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Population Ecology of Genus *Sinonatrix* in Taiwan

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Zusammenfassung

Taiwan ist wegen seines hohen Endemitenreichtums von besonders großem biogeographischem Interesse. Da die Phylogenie, Ökologie und Systematik einzelner Taxa noch weitgehend ungeklärt sind, analysierten wir seit 1997 die Herpetofauna des Landes. Dabei stellte sich heraus, dass insbesondere die Gattung *Sinonatrix* für die Aufklärung von Evolutionsvorgängen bedeutungsvoll ist. Deshalb konzentrierten wir zunächst die Analysen auf zwei sympatrische Populationen von *Sinonatrix* in den Chutzuhu-Sümpfen in Nord-Taiwan. Gleichzeitig wurde das vorhandene Museumsmaterial (u. a. Senckenberg Museum) überprüft und vergleichende Arbeiten an *S. pericarinata suriki* in Botanischen Gärten von Taiwan durchgeführt. Unsere morphologischen Analysen zeigten, dass die Phylogenie von *S. pericarinata suriki* entscheidend beeinflusst wurde von zwei Ausgangspopulationen, im Norden Taiwans von Fujien oder Zehjiang, im Süden von Guangdong oder Vietnam. Dies Muster wird durch molekulargenetische Analysen auch von Süßwasserfischen bestätigt.

In 22.462 „trap-nights“ wurden 361 Schlangen in den Chutzuhu Sümpfen gefangen. Die Populationsgröße wurde nach dem Lincoln-Peterson Index auf 988 ± 326 *S. annularis* und 129 ± 78 *S. pericarinata suriki* geschätzt. Untersuchungen an markierten Tieren zeigten, dass *S. annularis* streng an aquatische Bedingungen gebunden ist, während *S. pericarinata suriki* semiaquatisch leben kann. Beide sind in ihren home ranges vom hydrographischen System abhängig. *S. annularis* ist vivipar und bringt ihre Jungen bevorzugt im September zur Welt (durchschnittlich 8,19); *S. pericarinata suriki* ist eierlegend (6-24). Aber es gibt offensichtlich Oviparie. Der Reproduktionstyp wird beeinflusst von der Entwicklung des Klimageschehens und führt deshalb auch zu einer adaptiven Habitatdifferenz bei sympatrisch vorkommenden Populationen.

S. annularis zeigte sich als ausgesprochener Fischfresser (98%), während *S. percarinata suriki* je 50% Fische und Frösche in ihrer Nahrung aufwies. *S. annularis* scheint mittel- bis tiefgründige Sumpflandschaften als Mikrohabitat zu bevorzugen, *S. percarinata suriki* offene Bachläufe und Gräben. Die Vitalitätsbedingungen für die Population im Chutzuhu-Sumpf verschlechtern sich offensichtlich zunehmend, was sich auch in den abnehmenden Werten des Body-Condition-Index, geringen Mageninhalten sowie Infektionen bei *S. annularis* zeigt. Der

Faktor Wasser stellt offenbar die entscheidende Einflussgröße dar und ist streng mit den Schutzkonzepten korreliert. Für die Population von *S. annularis* im Chutzuhu-Sumpf ist die Formulierung konkreter Schutzmaßnahmen geplant.

Im Rahmen der vorliegenden Studie wurde überdies eine effektive Methode zur Verarbeitung morphologischer Daten und Abbildungen von Schlangen in einer Datenbank entwickelt. Dies geschah mit Hilfe von PC Notebook und Scanner in einer für die freilandökologische Studien adäquaten Vorrichtung. Weiterhin wird ein Komponenten-System zur Einrichtung einer allgemeinen Datenbank für Schlangenpopulationen zur Anwendung im Rahmen ökologischer Langzeituntersuchungen und Monitoringprogrammen vorgeschlagen (FPDS).

Abstract

Since November 1997, we started to focus on the population ecology of two sympatric *Sinonatrix* snakes in the Chutzuhu swamp, northern Taiwan. At the same time we also examined some specimens from Senckenberg Natural History Museum, Frankfurt am Main and accumulated field data of some observation made on *S. percarinata suriki* from Fushan botanical garden, Sanping and Gaoshu, Taiwan.

According to the specimens examined, we suspect that the close phylogeny of *S. percarinata suriki* may come from two ancestors, northeast Taiwan population closest to Fujien or Zehjiang and the southwest population closest to Guandong or Vietnam. This pattern was also represented in some molecular phylogeny studies of freshwater fish in Taiwan.

There were 22,462 trap-nights, taken from the Chutzuhu swamp, during the period November 1999 to September 2001 and 361 snakes were collected, comprising five species and 617 snake-times. The population sizes were based on the Lincoln-Peterson index and were estimated to be 988±326 in *S. annularis* and 129±78 in *S. percarinata suriki*. Movement and home range data showed *S. annularis* is a restricted activity water snake and *S. percarinata suriki* possesses great mobility in spatial patterns, but movement ability seems to be influenced by the size of the aquatic environment. *S. annularis* is live-bearing, on average 8.19 neonates and this principally occurs in September; *S. percarinata suriki* lays 6-24 eggs, but due to insufficient observations no conclusions can be drawn. It must be noted that oviposition was also noted in September. The reproductive mode may reflect on thermal requirement differences of the two sympatric snakes.

S. annularis tended to be a fish (98%) eater and *S. percarinata suriki* take 50% fish and 50% frogs in their diet. Middle to high ground cover marshland appears to be the favorite microhabitat of *S. annularis*, and *S. percarinata suriki* seems prefer open creeks and ditches. The population condition of *S. annularis* in the Chutzuhu swamp seems to be rapidly deteriorating and this trend is also reflected in the BCI declines, low proportion stomach contents and diseases of *S. annularis*. Water seems to be the major influencing factor and strongly correlates with the conservation strategy. Conservation proposals for *S. annularis* in the Chutzuhu swamp will be formulated.

During this study period we also developed an efficient technique for snake morphological data accumulation and image database, with the aid of the following devices, PC notebook and scanner, which is adapted for practical field studies. We also want to propose a component system for the establishment of a fundamental snake population databases (FPDS) for long-term snake ecological studies and monitoring herein.

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Chapter 1. Introduction

Taiwan is an island, 394 km in length 144 km in width and covers an area of about 36,000 square kilometer. It is locates at the margin of the Eurasia plate, about 130 km offshore of Mainland China and was formed about 5 million years ago. Numerous species have dispersed from the continent of Eurasia to Taiwan after the island's formation. OTA (1991, 1998) pointed out that Taiwan was directly connected to the continent by a land bridge throughout the Miocene to Pleistocene periods. Meanwhile, the Central Mountain Range has been lifting since the appearance of Taiwan Island. The uplifting of the Central Mountain Range consequently affects the surface and structure of Taiwan and naturally shapes the biota composition. The principal biota of Taiwan was formed consequently and consists of seven botanical biota from high elevation to low as follows: 1) Alpine tundra (elevation: 3,500m above), 2) Sub-alpine coniferous forest (elevation: 3,000-3,500m), 3) Cold temperature montane coniferous forest (elevation: 2,500-3,000m), 4) Warm-temperature montane coniferous forest (elevation: 1,400-2,500m), 5) Warm temperature montane rain forest (elevation: 900-2,100m), 6) Tropical rain forest (elevation: under 900m), 7) Sea shore forest (coast) and tropical savanna (lowland). The high differentiation of environments and biota composition is also reflected in biodiversity and the high proportion endemic species. According to authoritative compilations, the sum of lichen, fungi, algae, flora and fauna in Taiwan is about 36,880 species and consists of 25,126 forms of fauna, and 5,738 forms of flora. Of all the species distributed over Taiwan, 33.44% (12,333) are endemic. By studying extremely isolated populations of snakes in Taiwan we may be offered an excellent opportunity to develop a better understanding of the different environmental adaptations and divergences of snakes, we might even better understand the speciation evolution procedure.

The genus *Sinonatrix* is a member of Old World natricine snakes and is endemic to southern and eastern Mainland China, Indochina Peninsular and India, and contains six species and one subspecies (ZHAO AND ADLER, 1993; CAPTAIN AND PATEL, 1998; RAO AND YANG, 1998; ZHAO ET AL., 1998). It is one of the few semi-aquatic genera of Natricine in eastern Asia. MALNATE (1960) reorganized the genus *Natrix* by a combination of hemipenis morphology characteristics, maxillary dentition, internasal shape and nostril. He mentioned that *Natrix annularis* (=*S. annularis*) is an irregular species in the genus *Natrix* of the Old World tribe, since it is the only species that utilizes a viviparous reproductive mode. In 1977, ROSSMAN AND EBERLE, based on biochemical data, karyological data, scale characters, hemipenis and skull features partitioned the genus *Natrix*, which was reorganized by MALNATE (1960), into four genera: 1) genus *Natrix* distributed over Europe and western Eurasia; 2) genus *Nerodia* distributed over North American; 3) genus *Sinonatrix* distributed over Southeast Mainland China, Indochina Peninsular and Taiwan; and 4) genus *Afronatrix* distributed over North Africa. Except for *S. annularis*, the obvious ecological distinction between Old World Natricine and New World Natricine is the reproductive mode, the former uses viviparity and the later oviparity. In 1982, SCHWANER AND DESSAUER applied immunology transferring analyzed phylogeny on Old World and New World natricine snakes, the genus *Sinonatrix* is obviously distinct from the other three major branches of natricine snakes 1) *Afronatrix*, *Nerodia* and other American genera; 2) European *Natrix*; and 3) Asiatic genera - *Xenochrophis*, *Amphiesma* and *Rhabdophis*. But the four genera have been proven to have came from a natural assemblage and belong to a monophyletic group in phylogenetic relationship studies (SCHWANER AND DESSAUER, 1982). Following, a phylogenetic study on natricine snakes of Taiwan, also recognized that *Sinonatrix* was observably distinct from the tribes, *Xenochrophis*, *Amphiesma* and *Rhabdophis* on 12S rRNA fragment of mtDNA (MAO, 1998).

There are two *Sinonatrix* snake species in Taiwan, *S. annularis* and *S. percarinata suriki*. The earliest records of snake fauna in Taiwan were made by SWINHOE (1863) and listed seven snakes from Taiwan, including *Tropidonotus annularis* (=*S. annularis*) from Tamshy (=Tamsui, Taipei County). In 1914, OSHIMA pointed out that *S. annularis* is widely distributed in the lowlands of Taiwan and caused damages in freshwater fisheries. MAKI (1931) published a new species that was collected from Makazayazaya (=Macha district, Pingtung County) named *Natrix suriki*. POPE (1935) first point out that *N. suriki* may be a synonym of *N. percarinata* from China. In 1965, MAO compared and examined 115 specimens of *N. suriki* that were collected from Taiwan and revised the species as a new subspecies of *N. percarinata suriki* (= *S. percarinata suriki*). OTA (1991) analyzed the distributional patterns of endemic taxa and related offshore reptile species. He classifieds them into five groups (A, B, C, D, and E) for possible closest relatives outside Taiwan, and *Sinonatrix* snakes were classified as belonging to group C, which has closest relationship from Fujian Province, Mainland China. MAO (1998) found that *S. percarinata suriki* had two geological variations in color patterns, ventral scales and molecular differences in Taiwan. In 1999, we had *Sinonatrix* snake specimens examined in Senckenberg Nature History Museum, Frankfurt am Main and suspect that the two geological variations of *S. percarinata suriki* may have come from different ancestral lines and may belong to two subspecies, *S. p. percarinata* distributed in northeast Taiwan and *S. percarinata suriki* distributed in southwest Taiwan (MAO, UNPUBL.). Similar patterns also occur in phylogeny studies of freshwater fish and supported by molecular data (CHENG, 2001; POH, 2001)

Except for some taxonomy (STEJNEGER, 1907; MAKI, 1931; POPE, 1935; WANG AND WANG, 1956; KUNTZ, 1963; MAO, 1965; RAO AND YANG, 1998), phylogenetic (MAO AND DESSAUER, 1971; LAWSON, 1986; MAO, 1998) and brief observations (HE, 1983), there were no systematic ecological studies done on *Sinonatrix* snakes in Asia. Therefore, it is still a species of which the life history and ecology is poorly understood, compared to its sister groups *Natrix* and *Nerodia*.

