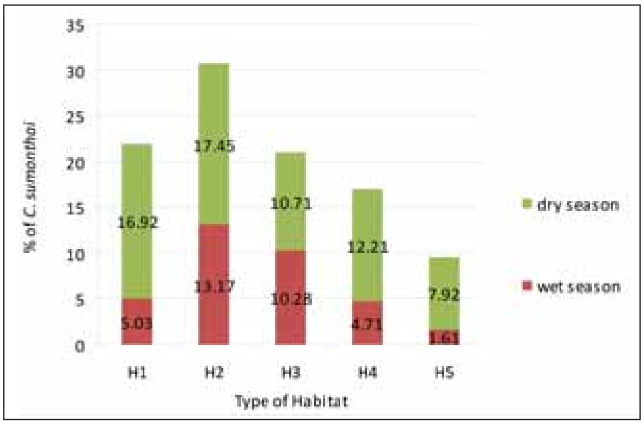
***Activity parameters.*** — Activity of the geckos was significantly negatively correlated with ambient moisture (r = 0.796), with higher moisture resulting in reduced activity, while ambient temperature had no correlation to the activity of the geckos (r = 0.158). However, females are more active than males as the ambient moisture rises, resulting in a sex-bias ratio in some surveys, with a maximum of 88% females (n = 7:1 female to male ratio) in one survey (Graph 5).

***Type of habitat use.*** — Of the five habitat types, *C. sumonthai* used H2 the most (30.62%), of which 17.45% was during the dry season and 13.17% during the wet season. H1 and H3 were used with comparable frequency (21.95% and 20.99% respectively). However, they used H1 habitat much less during the wet season compared to the dry season (5.03% vs. 16.92%), while at H3, it was comparable for both seasons (10.71% vs. 10.08%). H4 and H5 habitat were used less than H1–H3, and both were used less during the wet season compared to the dry (Graph 6).

With respect to size groups, our data showed that the S1 group was found mostly at H3 (35.29%) and H4 (33.82%). The S2 group was found most at H3 (38.85%) and H2 (30.94%), and the S3 group was found most at H1 (27.92%) and H2 (27.51%) (Graph 7).



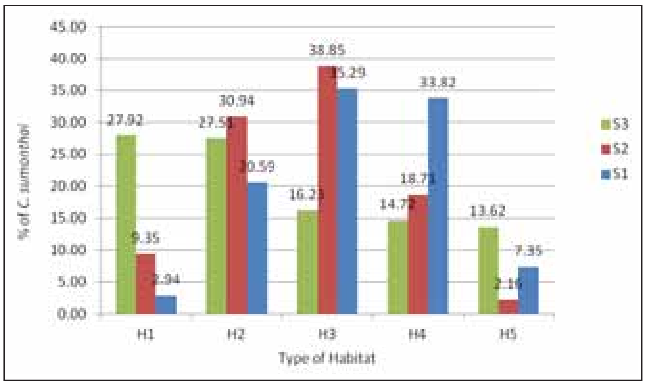

Graph 5. Number of *C. sumonthai* at different ambient humidity. (Note: Data from survey trip with lowest and highest count number of *C. sumonthai* is omitted.)



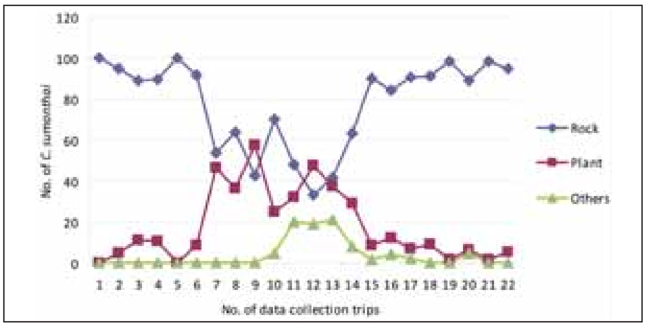

Graph 6. Percentage use of different types of habitats by *C. sumonthai* during the wet and dry seasons.

***Perching sites.*** — The geckos use rock perches 89.97% and 58.12% of the time during the dry and wet season, respectively. In the wet season, as ground cover plants emerged, the geckos were found more on plants (34.15%; vs. 8.35% for the dry season). Other perching sites were used more during the wet season (7.73%; vs. 1.69% for the dry season) (Graph 8).

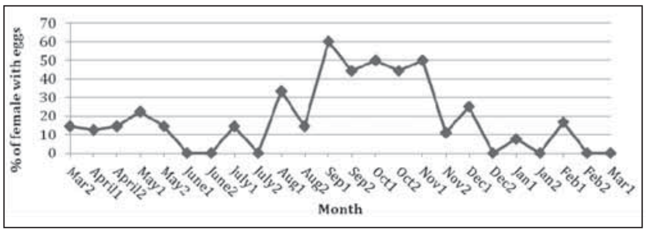
***Reproduction.*** — A total of 26 females (28.57% of females) were found with oviductal eggs. Although a small proportion of females can be found with well-developed oviductal eggs throughout the year, the percentages peaked at the end of the wet season between Aug–Nov, when 62.50% (n = 20) of all females observed with eggs for the whole survey were found during then, although this period accounted for only 25% of the survey period. The average SVL of females with oviductal eggs was 72.86 mm (std dev = 3.01, n = 26, range = 64.90–77.77 mm), with the majority (n = 22) longer than 70 mm (Graph 9).