Population studies of snakes are uncommon, perhaps because of the secretive nature and low population densities of snakes (PARKER, 1976), but population studies of natricine snakes in Europe and North American were reported in several former publications (SEIBERT AND HAGEN JR, 1947; SEIBERT, 1950; CAMIN AND EHRLICH, 1958; FRAKER, 1970; MUSHINSKY ET AL., 1980; KEPHART AND ARNOLD, 1982; MADSEN, 1984; HAILEY AND DAVIES, 1986; KING, 1986; CHARLAND AND GREGORY, 1995; MERTENS, 1995; GREGORY, 1996; LUISELLI ET AL., 1997). In our available literature, there were no evidence of any viviparous semi-aquatic natricine snakes that have been studied over a long-term period in subtropical Asia, only another two Temperate Zone natricine species *Amphiesna vibakari* and *Rhabdophis tigrinus* have been studied in Japan (MORIGUCHI AND NAITO, 1982; MORIGUCHI AND NAITO, 1983; MORIGUCHI, 1988). The ecological correlation of sympatric water snakes have been noticed and studied in America (MUSHINSKY ET AL., 1980) and in *Natrix natrix* and *N. maura* in Europe (HAILEY AND DAVIES, 1986). Different thermal requirements and life-styles seem to play a major role in resource partitioning within sympatric natricine snakes.

PARKER AND PLUMMER (1987) mentioned that island populations is one of the obvious important criteria for the selection of population studies. Both *S. annularis* and

S. percarinata suriki in Taiwan are extremely isolated island populations from Mainland China. Besides, *S. percarinata suriki* is a unique subspecies in the genus *Sinonatrix* and is restricted in Taiwan.

In 1992, TESRI (Taiwan Endemic Species Research Institute) initiated a species inventory determination project and since then more than 2/3 of Taiwan have been examined, which includes almost the entire distribution area of *S. annularis* that were mentioned in literature, but no trace of *S. annularis* was found (CHU pers. com.). About a century ago, focus on *S. annularis* in Taiwan was first due to the damages it caused to the local freshwater fisheries, and since then most lowland populations has disappeared unnoticed because of habitat destruction or some other suspected reasons. Even living in a national park of Taiwan is not a guarantee for the population extension or survival because of a lack of understanding and ignorance towards this species. This study may be the last chance to know the ecology and life history of the only island population of *S. annularis* and the unique subspecies of *S. percarinata suriki*. We hope our efforts can offer more information for further conservation projects of *Sinonatrix* snakes in Taiwan.

From November 1997 we started to focus on and study *Sinonatrix* snake populations in the Chutzuhu swamp and continued to accumulate field data of *Sinonatrix* in Taiwan. Chutzuhu was an ancient volcanic lake and now has a closed basin topography. During these five years we recorded the changes in the wetland and its effects on semi-aquatic snake dynamics. We also have some observations on *S. percarinata suriki* in different localities around Taiwan. Characteristics of *S. annularis* in Taiwan represented by seasonal dynamics, body size and *S. percarinata suriki* display behavior, phylogeny and both species exhibits sympatric water snake resource partitioning and niche differences. In addition, both sympatric *Sinonatrix* snakes exhibit some convergence on head shape, morphology, behavior and resource partitioning with their sister groups that are distributed over Europe and America. In this dissertation we will focus on population ecology aspects to clarify the characteristics of *Sinonatrix* snakes in Taiwan and their speciality. We will propose some conservation suggestions for extending the population of *S. annularis* in Taiwan. We also want to introduce a new technique for efficient snakes morphological data accumulation and proposes a standardized fundamental snakes population database (FSPD) for further population study procedures for snakes.

Chapter 2. Materials & Methods

This study was mainly based on the technique of mark-recapture. It is most dominant and widely applied technique for life-history studies and is based on estimated population sizes calculated by statistically manipulating incomplete counts (PARKER AND PLUMMER, 1987).

Preliminary study tests and snakes sampling were initiated in November 1997-January 1998 and continued in August-October of 1998. Primary and continuous sampling was done from November 1999 to September 2001. This population study mainly focuses on *Sinonatrix annularis* and the sympatric species *S. percarinata suriki* in Chutzuhu area. In addition to that, some field observations on *S. percarinata suriki* in three different localities; Fushan botanical garden (Ilan County), Sanping (Kaohsiung County) and Gaoshu (Pingtung County) will also briefly be discussed (Fig. 2.1-1).

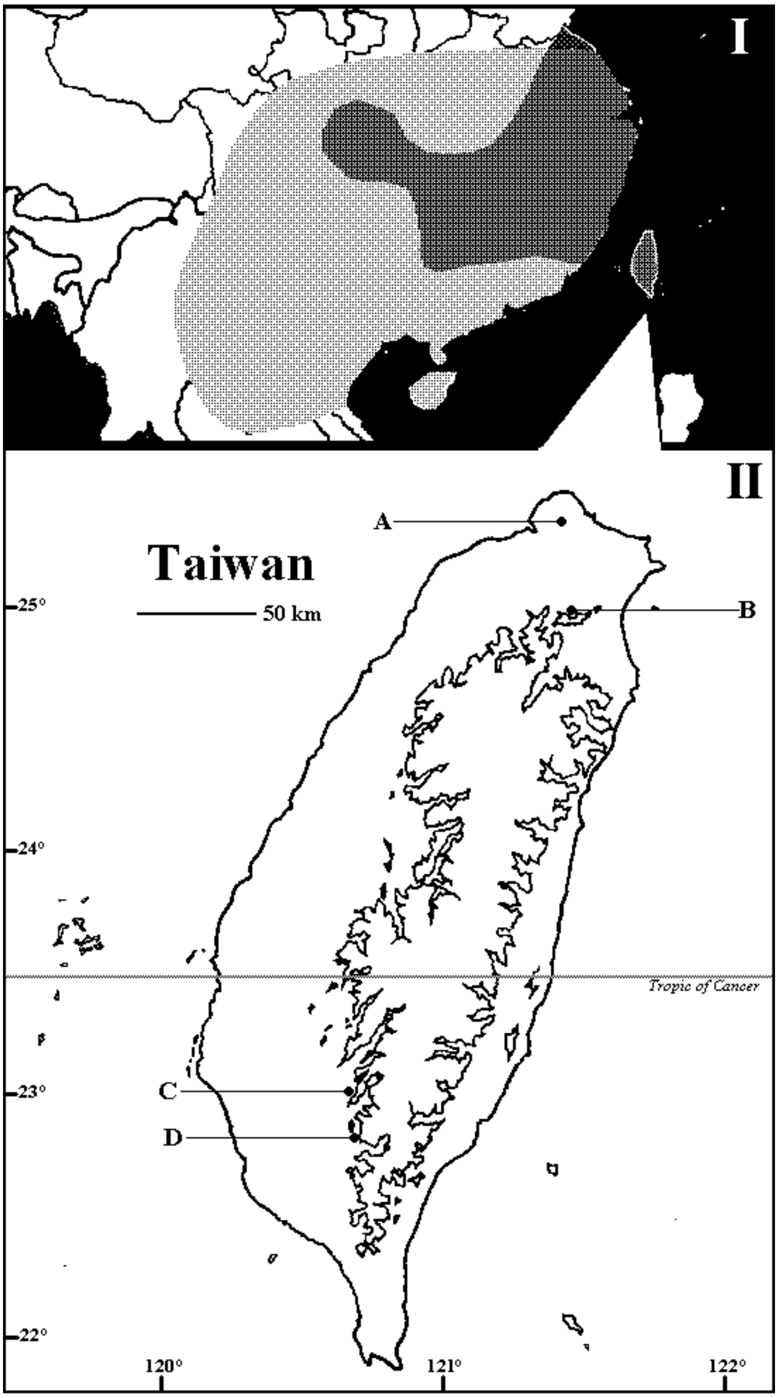

Fig. 2.1-1: (I) The distribution of *Sinonatrix annularis* (black with stippled) and *S. percarinata* (light gray with stippled), overlaps region indicated as dark gray with stippled (Ota, 1993); (II) Map of Taiwan and relate study localities of *Sinonatrix* snakes; (A) Chutzuhu swamp, Taipei City, (B) Fushan botanical garden, Ilan County, (C) Sanping, Kaohsiung County, (D) Gaoshu, Pingtung County, (contour line indicate 1,000 meter high in elevation).

2.1. Study Site Description

Fieldwork for *S. annularis* and *S. percarinata suriki* was continuously conducted, mainly in a highland swamp — Chutzuhu (elevation approximate 680 m), Yangmingshan National Park, in northern Taiwan.

According to geological data, Chutzuhu was a volcanic lake and conjectures the maximum depth was approximately 5 meters. A creek eroded an opening in the southern bank of this lake, and when the water drained from this area it formed the present basin. Three centuries ago, when people started to immigrate to this area, the original lake became the fertile marshland that it is now (Fig. 2.1-2).

Fig. 2.1-2: Topography of Chutzuhu swamp, red line represents the population study area and the yellow arrow indicates the volcanic opening with sulfury gas.

When anthropogenic utilization of this basin started, the cultivation activities were divers and changeable. Because it is an extremely closed swamp environment there is not any contact with nearby swamps. In 1900 the Japanese, who occupied Taiwan, proposed that the development of pure rice in Taiwan should be done in this area. This was to be the first pure semi-aquatic Japanese rice introduction study, which resulted in the amelioration and popularization of this cultivation site. In 1997, when this study just began, semi-aquatic Calla lily (= Cape lily; *Zantedeschia aethiopica* Spreng) was the main economical cultivated product in Chutzuhu area. This is no longer the case, most farmers face a problem, that have not been clearly identified, that may seriously affect the semi-aquatic Calla lily cultivation. Some farms have been abandoned or transformed into dry cultivation lands. Furthermore, several typhoons in recent years have caused torrents that deposited huge amounts of silt, soil and stones in the low-lying parts of this area, filling it. These changes are rapidly reducing the life of this highland swamp (Appendix 7.1).

The study area has highly humid climate (average = 86 %) and is usually fogbound in the afternoon. The annual rainfall is approximately 4,527 mm and the mean annual air temperature is about 18.5 . Rainfall and air temperature data were taken from the Chutzuhu Meteorological Station (elevation 609 m), located 1.68 km south of the study site.

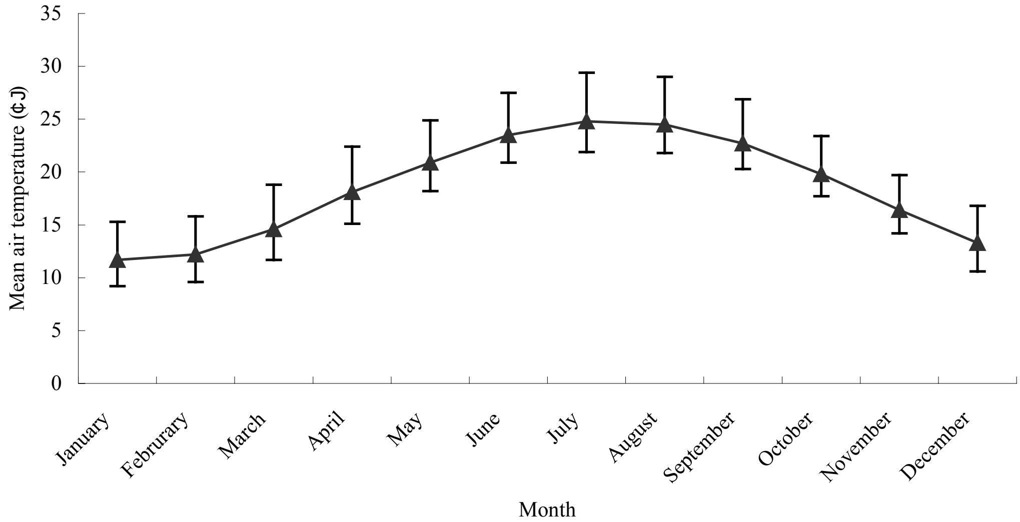

Fig. 2.1-3: Average air temperature (   ) of Chutzuhu area (1971-2000)

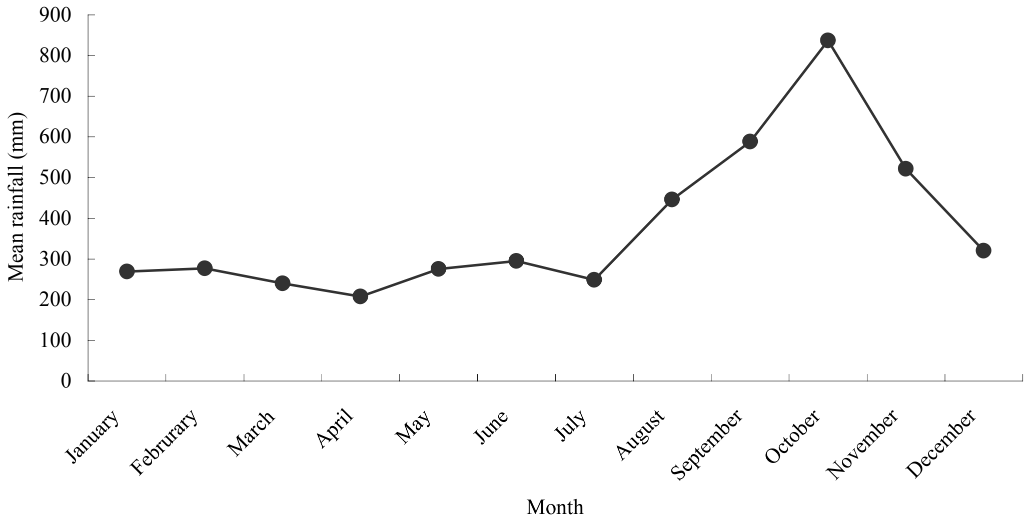

Fig. 2.1-4: Average rainfall (mm) of Chutzuhu area (1971-2000)

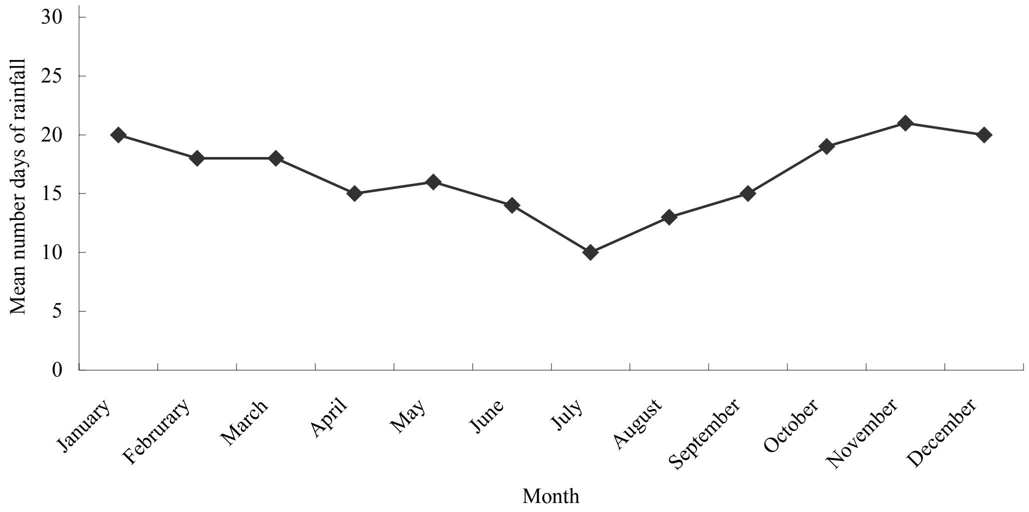

Fig. 2.1-5: Average number days of rainfall of Chutzuhu area (1971-2000)

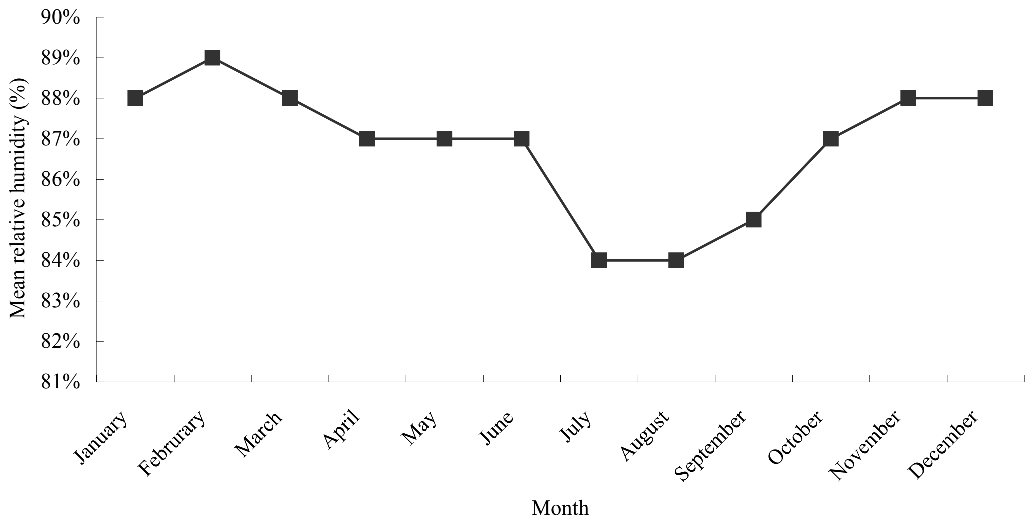

Fig. 2.1-6: Average relative humidity (%) of Chutzuhu area (1971-2000)

2.2. Snakes capture

Due to the marshland environment and secretive behavior of *S. annularis*, the collection of snakes depended primarily upon the domestically produced and utilized shrimp funnel trap and the few chance encounters (n=2). The dimensions of the funnel trap are, 36 cm in length and 12.5 cm in diameter, with a single entrance. The first funnel is situated in the entrance of the trap and the second funnel is positioned approximately 10 cm into the trap, with the funnel cones pointing inwards. A container compartment is created by the remaining part of the trap (Fig. 2.2-1). These traps were positioned horizontally and half-submerged in aquatic habitats in the study area. Local farmers had mentioned before that they regularly got *S. annularis* in their loach traps. Therefore, the traps were baited with loaches to increase the snake capture probability. To avoid affects on the stomach content analysis, the container of funnel trap was divided into bait compartment and a snake holding compartment. Isolating the loaches from the rest of the container compartment by nylon netting did this.

Fig. 2.2-1: Domestic manufacture shrimps funnel trap contents a *Sinonatrix annularis* in Chutzuhu swamp

Each trapping site was recorded and categorized as follows; ground cover ratio (in a circle with a diameter of 1 meter and classified into one of 9 classes), microhabitat type (creek, ditch, paddy field, swamp, and others), and maximum, minimum water temperature.

2.3. Individuals examined

All snakes were taken to the laboratory after capture, where they were sexed by gently probing posterior to the cloacal opening with a blunt stainless steel probe. The total body length (TBL, in cm), tail length (Tail-L, in cm) and body mass (BM, in g) of each individual was also measured.

Dietary condition perceived by palpation and by forcing the animal to regurgitate the stomach contents for identification. Those stomach contents were tagged and preserved in 75% alcohol.

Gestation of female *S. annularis* was also detected by palpation and confirmed by taking an X-ray. In our test, the most appropriate X-ray condition for gestation detection was 200 milliampere (mA), 40 kilovolt (KV), 0.2 second and with a 10:1 grid on the foreground of the film cassette (Fig. 2.3-1).

Fig. 2.3-1: X-ray detected the number of litter size of *Sinonatrix annularis*.

2.4. Marking and photo-image recognition

Two marking techniques were applied for individual recognition, passive integrated transponder tags (PIT tags) and fingerprinting. TROVAN LID-100 system PIT tags were used and although no significant PIT tag affects on neonatal snakes were previously reported by KECK (1994), low survival and recapture rates in neonatal and juvenile snakes were mentioned in other reports (PARKER, 1976; KING, 1986). The body diameter of the neonatal and yearling juveniles of this study were only twice that of the PIT injection needle, for avoiding serious damage during the inject PIT procedure.

In November 1999, an improved individual fingerprinting image collection and preservation system was developed and from that time it was first used in this study (Fig. 2.4-1). It can be applied on all *S. annularis* sizes and ages, neonatal, juvenile and adult, without any risk of injury to the animals (see Discussion 4.10). Therefore, which of the two marking techniques used depended on the size of the snakes, fingerprinting was applied on all individuals, and PIT tags were only applied on snakes with a total body length greater than 35 cm. After the snakes were examined and marked, they were released at the same place where they were captured.

Fig.2.4-1: Individual photo recognition of scans method on *Sinonatrix annularis*

2.5. Population estimate

The Chutzuhu basin has only one opening, located at southern side of the area, where a small creek drains from the basin. During the study period almost no *S. annularis* were captured in traps set at the opening end of the creek, except for a few that were washed out of the study site by typhoons or heavy rains. Therefore, this *S. annularis* population was treated as a geographical closed population. Population estimates for the whole periods (1997 and 1998, 1999-2001) were based on the Lincoln-Peterson index. In addition to that, the recapture rate for *S. percarinata suriki* was obviously lower than that of *S. annularis*, so the population estimation for this species also depended upon the Lincoln-Peterson index (LANCIA ET AL., 1994).