Graph 7. Types of habitat used by the different age groups of *C. sumonthai*.




Graph 8. Percentage use of perch sites by *C. sumonthai*. (Note: Data from survey trip with lowest and highest count number of *C. sumonthai* is omitted.)

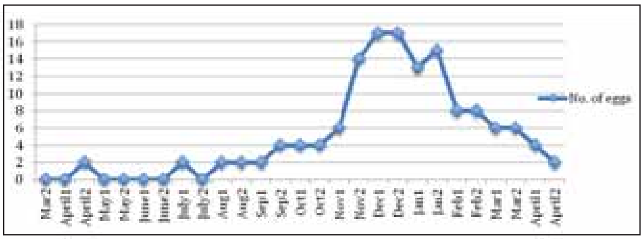



Graph 9. Percentage of females with eggs.

A total of 21 eggs were found. Only 10 were accessible and available for measurement; the others were lodged within small crevices. The mean diameter of the eggs was 13.63 mm. The majority were found in H1 (n = 19), with only two found in H2. Of the 21 eggs, 8 (38%) disappeared entirely, and was assumed to be possibly eaten or removed by predator(s), while 11 (53.38%) successfully hatched, as evidenced by matching numbers of empty shells in the crevices. Two eggs (9.53%) remained un-hatched at the end of our survey. Number of eggs found peaked in Dec (n=17), most of them in H1. Of these 17 eggs found during the peak period, four (23.5%) (all in the same crevice) disappeared without any empty shell remaining; 11 (64.7%) hatched successfully; and two (11.8%) remained un-hatched as of Apr.2011. Of the four eggs found during the off-peak period (two each in H1 and H2), all four eggs failed to hatch; all had disappeared by the time of the next survey (ca. 15 days later). (See Graph 10).

No eggs or empty shells were found in H3–H5, although the majority (76.4%) of juveniles were found in those habitat types. Most egg crevices located were dry throughout the year, with some fine sand, dirt, and broken eggshells as substrate. Nineteen eggs (90%) were found laid on the surface of the substrate, and two (10%) were found buried about 10 mm under the substrate (Fig. 4).

Of the six egg deposition crevices that we monitored throughout our survey, four were used. We found one additional crevice in Sep, two in Nov and one in Dec.2010, all already containing egg(s). 1–5 eggs were found in each crevice. Since our surveys were done at an interval of about 15 days, we did not determine the exact dates of eggs being laid or hatched. However, of the two crevices that we have monitored throughout the survey period with successful hatching, two eggs that were oviposited in Sep.2010 hatched in Mar.2011 (7 months), and one egg that was oviposited in Dec.2010 hatched in Feb.2011 (3 months). The substrate mean temperatures of these two crevices during our survey were 28.45°C and 27.43°C respectively. Two eggs that were found buried under substrate were found in Sep.2010 (which may not be the month that they were oviposited) hatched in Jan.2011 (5 months). Of the eggs for which month of oviposition is unknown, seven hatched in Jan, two in Feb, and two in Mar. The hatching time of the monitored eggs coincided with the appearance of S1 size group, which peaked in Feb–Mar.




Graph 10. Number of eggs found during the study period.

Fig. 4. Egg crevice of *C. sumonthai*, four eggs remained unhatched in the image. Many emptied shells showing communal nesting behaviour or repeated use of the same crevice by the same individual of this species. Average size of eggs was 13.63 mm.

***Mark and recapture.*** — Head markings and tubercles of each individual proved to be unique among *C. sumonthai* and with very little change over time. There were 386 marked individuals, with 43 (11.14%) recaptures. Of these 43, 28 (65.12%) were recaptured once; 10 (23.26%), twice; and 5 (11.62%), thrice. With respect to age group, 3 (6.98%) individuals were first captured as S1, 14 (32.56%) as S2, and 26 (60.46%) as S3. Average time between each capture was 4.24 months (Std dev = 2.97 months, Range = 0.27–10.03 months). Almost all of the individuals recaptured (n = 39, 90.69%) were found in the area where they were previously captured. Only 4 (9.30%) individuals were found to move between types of habitat: (1) One S2, first captured in H1 in Jun.2010, was found as an S3 in H3 in Aug.2010, then it was recaptured again in H1 in Sep.2010 and Nov.2010. It had grown from an SVL of 58.12 mm to 68.94 mm from its first to last capture. (2) An S3 first captured in H2 in Aug.2010 was recaptured in H1 in Mar.2011. Its SVL increased from 66.58 mm to 69.20 mm. (3) An S2 was captured twice in H3 in Jul. and Sep.2010. It was later recaptured in H2 in Jan. and Feb.2011. SVL increased from 49.44 mm to 61.75 mm. (4) An S3 first captured in H1 in Jun.2011 and later recaptured in H2 about 23 m away in Jul.2011. It was later recaptured again in H1, about 6 m away from where it was first captured, in Dec.2010. SVL increased from 69.80 mm to 80.68 mm.