2.6. Movement determination

In Spring 2000 we attempt to use implanting radio-transmitter for movement determination, but unfortunately we were unable to resolve the wound infection problem, due to an alternative choice after transmitter implanted, snakes dehydration or infection. Therefore, another two methods were applied for movement determination and comparison of *Sinonatrix* snakes in this study. First, the measurement, in straight-line, the distance (in meters) between two capture localities compared to the number of days between the intervals. It has been applied for movement study of *Rhabdophis tigrinus* in similar habitat of Japan (MORIGUCHI AND NAITO, 1983). The second method was based on the former method, but the data was manipulated to form a 10 x 10 m grid on a 1/2000 Chutzuhu area map, and snakes present or absent was determined by the recording the grid numbers that fell within the straight-line, excluding previously recorded grids. This crude method could reduce some misinterpretations due to frequently and repeated short distance movements of snakes. We determined the movement of both species from November 1999 to September 2001, since continuous trapping, without any interruptions, took place during that period.

2.7. Growth rate and maturity determination

Since November 1997 to September 2000 the recapture proportion of neonatal and juvenile snakes was relatively lower. There were 3 litters applied in the determination of the growth rate of neonates in October 2000. Three tanks were design to hold the snakes that were used for this study and set in 3 different localities in the study area, a paddy field, the swamp and a ditch. The dimensions of the captivity tank were 50 cm in length, 40 cm in width and 40 cm in high (Fig. 2.7-1). In addition to that, to avoid genetic influences on the growth rate calculation, all three tanks were just stocked with neonates from the same litter. Every ten to fourteen days 150 g of live loaches were placed in the tanks as food for the neonatal snakes. Each tank had an opening, covered by netting to avoid the snakes and loaches from escaping, in two opposite sides of the tank, which allowed fresh water to constantly flow through the captivity tank. Unfortunately, in November 2000 a typhoon destroyed the tanks located in the swamp and paddy field. Therefore, only one tank completed the required period to allow the measure the neonatal growth rate.

Fig. 2.7-1: *Sinonatrix annularis* neonates captivity tank for growth rate determination study in paddy field environment of Chutzuhu area.

The growth rate of adult snakes was based on the snout-vent length (SVL) measurement of two subsequent recaptures. FITCH (1987) mentioned that stretching the snake during SVL measurement stunted and set back the growth of the snake for several weeks. Two recaptures with an interval period shorter than three months were therefore excluded. In addition to that, gravid snakes were also excluded from the growth rate calculation.

In this study, the size at which a female is sexually mature was determined by the minimum size at which a female was found to be gravid. There were no basic data and direct evidence to assist with determining the size at which the male snakes became sexually mature. But two indirect evidences may offer some information about the sexually maturity of males. POPE (1935) mentioned that male *Sinonatrix* snakes developed tubercles on the anterior infralabials and chin-shields, but in my observations, none of the juveniles and small individual possessed this character. It was presumably to be the adult male character of *S. percarinata suriki* (MAO, 1965). Therefore, it may only be present in sexually mature *S. annularis* males. In addition to that, on several occasions during the breeding season the funnel traps were have one large body fitness female and full of males, and the smaller male sizes may also reflects the minimum size at which they reach sexual maturity. Hence, we attempted to recognize the minimum size at which males become sexual mature based on the former two types of evidence. Furthermore, sperm tests of individual neonatal males, which were maintained in captivity for the growth rate determination, may also offer some information about at what age *S. annularis* males become sexually mature.

2.8. Body condition index (BCI) application

Body reserves (fat body) are known to be important determinants for reproduction in many species. The body condition index (BCI) was proposed to calculate the body reserve condition and for determining reproduction in snakes (BONNET AND NAULLEAU, 1994). In my opinion, it may also reflect the health and nutritional condition of individual snakes. Hence, I use BCI for determining the condition of the *S. annualris* population in this study. Leloup first set forth the BCI formula in 1976 and it was as follows (BONNET AND NAULLEAU, 1994):

Body condition index (BCI)= M/MT

M= Body mass of study individual.

MT=$(L/l)^3$ x m

L= Length of study individual

l= Average length of conspecific neonatal snakes.

m= Average body mass of conspecific neonatal snakes.

The BCI estimation must be based on neonatal size, and focuses on the fat body reserve of the snakes in a certain population. Even though it can reflect the realistic condition of the snakes, it is not suitable for body condition comparisons in grade neonatal, juvenile or a population that lacks neonatal data. Therefore, another simple determination technique for body condition was applied; the application of BM/TBL ratio has been in practice for population studies of *Sistrurus catenatus* (SEIGEL ET AL., 1998). Thus, it was also applied in this study for body condition comparisons, especially on neonates, juveniles and *S. percarinata suriki*.

2.9. Statistical analysis

SPSS 11.0 for Windows was used to process all statistical analysis. Pearson correlation was applied for significance tests of correlation respectively in climatical factor to population monthly dynamic; movement area to recapture time intervals and body size; BCI, genders and body size to microhabitats condition; maternal size to litter-size, offspring-size and litter-size to offspring-size. Regression analysis was applied for movement area to time interval correlation, inter and intra-specific SVL and BM correlation, maternal size and their litter size correlated predictions. Chi-square test was applied for the homogeneous test of the failure predation proportion, annual and seasonal sex ratio, maturity ratio, dietary tendency and significant examination.

Chapter 3. Results

From November 1997 to September 2001, 459 snakes were captured, 746 times in total; 381 *S. annularis* (647 times), 70 *S. percarinata suriki* (91 times), 3 *Elaphe carinata* (3 times), 3 *Dinodon r. rufozonatum* (3 times) and 2 *Amphiesma sauteri* (2 times; Fig. 3.1-1, Tab. 3.1-1, Fig. 3.1-2**)**. The ability of the funnel traps did not show any biased ability to capture only *Sinonatrix* snakes (Tab. 3.1-2). In addition to that, we exclude 13 trapping records (10 *S. annularis* and 3 *S. percarinata suriki*) from the seasonal activity, sex ratio, maturity and BCI analysis, due to snakes escaping or being preyed upon by brown rats (*Rattus norvegicus*) and snakehead fish (*Channa asiatica*). These 13 records were however included in the occurrence analysis of population estimations, dynamics, and habitat utilization.

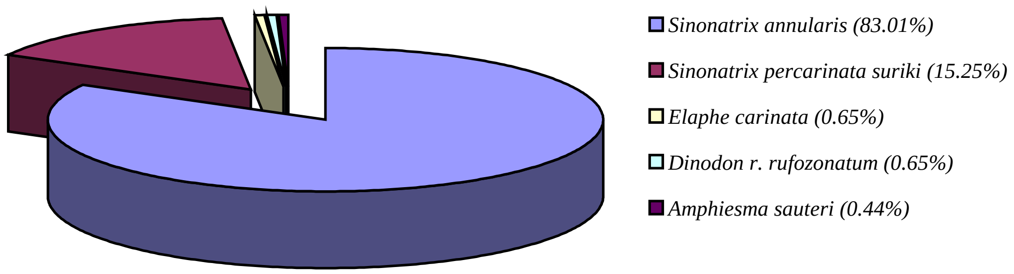

Fig. 3.1-1: Capture probability (%) of snake species in the Chutzuhu swamp

Tab. 3.1-1: Study intervals and related trap-night, number of *Sinonatrix* snakes obtains, snakes-times collection and capture probability (%) in Chutzuhu swamp.

Study interval	Nov. 1997-Jan. 1998	Aug. 1998-Oct. 1998	Nov. 1999-Sep. 2001
Trap-night	456	2,052	22,462
Snakes number	9	101	361
Snakes-times	11	110	617
Capture probability (%)	2.41 %	5.36 %	2.75 %

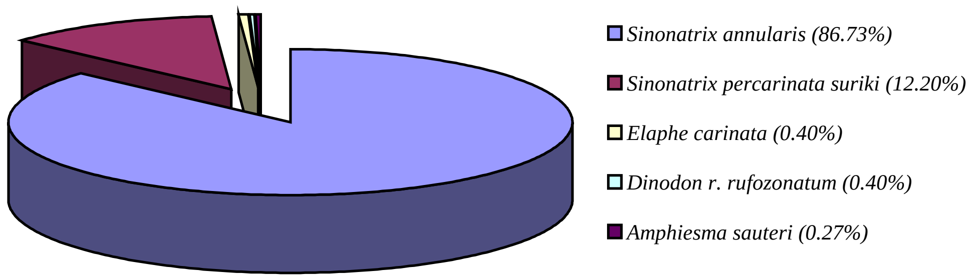

Fig. 3.1-2: Capture probability (%) of snake-times in the Chutzuhu swamp

Tab. 3.1-2: The capture and recapture frequency of the two *Sinonatrix* snake species in the Chutzuhu swamp

Capture frequency	1	2	3	4	5	6	7	8
Sinonatrix annularis	243	75	29	16	10	4	3	1
S. percarinata suriki	53	14	2	1	0	0	0	0

3.1. Population estimates

3.1.1. Population size

The environment of the study site is classified as a closed geological condition (see Materials & Methods 2.5), thus we ignored the possibility of immigration and emigration, and by using the Lincoln-Peterson index for the whole period used for the population estimation. Furthermore, based on our personal observations, compared to other natricine snakes in Taiwan, *Sinonatrix* species dehydrate relatively easily within a short period of time. This may indicate that *Sinonatrix* snakes are not suited for migration over the dry and slopes surrounding of the basin.

The population size of the two *Sinonatrix* species were based on snakes that were marked and released in August-September 1998 and were continuously recaptured during the period November 1999 – September 2001. Seventy-two *S. annularis* (male = 28, female = 44) were marked and released in 1998, and then from 1999-2001 a total of 297 individuals (male = 130, female = 126, juvenile = 31, data missing = 10) were captured. This number also includes 21 individuals (male = 12, female = 9) that were originally marked in 1998. The *S. annularis* population in Chutzuhu area was estimated to be about 662 (lower limit) to 1314 (upper limit) snakes, with a confidence interval (CI) of 95%. Furthermore, the male portion of the population was estimated to range from 183 (lower limit) to 399 snakes (upper limit), the female portion from 284 (lower limit) to 858 snakes (upper limit), with a CI of 95%.

In September 1998, seven *S. percarinata suriki* (male = 1, female = 6) were marked and released. Captures from November 1999- September 2001 consisted of 64 snakes (male = 30, female = 25, juvenile = 6, data missing = 3) and included three individuals (male = 1, female = 2) that were marked in August 1998. The *S. percarinata suriki* population in Chutzuhu area was estimated, with a 95% CI, to range from 51 (lower limit) to 207 (upper limit) snakes. With a 95% CI, it was estimated that the female portion of the population consisted of about 18 (lower limit) to 102 (upper limit) individuals. Due to the poor recapture of males, the male portion of the population could not be accurately determined and was thus rejected.

3.1.2. Relative abundance and seasonal activity

Monthly relative abundance showed the dynamics and occurrence of *Sinonatrix* snakes in Chutzuhu area (Fig. 3.1-3). These trends were based on the number of snakes captured and number of trapping nights during the period November 1999 to September 2001. For monthly relative abundance analysis, every snake capture is considered an independent event.

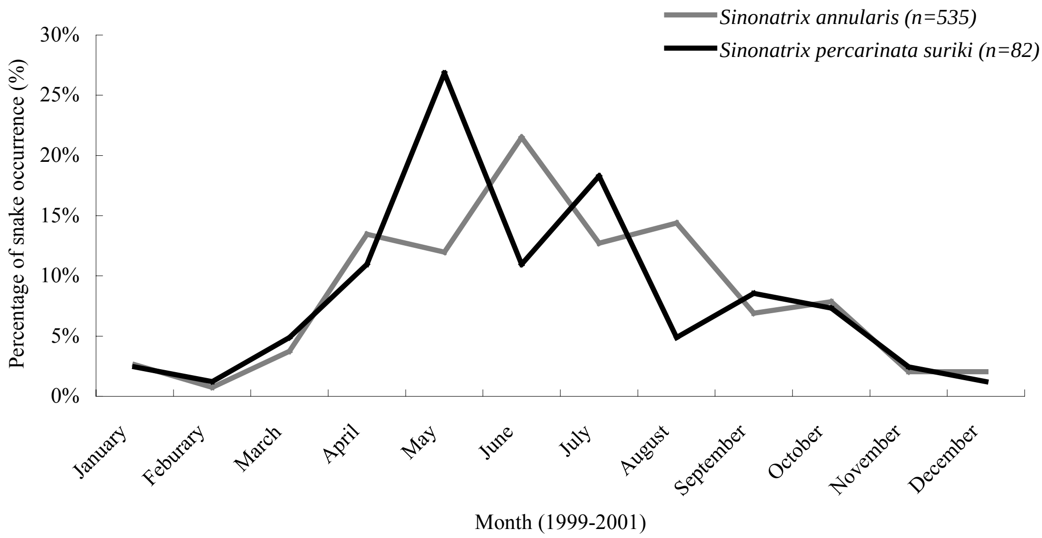

Fig. 3.1-3: Monthly dynamics of *Sinonatrix* snakes in the Chutzuhu swamp

Capture probability (CP) = Number of snakes capture / Number of trap nights.

During the period November 1999 to September 2001, a total of 617 snake-times (535 *S. annularis* and 82 *S. percarinata suriki*) and 22,462 trapping nights were recorded (Tab. 3.1-3). The overall mean capture probability (CP) was 2.75%, and consisted of 52 % in the marshland (11,681 trapping nights; CP = 3.57%), 22.22 % in the ditch (4,990 trap nights; CP = 2.27%), 15.54 % in the paddy field (3,491 trapping nights; CP = 1.40%), and 10.24 % in the creek (2,300 trapping nights; CP = 1.52%). In overview, from April to June seems to have been the annual peak activity period for both species, while the period from December to the February, the following year, was the lowest activity period (Fig. 3.1-4, Fig. 3.1-5). Monthly dynamics of the two *Sinonatrix* species were obviously correlated to air temperature (r = 0.645**, P =0.01 in *S. annularis*; r = 0.506*, P = 0.019 in *S. percarinata suriki*) but without any significant relationship to rainfall (r = -0.018, P = 0.938 in *S. annularis*; r = -0.182, P = 0.431 in *S. percarinata suriki*). Viewed from an annual perspective, both species were more frequently active in 2000 than 2001. In other words, more snakes were captured in 2000, but this might also be an indication of some environment changes in the Chutzuhu basin.

Tab. 3.1-3: The relationships within microhabitat, trap-night, capture probability and number of two *Sinonatrix* snakes in Chutzuhu swamp (November 1999-September 2001)

Microhabitat type	Trap-night	Total capture	No. *S. annularis**	No. *S. percarinata*

		probability (%)		***suriki***
Marshland	**11,681**	**3.57 %**	**416**	**1**
Ditch	**4,990**	**2.27 %**	**75**	**38**
Paddy field	**3,491**	**1.40 %**	**36**	**13**
Creek	**2,300**	**1.52 %**	**5**	**30**

***: There are another three records excluded from above four microhabitats, due to capture locality out of former habitat definition.**

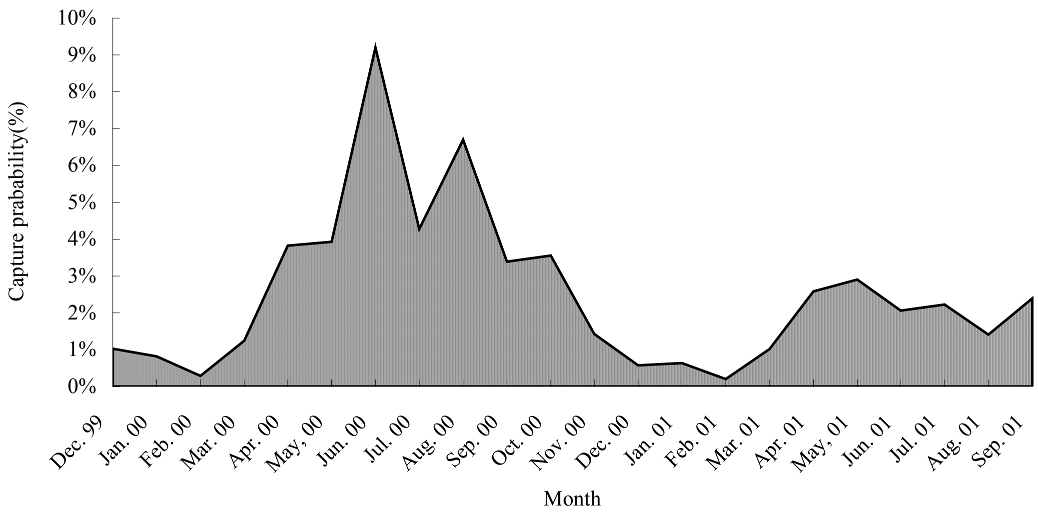

Fig. 3.1-4: Population dynamics of *Sinonatrix annularis* in the Chutzuhu swamp (December 1999- September 2001)

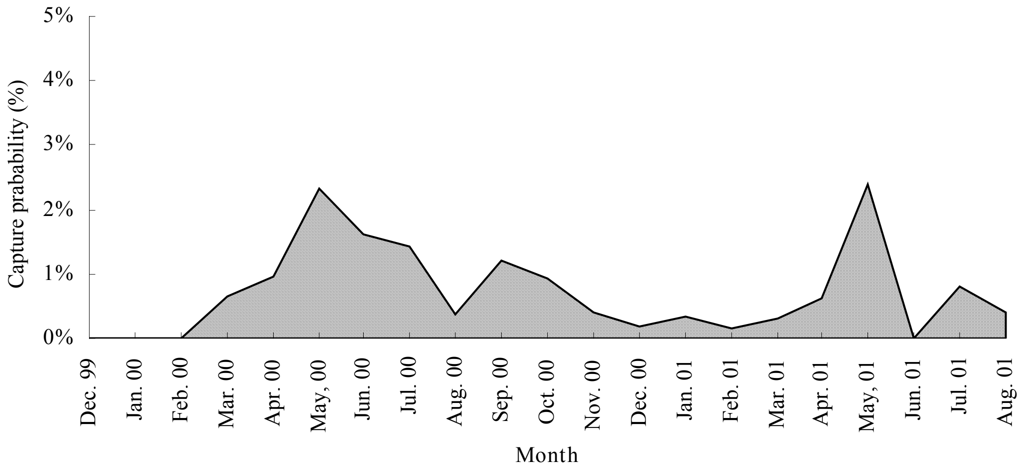

Fig. 3.1-5: Population dynamics of *Sinonatrix percarinata suriki* in the Chutzuhu swamp (December 1999- August 2001)

Seasonal occurrence of *Sinonatrix* were based on the snakes data collected from November 1997-January 1998, August-September1998 and November 1999 - September 2001. Once again, for the seasonal activity analysis every snake capture was regarded as an independent occurrence. Because of the absence of any hibernation behavior, like that in snake species from Temperate Zones, snakes of all ages were captured throughout all the seasons. But February seemed to be the month in which activity is at its lowest in both *Sinonatrix* species. Late spring to early summer tended to be the peak activity period, no matter which gender or species. This might be due to activities related to courtship and mating. Except for juveniles, the activity of the male proportion of the *S. annularis* population was significantly higher than that of the female proportion during the spring season (February-April; x^2=7.43**, df=1, P<0.01), and also higher than during any other season. Female snake activity was slightly higher than that of the males during the summer, autumn and winter, but without any obvious statistical significance (Tab. 3.1-4).

Tab. 3.1-4: Seasonal occurrence different of *Sinonatrix annularis* between two genders (combine snakes capture data of 1997, 1998, 1999, 2000 and 2001)

Periods	Spring Feb.-Apr.	Summer May-Jul.	Autumn Aug.-Oct.	Winter Nov.-Jan.
Male	59	102	110	18
Female	32	122	135	25
Chi-square test	x^2=7.43**, df=1, P<0.01	x^2=1.61, df=1, P>0.05	X^2=2.35, df=1, P>0.05	X^2=0.84, df=1, P>0.05

Seasonal activity of *S. percarinata suriki* males was slightly higher during the spring, summer, and winter seasons. Female activity was higher during the autumn season, but both patterns seemed to reflect activity related to reproduction, and there were not any statistical significance between two genders in different seasons (Tab. 3.1-5).

Tab. 3.1-5: Seasonal occurrence differences of *Sinonatrix percarinata suriki*, between two genders (combined snakes captured data of 1998, 1999, 2000 and 2001)

Periods	Spring Feb.-Apr.	Summer May-Jul.	Autumn Aug.-Oct.	Winter Nov.-Jan.
Male	9	23	9	3
Female	3	18	15	2
Chi-square test	x^2=2.08, df=1, P>0.05	x^2=0.39, df=1, P>0.05	X^2=1.04, df=1, P>0.05	—

3.1.3. Movement

Average straight-line movement in non-gravid *S. annularis* females was estimated to be 0.95±1.94 (n=51) meters/day (=m/d) higher than that of males (0.70±0.75 m/d; n=52), and juveniles (0.48±0.42 m/d; n=5) and maternal females (0.45±0.34 m/d; n=8; Tab. 3.1-6). The mean movement area was also higher in non-gravid females 12.36±32.8 meter^2/days (=m^2/d; n=51) and was followed by juveniles (9.79±6.15 m^2/d; n=5), males (9.42±13.02 m^2/d; n=52) and maternal females (6.14±5.04 m^2/d; n=8), in that order. But the home range was higher in male (796.2±959m^2, n=52) than non-gravid female (589.7±350.8m^2, n=51) and juvenile (180±130.4m^2, n=5). There seems to be no correlation between movement range and body size in the two genders of *S. annularis* (r=0.126, P>0.01 in male; r=-0.150, P>0.01 in non-gravid female). But it was extended and correlated to intervals of capture and recapture in *S. annularis* females (r=0.522**, P<0.01; n=58; Fig. 3.1-7). Movement areas of males showed no significant correlation to intervals of two captures and may indicate that males occupy specific home ranges (r=0.057, P>0.01; n=52; Fig. 3.1-6).