The average growth rate of each group was 5.14 mm mth$^{-1}$ for S1, 1.49 mm mth$^{-1}$ for S2, and 0.46 mm mth$^{-1}$ for S3.

***Syntopic reptiles and amphibians.*** — Others gekkonids were recorded in our study area. These include (1) Three sightings of *Cnemasphis chanthaburiensis* Bauer & Das, 1998, probably of two individuals (in H4); (2) two sightings of *Gehyra mutilata* (Wiegmann, 1834) (in H4); (3) one sighting of *Dixonius siamensis* (Boulenger, 1898) (H1); (4) one sighting of *Gekko gecko* (Linnaeus, 1758) (H1). *Cyrtodactylus intermedius* (Smith, 1917), which is widespread in Eastern Thailand and commonly found in Khao Chamao, was absent from Khao Wong. The adjacent Khao Chamao area also supported at least three *Calotes* spp. [*C. versicolor* (Daudin,

Table 1. List of amphibians.

| S/No. | Species | Habitat Type / Presence | | | | |
|---|---|---|---|---|---|---|
| | | **H1** | **H2** | **H3** | **H4** | **H5** |
| 1 | *Sylvirana mortenseni* (Boulenger, 1903) | x | x | x | x | |
| 2 | *Hoplobatrachus rugulosus* (Wiegmann, 1835) | | | | x | |
| 3 | *Fejervarya limnocharis* (Gravenhorst, 1829) | | | | x | |
| 4 | *Hylarana taipehensis* (Van Denburgh,1909) | | | | x | |
| 5 | *Duttaphrynus melanostictus* (Schneider, 1799) | x | x | x | x | |
| 6 | *Polypedates leucomystax* (Gravenhorst, 1829) | | x | x | x | x |
| 7 | *Kaloula pulchra* (Gray, 1831) | | x | x | x | |
| 8 | *Micryletta inornata* (Boulenger, 1890) | x | | x | x | x |
| 9 | *Microhyla berdmorei* (Blyth, 1856) | | | | x | 'x |
| 10 | *Microhyla butleri* (Boulenger, 1900) | | | | x | x |
| 11 | *Microhyla pulchra* (Hallowell, 1861) | | | | x | x |
| 12 | *Kalophrynus interlineatus* (Blyth, 1855) | | | | x | |

Table 2. List of potential predators of *Cyrtodactylus sumonthai*.

| S/No. | Species | Habitat Type / No. of Occurrence | | | | | Total No. |
|---|---|---|---|---|---|---|---|
| | | **H1** | **H2** | **H3** | **H4** | **H5** | |
| | **Snakes** | | | | | | |
| 1 | *Python reticulatus* (Schneider, 1801) (Juvenile) | 1 | 1 | | | | 2 |
| 2 | *Dryocalamus davidsonii* (Blanford, 1878) | | 4 | | | | 4 |
| 3 | *Lycodon capucinus* Boie, 1827 | | 4 | 2 | | | 6 |
| 4 | *Boiga cyanea* (Dumeril, Bibron & Dumeril, 1854) | 2 | | | | | 2 |
| 5 | *Boiga siamensis* Nutaphand, 1971 | | | | 1 | | 1 |
| 6 | *Boiga* sp. | | 1 | | | | 1 |
| 7 | *Oligodon fasciolatus* (Günther, 1864) | 1 | | | 1 | | 2 |
| 8 | *Rhabdophis subminiatus* (Schlegel, 1837) | | | | 3 | | 3 |
| 9 | *Cryptelytropscardamomensis* Malhotra, Thrope, Mrinalini & Stuart, 2011 | | | 1 | 1 | | 2 |
| | **Others** | | | | | | |
| 10 | *Eosamon smithianum* (Kemp, 1923) | 36 | | | 34 | 251 | 321 |
| 11 | *Megaderma lyra* E. Geoffroy, 1810 | 25 | | | | | 5 |
| 12 | *Scolopendra subspinipes* Leach, 1815 | | | | 3 | | 3 |

1802), *C. emma* Gray, 1845, and *C. mystaceus* Duméril & Bibron, 1837], *Acanthosaura cardamomensis* Wood et al., 2010, two *Draco* spp. (*D. taeniopterus* Günther, 1861 and *D. maculatus* (Gray, 1851), and *Physignathus cocincinus* Cuvier, 1829. None of these Agamidae was found in the Khao Wong area. However, most of these Agamidae are diurnal, thus they would not be direct competitors to the gecko. We also recorded four sightings of *Scincella* sp. foraging under leaf litter on the ground and one sighting of *Eutropis multifasciatus* (Kuhl, 1820) (Scincidae) which was found on a tree stump about 4 ft from the ground in H5 during night time. Compared to the 934 sightings/captures of *C. sumonthai*, there were very small numbers of competitors in the form of other lizard species within the study area.

Some species of amphibians also use karst habitats. In our study area, the most common ones were *Sylvirana mortenseni* (Boulenger, 1903), *Duttaphrynus melanostictus* (Schneider, 1799), *Micryletta inornata* (Boulenger, 1890), and *Polypedates leucomystax* (Gravenhorst, 1829). Amphibian activity was very much correlated with ambient moisture and rain, as frogs were much more active during wet season. It was impossible to count some of the smaller and more numerous species such as the *Microhyla* spp. and *Micryletta inornata*, thus the number of occurrences of amphibians were not recorded. However, a list of the species and of their respective habitats is provided in Table 1.