Tab. 3.1-6: Maximum straight-line distance in a capture-recapture interval of *Sinonatrix* snakes in Chutzuhu swamp

Species	Gender	Maximum straight-line distance (meter)	Intervals (No. days)	Mean movement (meters/day)
Sinonatrix annularis	**Male**	**70**	**97**	**0.72**
	Female	**106**	**147**	**0.72**
Sinonatrix percarinata suriki	**Male**	**132**	**16**	**8.25**
	Female	**32**	**238**	**0.14**

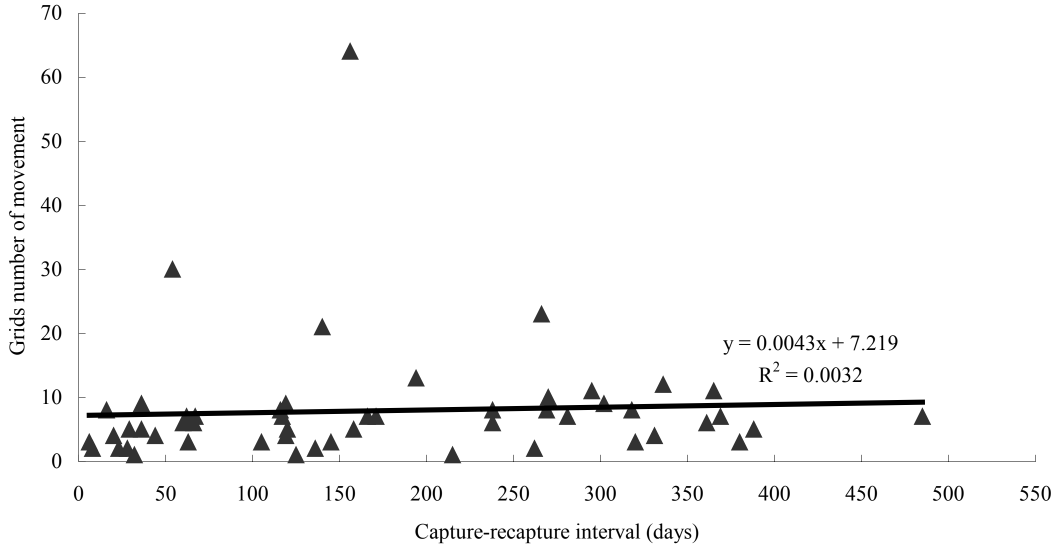

Fig. 3.1-6: The correlation between capture-recapture intervals and movement range of *Sinonatrix annularis* males in the Chutzuhu swamp (November 1999- September 2001)

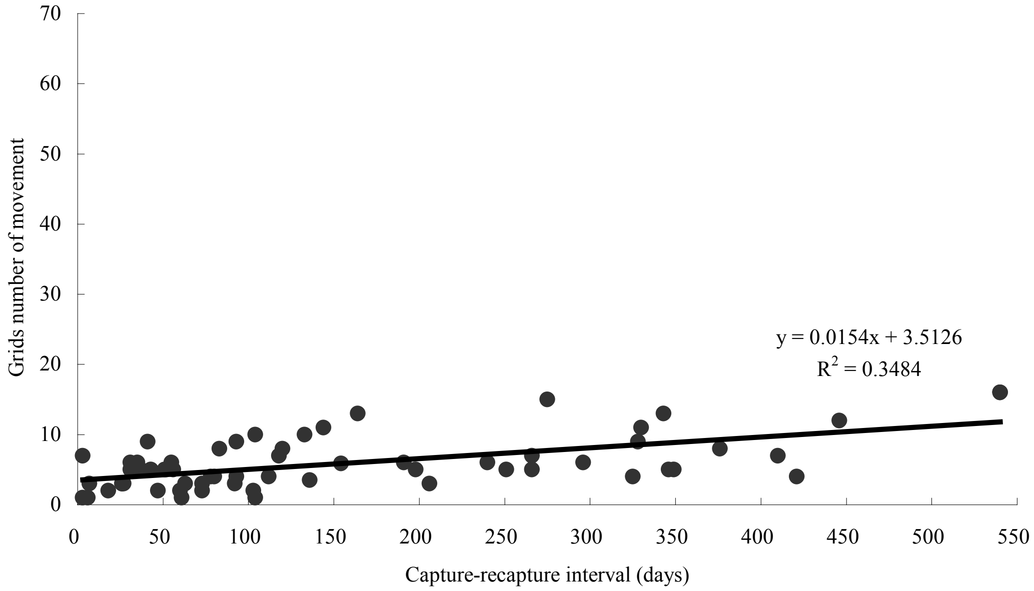

Fig. 3.1-7: The correlation between capture-recapture intervals and movement range of *Sinonatrix annularis* females in the Chutzuhu swamp (November 1999- September 2001)

Irrespective whether in straight-lines or based on area, data gathered on the movement or home range of *S. percarinata suriki* males (1.34±2.34 m/d, 17.68±33.71 m^2/d, 722±678 m^2; n=9) indicated that their movements were greater than that of the females (0.57±0.61 m/d, 11.38±7.61 m^2/d, 300±235 m^2; n=5) and that of *S. annularis*. This may be an indication that *S. percarinata suriki* males have greater mobility in linear habitats (Fig. 3.1-8). In addition to that, body size was found not to be a correlation factor in the movement of both genders (r=-0.017, P>0.01 in male; r=-0.796, P>0.01 in non-gravid female). But, movement range was extended in females in prolonged recapture intervals (r=0.975**, P<0.01; n=5) and reflects similar patterns as those observed in *S. annularis* (Fig. 3.1-9).

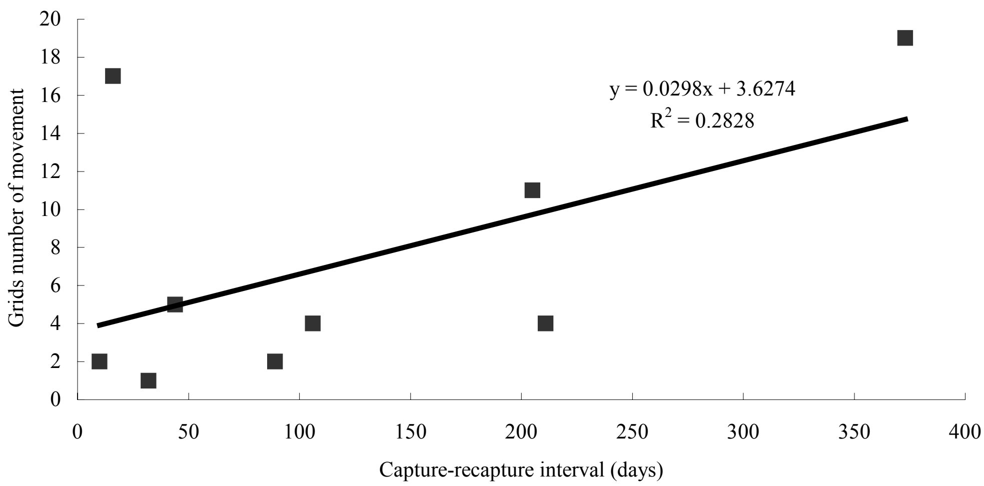

Fig. 3.1-8: The correlation between capture-recapture intervals and movement range of *Sinonatrix percarinata suriki* males in the Chutzuhu swamp (November 1999- September 2001)

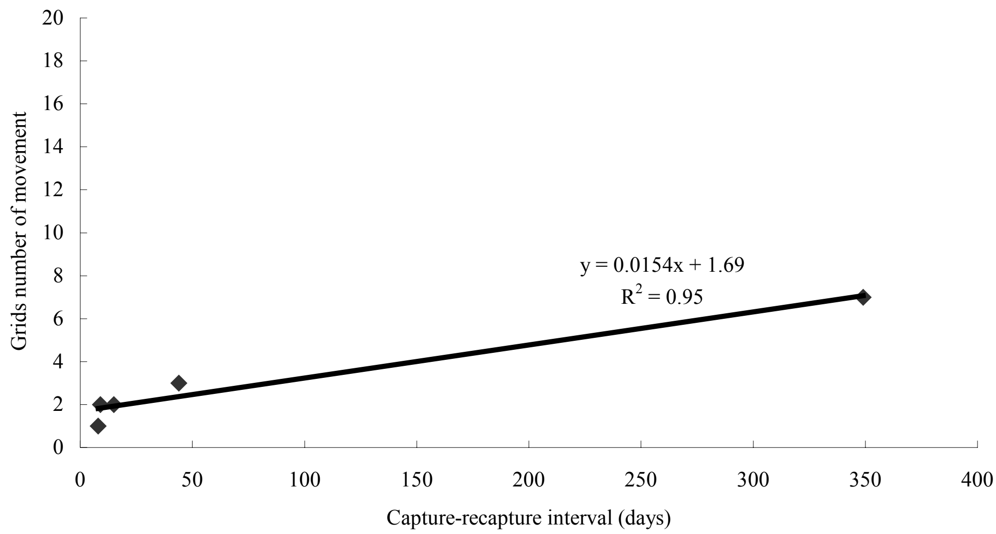

Fig. 3.1-9: The correlation between capture-recapture intervals and movement range of S*inonatrix percarinata suriki* females in the Chutzuhu swamp (November 1999- September 2001)

3.2. Population structure

3.2.1. Sex ratio

POPE (1935) found that *S. annularis* and *S. percarinata suriki* males have darker subcaudal bands than females, but the actual application of this as a sexing method was impractical. The markings were often indistinct and sometimes no observable differences could be observed between the two genders, in both species. With regards to the juvenile snakes (<35cm), it was difficult to determine the sex by using a sexing-probe or by some morphological features; they were therefore excluded from the specimens used for the determination of the sex ratio. The ratio of non-juvenile females to males in 1997 (November and December), as well as in 1998 (from August to September), was 1.63 : 1 (female = 62, male = 38), and it was obvious that the ratio was strongly skewed to the number of females (x^2=5.29**, df=1, P<0.01). But the numbers of females and males in November 1999 to September 2001 were approximately equal, with a rex ratio of 0.96 : 1 (female = 126, male = 132; x^2=0.0969, df=1, P>0.05).

In 1998, the female to male sex ratio in *S. percarinata suriki* was unequal; 3.5 : 1 (female = 7, male = 2), but during the period 1999 to 2001 it was 0.71 : 1 (female =30, male =42), slightly skewed to the number of males, but without any statistical significance (x^2= 1.681, df=1, P>0.05).

3.2.2 Growth rate

The neonatal growth rate of *S. annularis* was based on a litter of PIT No.: 00-01ED-E2B4, live bearing in 2000. At first, there were 11 individuals used in the study to determine the growth rate, but three snakes escaped after the cover of the captivity tank was damaged by a typhoon, and another one was lost due to unknown reasons. Therefore, only seven individuals (3 female and 4 male) completed the period utilized for the growth rate calculation (Tab. 3.2-1). The average growth rate for the first year was 0.024 cm/day. From June to September was the rapid growth period and the mean rate was 0.061± 0.016 cm/day. December to March was the lowest growth period and the average rate was 0.007± 0.006 cm/day. The growth rate during the first year, irrespective of the gender, had no observable differences. In the second year, the growth rates of females were more rapid than that of the males (Fig. 3.2-1).

Tab. 3.2-1: Snout-vent length (SVL) growth rate of neonatal *Sinonatrix annularis* in the Chutzuhu area (an intervals 0-17 months)

Interval	1	2	3	4	5	Mean

	Oct.-Dec.	Dec.-Mar.	Mar.-Jun.	Jun.-Sep.	Sep.-Mar.	
Male (cm/day; n=4)	**0. 006±0.009**	**0.008±0.005**	**0.017±0.007**	**0.062±0.022**	**0.016±0.003**	**0.022±0.02**
Female (cm/day; n=3)	**0.019±0.011**	**0.004±0.009**	**0.018±0.008**	**0.059±0.006**	**0.026±0.0003**	**0.025±0.023**
Mean (cm/day; n=7)	**0.012±0.011**	**0.007±0.006**	**0.017±0.007**	**0.061±0.016**	**0.021±0.006**	**0.023±0.006**

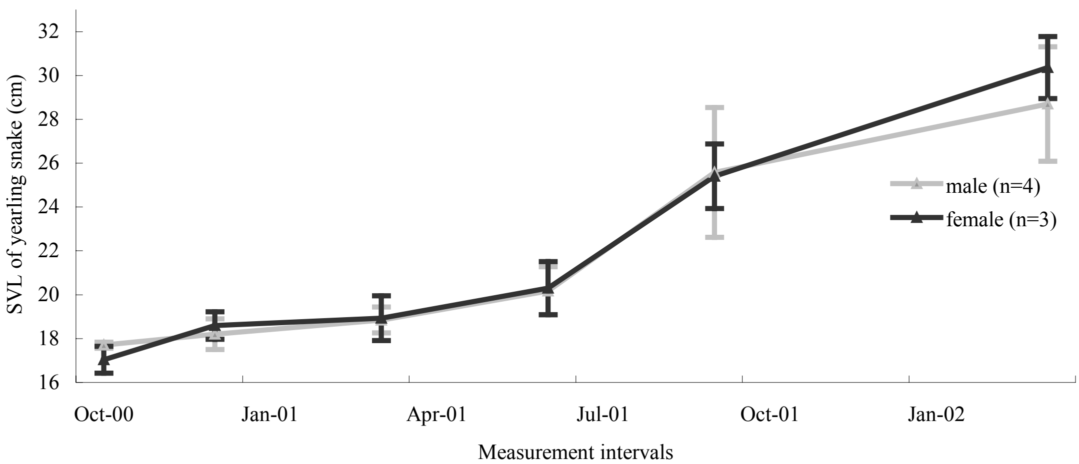

Fig. 3.2-1: Growth rate of captive neonatal *Sinonatrix annularis* in the Chutzuhu area

The average growth rates of adult *S. annularis* snakes were based on recaptures over intervals of 91-989 days. Forty-four individuals, 24 males and 20 females, were used in the mean growth rates determination of the adult snakes. The average growth rate in males was 0.0055±0.0044 cm/day (n=24), observably lower than that of females, 0.0176±0.015 cm/day (n=20).

Growth rates of adult *S. percarinata suriki* were determined by utilizing five individuals (2 female and 3 male respectively), which were recaptured at intervals of 231-744 days. The average growth rate in females was 0.0113±0.0048 cm/day, relatively higher than 0.007±0.0053 cm/day, which was the average growth rate for males. During the study periods, neonates and juveniles were rarely collected, there are therefore no results and no conclusions can be drawn.

3.2.3. Maturity and size-age distribution

PARKER AND PLUMMER (1987) found that most snakes become sexually mature at 60-75% of their maximum length. Therefore, the theoretical sexual mature size of *S. annularis* females are TBL 55.8-69.75 cm and SVL 46.32-57.9 cm, and the males TBL 47.16-58.95 cm and SVL 38.4-48 cm. This determination was based on the largest female (TBL= 93 cm, SVL= 77.2 cm) and largest male (TBL= 78.6 cm, SVL= 64 cm) collected in this study. Actually the smallest female, to be found gravid, had a SVL of 54.4 cm and a TBL of 66.6 cm. This seems to correlate with the theoretical mature size. Based on the average annual growth rate of the captive neonatal snakes, it is estimated that it would take four years for a female *S. annularis* to become sexually mature.

Several methods were utilized to determine the minimum size at which males become sexually mature; annual sperm tests on captive juveniles, the minimum size at which tubercles are present on the anterior lower jaw, and the smallest sized male in trapped groups during the breeding season. Based on the results of cloacal sperm tests, it was determined that the probability of a male individual maturing in one or two years can be excluded. In addition to that, when attempts were made to locate the tubercles on the anterior lower jaw of *S. annularis*, it was found that these structures could not be observed as on *S. percarinata suriki*. The smallest sized male collected in a trapped group was 49.9 cm in TBL, 40.2 cm in SVL, which matches the hypothetical value. Based on the mean growth ratio of individuals studied in captivity, males are expected to become sexually mature (SVL: 40.2 cm) after a minimum period of three years.

Ignoring the sizes of the yearlings, in 1997-1998 the proportion of mature *S. annularis* female snakes to immature females was 2 : 1 (mature= 42, immature= 21), in 1999-2001 the ratio was 1.8 : 1 (mature= 81, immature= 45). The mature to immature ratio of females was not skewed 2 : 1 and without obvious differences within the periods of 1997-1998 and 1999-2001 (x^2= 0.289, df=1, P>0.05). For the *S. annularis* males the mature to immature ratio was 2.7 : 1 (mature= 32, immature= 6) in 1997-1998 and 2.9 : 1 (mature= 98, immature= 34) in 1999-2001.

The theoretical sexually mature size for *S. percarinata suriki* is TBL: 59.1-73.9 cm, SVL: 44.3-55.4 cm for females and TBL: 51.6-64.5 cm, SVL: 38.8-48.5 for males, which was determined and based on the largest female (TBL= 98.5 cm, SVL= 73.9) and largest male (TBL= 86, SVL=64.6) that were collected in Chutzuhu area. But, we were unable to collect enough gravid females to determine the exact minimum size at which this species become mature; therefore it was assumed that it is the same as *S. annularis* females, since the SVL length of the largest collected female was very similar to that of the largest collected *S. percarinata suriki* female in Chutzuhu area. Based on the former sexually mature size determination, the ratio of mature females to immature females was 6 : 1 (mature =6, immature=1) in 1998 and 1.9 : 1 (mature= 17, immature= 9) in 1999-2001.

The minimum size of sexually mature males was determined the smallest males collected and that possesses tubercles on the anterior lower jaw. It was found that the SVL of those individuals that had tubercles present ranged from 40.3-64.6 cm, which matches the theoretical proportion. Therefore the minimum size at which *S. percarinata suriki* males became sexually mature was determined to be at SVL 40-44.9 cm. The mature male proportion to that of immature males in this population was 1 : 1 (mature= 1, immature= 1) in 1998 and 9 : 1 (mature= 27, immature= 3) in 1999-2001.

Size distributions were classified according to the snout-vent lengths (SVL) and the individuals were sorted into 13 classes. Each class width is 5 cm long. The sizes of *S. annularis* were normally distributed, irrespective of the gender, but the SVL of females seemed larger than that of males and indicated the difference between the two genders (Fig. 3.2-2, Fig. 3.2-3).

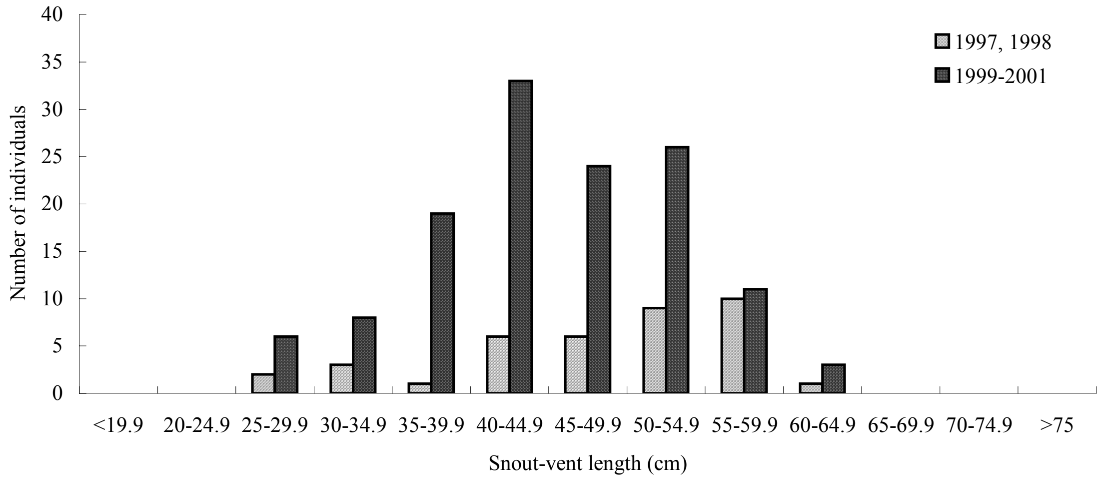

Fig. 3.2-2: Size class distribution of *Sinonatrix annularis* males in the Chutzuhu swamp

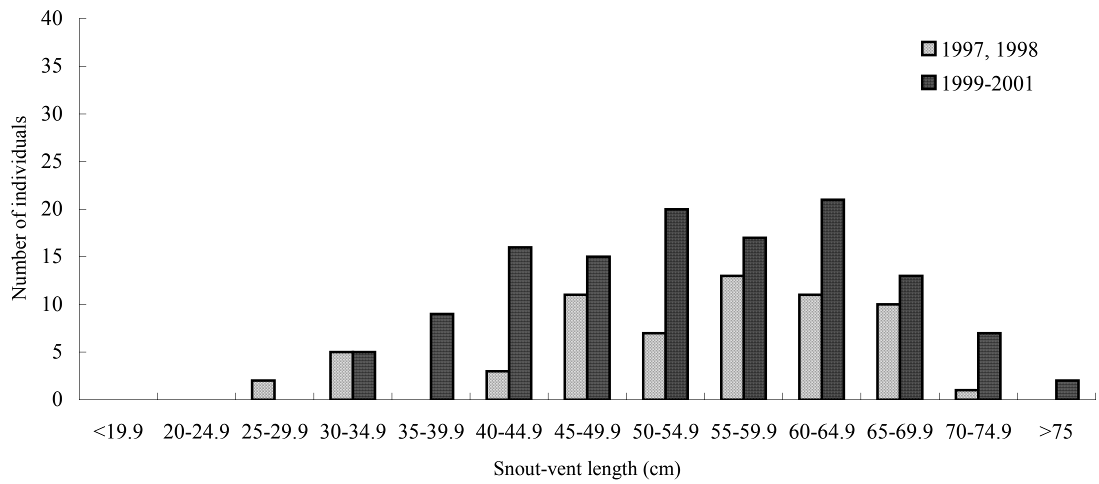

Fig. 3.2-3: Size class distribution of *Sinonatrix annularis* females in the Chutzuhu swamp

Snake sizes were nearly normally distributed in the period 1999-2001 for *S. percarinata suriki* males. But during all the study intervals in 1998 females and males appeared to have no particular patterns and this may be due to insufficient sampling (Fig. 3.2-4, Fig. 3.2-5).