***Potential Predators.*** — Some snakes are known to prey on lizards and their eggs, and such snakes were sighted 22 times during our survey (Table 2). Four sightings of large centipedes, *Scolopendra subspinipes* Leach, 1815, were recorded. On one occasion, we witnessed it feeding on an S3 size *C. sumonthai*. Land crabs, *Eosamon smithianum* (Kemp, 1932) were numerous, especially during the wet season, and 34–60 individuals could be found in H1 (5.5%), H4 (10.5%), and H5 (84%). Although the majority of them foraged on the ground and were seen eating leaf litter, fruits, termites, and earthworms, a few individuals were often found on the karst wall, sometimes as high as 3 m, probably to ambush prey. On one occasion we found a crab (carapace length = 45.35 mm) eating an S3 *C. sumonthai*. We also recorded 25 sightings of the carnivorous bat, *Megaderma lyra* Geoffroy, 1810, roosting inside the cave where geckos can sometimes be found. This species of bat is known to take lizards as prey (Audet et al., 1991). Other small carnivorous mammal species, such as the leopard cat, *Prionailurus bengalensis* (Kerr, 1792), were recorded from the Khao Chamao area, although we did not find any of them during our survey. *Macaca fascicularis* (Raffles, 1821) (Primates) was abundant in some parts of the study site but their diurnal activity did not seem to have any effect on the nocturnal gecko. On many occasions the voice of owls (Strigidae), possibly of *Athene brama* Timminck, 1821, could also be heard in our study area (Fig. 5).

***Prey.*** — The main potential prey items inside the cave were cave crickets (Rhaphidophoridae). They occurred randomly in the cave sometimes individually, sometimes in small groups of 3–4 individuals. Others potential preys were spiders, cockroaches, and moths that can be seen occasionally on the cave wall. A few cave centipedes (Scutigera) were found in every survey—smaller individuals can be potential prey items for the geckos but adults were too big and acted more like competitor and predator as they are known to prey on insects and possibly small vertebrates. Whip spiders (Amblypygi) can also be found inside the cave, and small individuals can be potential prey item for the gecko. Outside the cave, prey items were numerous, as reported elsewhere in the tropics (Aowphol et al., 2006). Some of the more abundant groups of insects in the study area were Tetrigidae, Cercopidae, Lampyridae, and Cicadidae. Winged Hymenoptera (ants) and Isoptera were also available during rainy season (Fig. 6).

## DISCUSSION

*Cyrtodactylus sumonthai* showed no apparent external sexual dimorphism. This finding is in-line with other nocturnal lizards where detailed visual cues between sexes are not very important (Zug et al., 2001). However, they showed sexual size dimorphism. Females were on average, larger than males. The males showed no territorial behaviour or mate guarding, as is sometimes associated with some gekkonid species where males are larger than females (Johnson & Bouskila, 2007). The mean size of the adult group (> 60 mm) declined over the period of the survey as subadults gradually crossed the 60 mm threshold to join this group later in the survey period. Juvenile size (< 40 mm) declined due to the fact that new hatchlings near the end of the survey period reduced the average size as the survey progressed. Meanwhile, mean size of subadults (40–60 mm) increased as the young of the year grew.

The greater number of female records in our study was mainly due to the fact that females were more active during the wet season. Temperature has been linked with the activity of gekkonids and other reptiles; generally, higher temperature results in higher activity (Henle, 1990; Aowphol et al., 2006; Frenkel, 2006). However, a study on snakes in a tropical climate found no correlation between snake activity and temperature but a strong correlation between activity and ambient relative humidity. They reasoned that temperature in the tropics normally stayed warm and relatively constant throughout the year, so the reptiles could passively maintain their body temperature within a fairly narrow preferred range (Daltry et al., 1998). We did not find a correlation between temperature and activity for *C. sumonthai*. However, its activity was negatively correlated with ambient humidity, with a higher ambient humidity resulting in lower activity by the gecko. However, Aowphol et al. (2006), who studied foraging behaviour of *Gekko gecko* in Chon Buri Province (adjacent to Rayong, where we conducted our study), showed that gecko activity was positively correlated with ambient humidity. The activity of *Cyrtodactylus intermedius* in Northeastern Thailand was also found to be reduced during time of the year with low humidity (Suttanon & Lauhachinda, 2008). Both studies reasoned that activities of the geckos were reduced in low humidity due to their need to reduce water loss. However, the study by Aowphol et al. was carried out in a residential area, thus other parameters we considered, such as activity of predators and competitors, were low/absent and were thus not recorded (Aowphol, pers. comm.). Northeastern Thailand, where Suttanon & Lauhachinda (2008) made their study, also has a much drier climate than in Southeastern Thailand, where we conducted our research. Thus overall humidity was much lower compared to our site. Behavioural shifts due to presence of predators has been reported in gekkonids (Hoare et al., 2007) and *Anolis* lizards (Losos et al., 2004). In our study site, activity of potential predators (crabs) and competitors (amphibians) significantly peaked when humidity was high. Thus we reasoned that activities of predators and competitors during high ambient humidity probably resulted in lower activity of gecko. However, because we did not survey the whole altitude of the mountain range, we cannot rule out migration of the gecko to higher parts of the karsts out of our study area. A detailed study of interaction between *C. sumonthai* and land crab as its potential predator would help to confirm our hypothesis.

Since ambient humidity had an adverse effect on activity of *C. sumonthai* and females appeared more during the wet season, we suspect that the activities of females during this period were mainly due to their need for more food to nourish their developing eggs which they would deposit at the end of the wet season. The fact that females were more active over this period of the year also partly explains why they are on average larger than males.

As in the work of Bustard (1969), the population of *C. sumonthai* consisted mainly of adults, with much smaller number of subadults and juveniles. This is in contrast to a study of *Oedura lesueurii* by Webb et al. (2008) in Australia where, in some years, juveniles and subadults accounted for as much as 73.8% of the population. This is almost the opposite of the situation found in *C. sumonthai* where adults

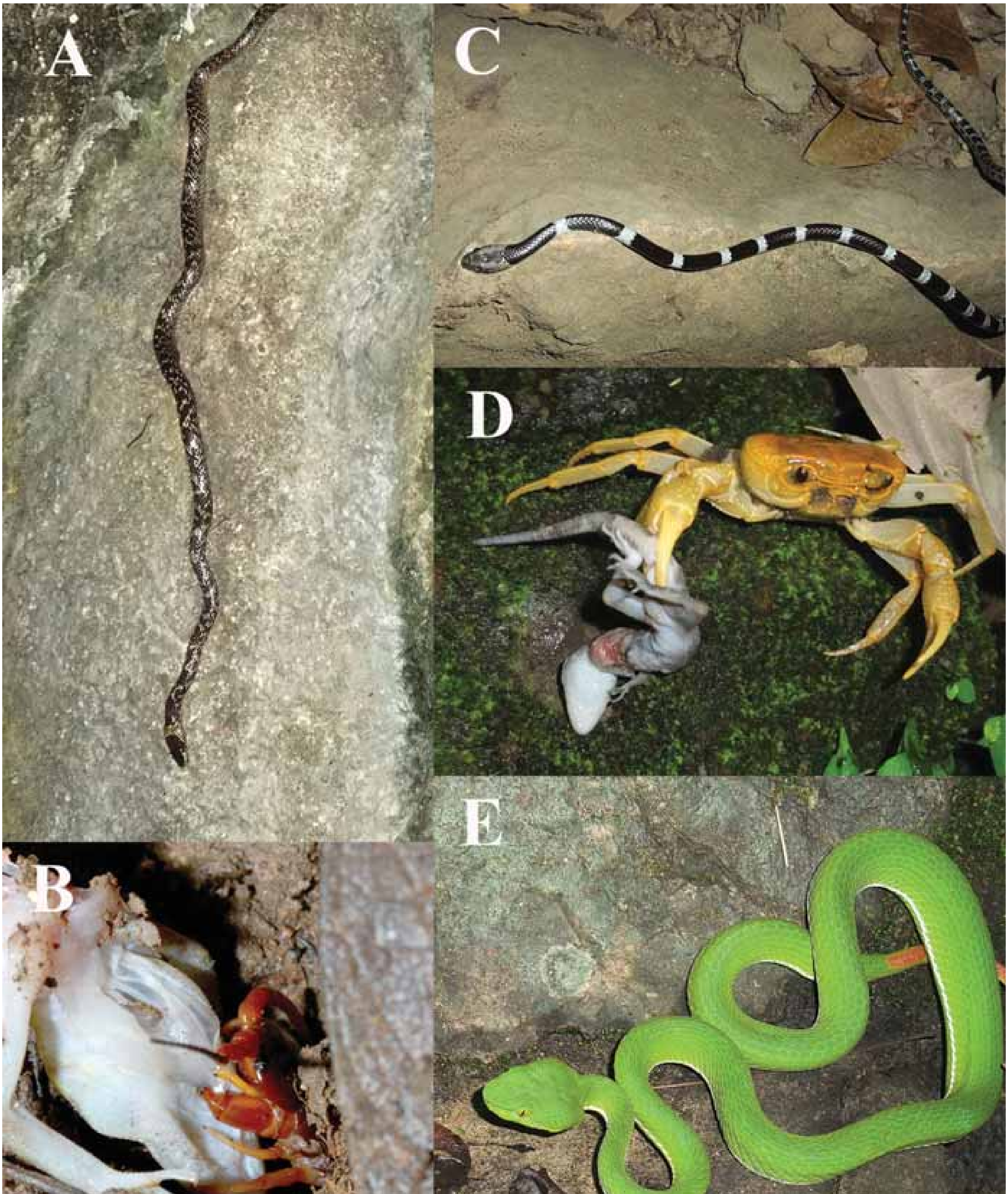



Fig. 5 Images of some of the predators in our study site. A, *Lycodon capucinus* (Colubridae); B, *Scolopendra subspinipes* (Scolopendridae); C, *Dryocalamus davidsonii* (Colubridae); D, *Eosamon smithianum* (Potamidae); and E, *Trimeresurus* [*Cryptelytrops*] *cardamomensis (Viperidae)*.

accounted for 75% of the population. Webb et al. (2008) reported that *Oedura lesueurii* was long-lived and that mortality of juveniles was low. However, they also stated that population size was stable. If this is the case, then mortality or migration must be high at some point to accommodate such large percentage of young. In *C. sumonthai*, with a much lower number of young in the population, turnover rate must be lower.

Recapture rate was used to determine individual survival; in our study, the percentage of recapture of different size groups were not very different. Adults were recaptured the least, but, they were found to forage more widely than the smaller size groups, which were found to be more site specific, thus adults were less likely to be recaptured. Adults can also afford to be less active when the conditions are less favorable, as they have more reserve energy sources.

Since the area of each habitat in our study was not equal, the respective number of geckos from each site is not directly comparable; however fluctuation in each site is clearly recognisable. At least in habitats H1, H4 and H5, the lower activity of the geckos in the wet season can probably be attributed to a much higher number of predators in the form of land crabs. This can partly explain why the number of geckos found in H2 and H3 habitats, with no presence of crabs, seems to increase or be stable during the wet season. Interspecific competition and potential predators also increased in the wet season due to greater activity of the amphibians in the study area. In this regard, H2 had the fewest amphibian competitors in the area whereas H4 had the most species; this may partly explain why more geckos were found in H2 and why they were almost completely absent from H4 in the wet season.

Avoidance behaviour may also explain why habitats H1, H4 and H5 were being used less during the wet season. In our study, we found that if the danger was not immediate the gecko tended to stay on the cave wall, tree or rock that it was originally perched, and slowly moved away into the hiding place. However, if the danger was immediate they would jump down to the ground and scramble off. Since H1,

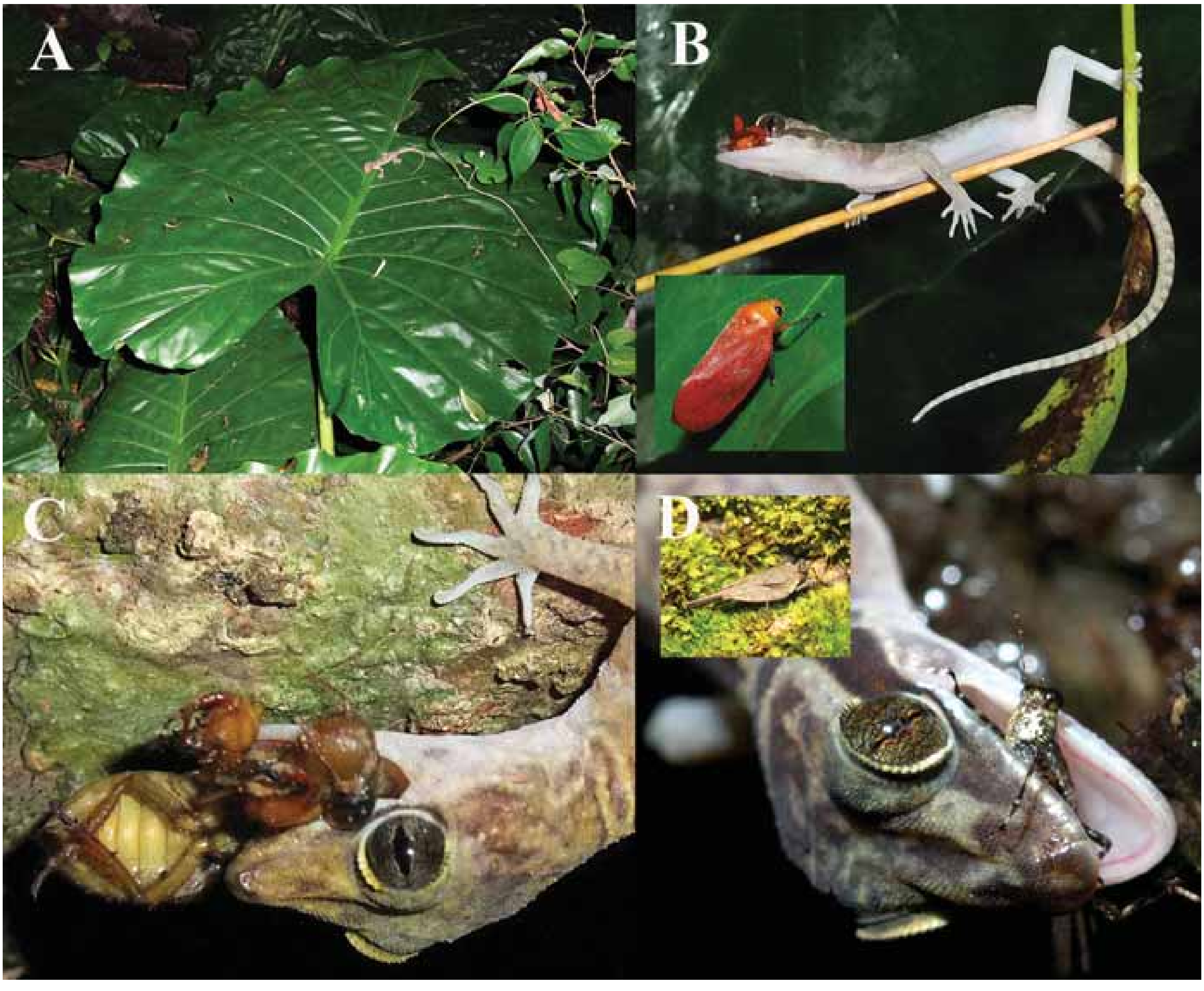



Fig. 6. A, perch site on leaf of *Alocasia* sp. during the wet season. B, perch site on thin branch, prey captured was a Cercopidae species. (Insert photograph by: Seelawut Damrongsiri). C, Cicadidae pupae being captured by adult. D, dwarf grasshopper (Tetrigidae), one of the main prey items found in the study area during wet season.

H4 and H5 were almost permanently flooded, some parts as high as 50 cm during the wet season, the latter mode of escape was not possible which reduced the geckos' chance of fleeing from predator.

Egg deposition crevices have been reported to be a limiting factor in some populations of gekkonids (Pike et al., 2010). We did not find this to be the case in our study site, since we found some unoccupied crevices during the peak of the egg-laying season. Temperature fluctuation has been reported to cause less fit or smaller hatchlings in reptiles (Patterson, 2007). Therefore it is not surprising to find most egg-laying crevices inside or around the cave entrance, as the temperature inside caves has been reported to be more stable (Culver & White, 2005). Since we found the majority of eggs inside the cave, while the majority of the juveniles were found outside of the cave, we assumed that, once hatched, the juveniles must find their way out and find a place to settle down and grow. However, we do not rule out the fact that suitable egg crevices may also be available in habitats outside the cave, as there are numerous large boulders and outcrops with small crevices that were inaccessible to us.

*Cyrtodactylus sumonthai* used communal nest sites, a habit well documented in other gekkonids (Somaweera, 2009; Pike et al., 2010; Sreekar et al., 2010). However, the number of eggs in each crevice was low (Max no. = 5) compared to some species reported such as *Calodatylodes aureus* from India with as many as 46.92 eggs per site (Sreekar et al., 2010). We attributed this difference to two reasons: firstly, there were more suitable egg deposition sites than needed in our study site, and secondly, eggs of *Cyrtodactylus sumonthai* were non-adhesive, thus requiring a level space with sufficient indention to stay in place. Such places are normally small in our study site, and fewer eggs could be laid in one site, contrary to adhesive eggs of some species which can be attached to the vertical surfaces. Multiple clutches per year have been reported in some species of gekkonids with some females laying one instead of two eggs in the second clutch of the year (Culver & White, 2005). This might be the case for *C. sumonthai* as we found an odd number of eggs (one and five) in some crevices. Juveniles can be encountered throughout the year, although egg mortalities were found to be high outside of the peak breeding season.

The fact that some eggs took as long as eight months to hatch, while some took only three months, was very puzzling. However, whenever the eggs were laid, most juveniles hatched during the dryer and hotter period, after an episode of unusually cold winter during Dec.2010 – Feb.2011. Perhaps the lower humidity and/or higher temperature in Mar–Apr.2011 might have caused an acceleration in embryonic development and synchronous hatching together with other eggs laid at the peak period. Generally, development of squamate embryos is initiated at fertilisation, development then continues once the eggs are being laid until hatching (Andrews & Mathies, 2000). So far the only known embryonic diapause in a reptile is in a group of chameleons in the genus *Chamaeleo*. Andrews & Donoghue (2004) found that higher temperatures, not humidity, was the main factor that initiated the diapaused embryos to begin their development in the veiled chameleon (*Chamaeleo calyptratus* Duméril & Bibron, 1851). This might also be the case in *C.sumonthai*. However, further studies into developmental physiology are needed to solve this puzzle, probably under controlled laboratory conditions.

Niche partitioning in co-existing species of geckos has been reported (Pianka & Pianka, 1976; Noble et al., 2010). In Thailand, *Cyrtodactylus chanhomeae* of the central limestone karst system is known to share its habitat with five other species of gekkonids (Konlek & Lauhachinda, 2008). There were very low numbers of direct competitors in the form of other species of gekkonids in our study area. However, there was habitat partitioning between different age groups in *C. sumonthai*, with the S1 and S2 groups preferring to be outside the cave, which probably provided more access to prey items. As sit-and-wait predators, *C. sumonthai*, theoretically, rely on mobile or winged preys which are very limited in the cave environment but more numerous outside the cave. On the hill side, loose rocks also provide complex hiding places for small individuals, compared to the bare substrate inside the cave, resulting from years of bat guano deposition in some places and presence of ephemeral streams which washed soil deposition into the cave in some places. Some species of gekkonids are known to be tolerant of their young (Bustard, 1969; 2009). However, Frenkel, 2006 reported that adults of *Hemidactylus frenatus* cannibalised the young. In our study, we observed a few occurrences where juveniles were perched within sight of adults, and assumed that cannibalism might not be the factor for habitat partitioning between age group in our studied species. Our mark and recapture results showed that the S3and S2 size groups stayed in the vicinity of their previous site of capture, thus we assumed that once they settle down they do not move very far from their home range. However, our study also showed that an S2 individual moved closer to the cave entrance once it grew to adult size. As for adults, some short migrations were observed, as they move from inside of the cave during the dry season to the entrance of the cave during the wet season and moved back inside the cave in the next dry season. In Khao Yai National Park (Nakhon Ratchasima Province, Northeastern Thailand) *Cyrtodactylus intermedius* has been observed mating in early Jul. (pers. obs.). Therefore, it is possible that the movement of adult *C. sumonthai* to congregate around the cave entrance during this time of the year might also provide opportunity to find mates.

*Cyrtodactylus sumonthai* demonstrated some plasticity in perch site selection as some shifted from rocks to plants during the wet season. Majority of them were found on top of the large leaves of *Alocasia* sp. (Araceae) which were present only during the wet season. Given the sit-and-wait foraging behaviour of the gecko, the large smooth surface of the leaf offered a good opportunity for flying insects to land and be captured by the gecko. The higher incidence of use of man-made structures as perch sites during the wet season was not surprising as these were mostly wooden and concrete stairs present only in H2 and H3 habitats. Since more geckos were found in these types of habitats during the wet season, there was greater chance of them being found on these structures. This also showed that the gecko accepted the modification of their habitat in the form of permanent structures, as long as it did not greatly alter the habitat. Inside the cave, *C. sumonthai* showed no preference for smooth or highly porous or complex cave walls as long as there were small crevices in the vicinity where they could retreat when disturbed.

Tourism, religious activities and film making occurred regularly in our study area. In the span of 12 months there were three films done in the area, with crews from three different nations. These activities mostly happened only during daylight hours. Since only a small proportion of the geckos were active during these hours, they were not much affected as long as the habitat was not being greatly modified. Inside the cave, where they are active during the daytime, *C. sumonthai* showed no flight behaviour as tourists walked past their perch sites, sometimes as close as 1.5 m; this approachability has also been reported in *Cnemaspis kendalli* from Singapore (Werner & Chou, 2002). In our study, *Cyrtodactylus sumonthai* only took flight when being approached with light shone directly on them from around 1–2 m. Even then, if left undisturbed, they came back to the same area or perch site within 5–10 min. Some individuals which were captured in our study and released back at the same spot from which they initially took flight into the crevice, were sometimes found back in the vicinity of the same spot a few minutes later.

Tail condition has been used to determine predation pressure (Pianka & Pianka, 1976). However, there are some arguments against such assessment as some specialised gecko predators might be able to capture the entire gecko and leave no tail-less ones behind. Tail autotomy frequencies among geckos may range from 4% in *Stenodactylus doriae* to 100% in *Asaccus* spp. (Bauer & Russell, 1994). In *C. sumonthai*, the frequency of tail loss, when all size groups are being considered, is high, being higher than 17 of 18 species reported from Australia by Pianka & Pianka (1976). However, if only the adult frequency of tail loss (85.44%) is used for comparison, then the rate is very high compared to all 18 species reported in the above paper and other species reported from other parts of the world (Frenkel, 2006; Johnson & Bouskila, 2007). In our study, juveniles were found to have the highest percentages of original tails among age groups. It should not be the case that they experience less predation pressure since predators of different sizes were present in our study area. Tail loss is also cumulative, so even under equal risk of loss, the older geckos will have more tail loss.

*Cyrtodactylus sumonthai* with a maximum length of around 80 mm should be considered as a medium-sized gekkonid species. Our data showed that individuals grew from hatchling size at around 25 mm to 60 mm within 17 months. However, since females need to grow to at least 64.90 mm to breed and growth rate decreases with increasing size (as shown in our data), females probably take at least 24 months before they are sexually mature and ready to breed.

Gekkonids are reported to prey mainly on arthropods, and they do not seem to limit their food to any particular group of arthropods (Henle, 1990; Werner, 1998). We found this to be the case for *C. sumonthai*. The prey variety is higher outside the cave, while inside, the highest biomass, as far as potential prey for gecko is concerned, comes from cave crickets (Rhaphidophoridae). These crickets seem to be about the right size, with maximum size not larger than the width of the gecko's head. However, from our observations, they do not seem to move very much, probably an adaptation to avoid ambush predators like geckos in their environment.

## CONCLUSIONS AND RECOMMENDATIONS

1. *Cyrtodactylus sumonthai* takes at least 2 years to become sexually mature and females probably lay only 1–2 clutches per year.
2. Our study noted the importance of ecotone habitat between the cave and outside environments as well as karst outcrops and boulders outside the cave as habitats of the so-called "cave-dwelling species". There is habitat partitioning between different age groups of *C. sumonthai*, with juveniles and subadults tending to prefer habitats outside of the cave. Thus any conservation plan focused on "cave-dwelling species" should also include the area outside of the cave as a precaution.
3. There were seasonal movements of geckos from inside the cave to outside and vice versa, thus the entrance of the cave must be kept open and relatively undisturbed so that geckos can move in and out freely.
4. Night-time activity by human should be avoided in nocturnal gecko habitats, while daytime activity does not have much effect on the gecko.
5. Pattern and tubercles may be reliably used to recognise individual geckos, at least for *C. sumonthai*.
6. Predation pressure from various groups of predators and interspecific competition from amphibians seem to be factors limiting foraging sites and population size of *C. sumonthai*.

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