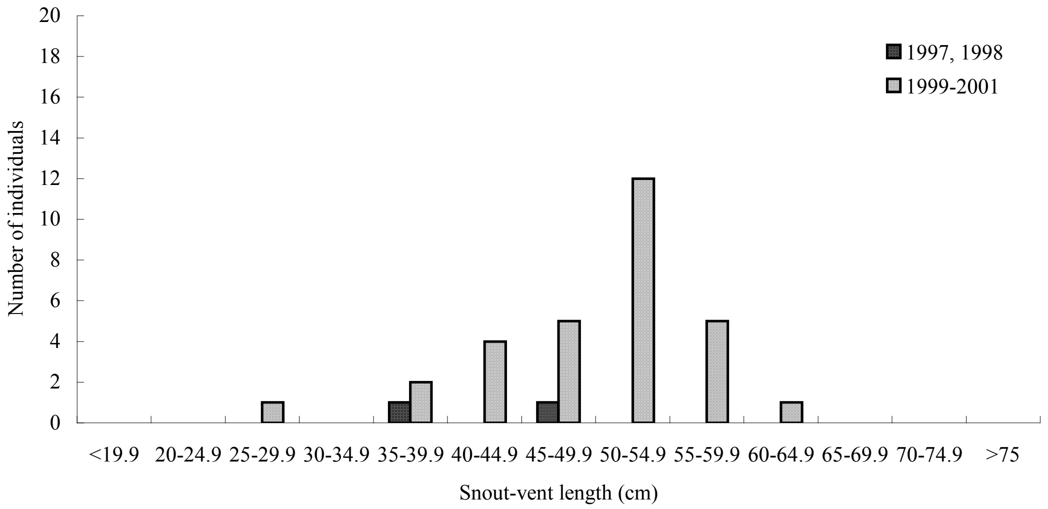

Fig. 3.2-4: Size class distribution of *Sinonatrix percarinata suriki* males in the Chutzuhu swamp

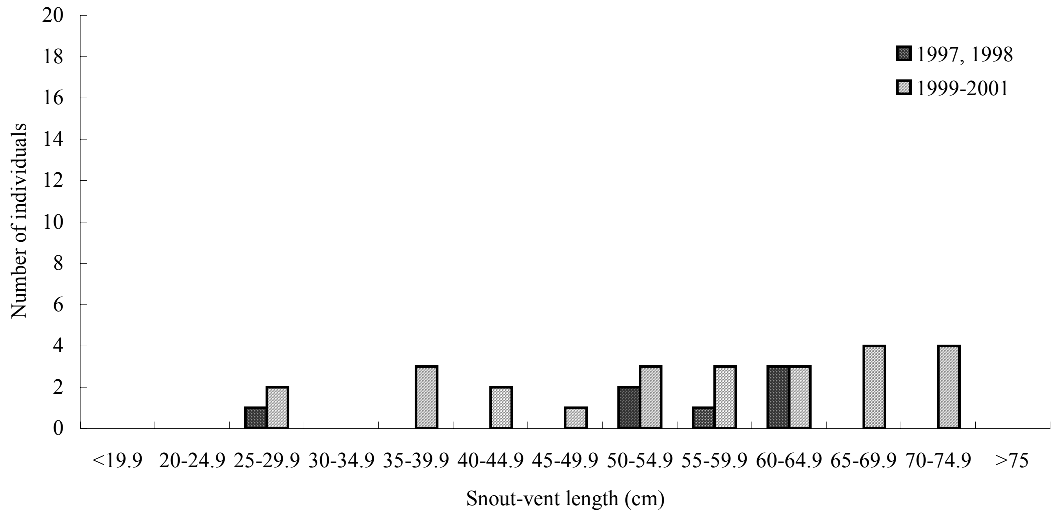

Fig. 3.2-5: Size class distribution of *Sinonatrix percarinata suriki* females in the Chutzuhu swamp

Before they reached a sexually mature size, the age of *S. annularis* was determined by the average growth rate of juveniles, after that it was calculated, based on the mean growth rate of the two genders. In males, the individuals older than six years were the largest proportion in 1997-1998, but were replaced by the three-years old class in 1999-2001 (Fig. 3.2-6). But in females, the five-years old class tended to be the predominant class, during all the periods 1997-1998 and 1999-2001 (Fig. 3.2-7).

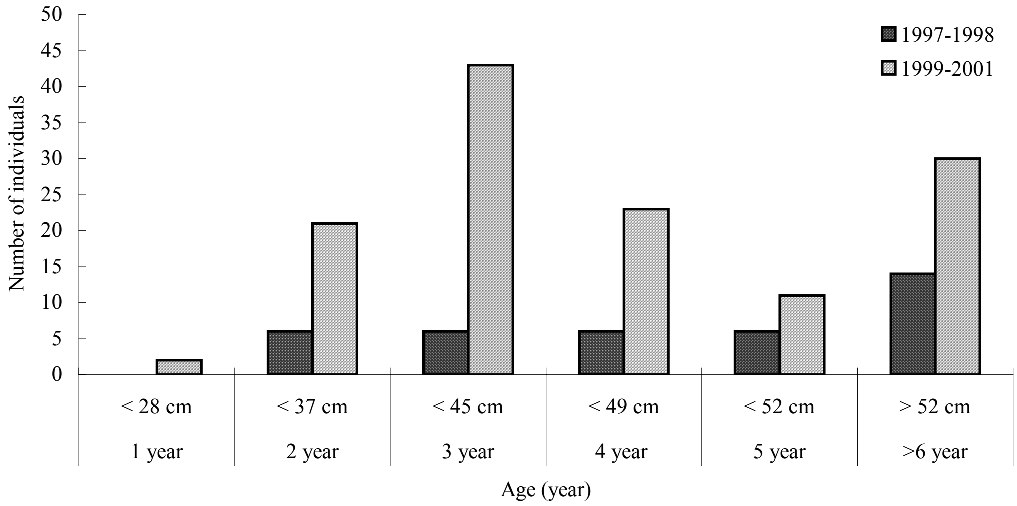

Fig. 3.2-6: Age structure of *Sinonatrix annularis* males in the Chutzuhu swamp.

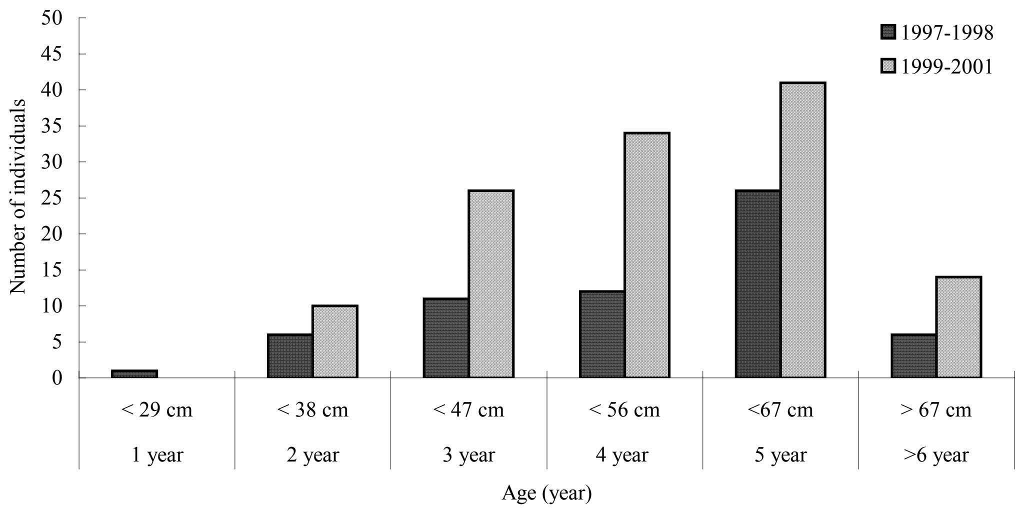

Fig. 3.2-7: Age structure of *Sinonatrix annularis* females in the Chutzuhu swamp

3.3. Reproduction

Based on capture dates of gravid females and neonatal snakes, it appeared that *S. annularis* has a seasonal reproductive cycle in which birth occurred from late August until late October and peaked in September in Chutzuhu (Tab. 3.3-1). Furthermore, no breeding data for *S. percarinata suriki* was collected during the whole study period, so no results can be presented and no accurate conclusions can be drawn. But it must be stated that in 1996, we obtained a gravid female from the area surrounding Chutzuhu and oviposition (24 eggs) occured in late August. In addition to that, in 05 September 2000 a gravid female was collected from Fu-Shan botanical garden. It was found that she had a swollen abdominal area and was later found to be carrying 6 eggs. These observations might be an indication that the breeding of *S. percarinata suriki* occurs at about the same time as the occurrence of *S. annularis* neonates in northern Taiwan.

Tab. 3.3-1: Live bearing periods and frequency of *Sinonatrix annularis*, observed in 1998, 2000 and 2001

Month / Year	August	September			October		
	Late	Early	Middle	Late	Early	Middle	Late
1998	-	2	3	-	-	-	1*
2000	-	-	1	1	1	1	-
2001	1	2	2	-	-	-	-

***: Breeding failure**

Gestating and reproducing female SVLs ranged from 54.4 cm to 72.7 cm (n=31, mean=63.25, SD=4.89) showing a pattern of normal distribution. The primary gravid SVL size was concentrated in the range 60-70 cm (n= 19), which may indicate fecundity in *S. annualris* females in this range. Based on our available data, it was found that the minimum maternal size in *S. percarinata suriki* is 56.6 cm in SVL and 74.5 cm in TBL respectively. But maternal samples were not enough to allow the determination of the exact SVL range of fecundity in this study (Tab. 3.3-2).

Tab. 3.3-2: Size distribution frequency of snout-vent length (SVL) of gravid *Sinonatrix* females

SVL size (cm)	50-54.9	55-59.9	60-64.9	65-69.9	70-74.9
Sinonatrix annularis	2	5	12	7	5
Sinonatrix percarinata suriki	-	1*	-	1	-

***: Collected from Fu-Shan botanical garden.**

3.3.1. Courtship and mating

No courtship and mating behavior was observed during this study process in both *Sinonatrix* species. But, according to our trapping records, there were on five occasions traps stuffed full of males, between late March and early June, in our *S. annularis* collection process. All of those traps contained one or two mature large females and two to five male snakes. These situations only occurred during that period every year. Besides that, there were several local farmers who eye-witnessed and mentioned the courtship behavior of *S. annularis*. They descried it as being just like a snake ball rolling in the paddy field and happening every April and May.

3.3.2. Fecundity

There were no evidence or observations to indicate that female gestation and breeding occurred annually. Only one individual (PIT No.: 00-012C-3B21) was breeding in 1998 and 2000, but the breeding attempt of 1998 was a failure and she delivered five undeveloped yolk sacks. Consequently, the breeding frequency of *S.*

annularis females is believed to be a period longer than biennially. In addition, Seigel and Ford (1987) stated that reproduction frequency of snakes can be estimated by the proportion of mature females that are reproductive. In our study, the mean ratio in the mature female size class of gravid and non-gravid females is 40.02% (SD= 0.2619; Tab. 3.3-3). Therefore, it can be accepted that the reproduction frequency of *S. annularis* is between biennially to triennially under normal situations. Furthermore, weakness and death in the post-gestation period also occurred in some cases of *S. annularis* reproduction in this study.

Tab. 3.3-3: Monthly occurrence proportion and percentage of mature pregnant and non-pregnant *Sinonatrix annularis* females in the Chutzuhu swamp in the period May to September of 1998, 2000 and 2001

	1998		**2000**		**2001**	
	Preg./Non-Preg.	**%**	**Preg./Non-Preg.**	**%**	**Preg./Non-Preg.**	**%**
May	–	–	–	–	**3/8**	**37.50%**
June	–	–	**9/29**	**31.04%**	**4/7**	**57.14%**
July	–	–	**5/13**	**38.46%**	**3/5**	**60%**
August	–	–	**3/14**	**21.43%**	**0/7**	**0**
September	**6/35**	**17.14%**	**3/8**	**37.50%**	**1/1**	**100%**

There were 31 gravid females observed from 1998 (16 X-ray, 2 anatomize and 15 live borne; Fig. 3.3-1). The litter sizes ranged from 4 to 14 (mean±SD = 8.19±2.52). It is obviously positively related to the SVL of female parent (r=0.634**, P=0.01), indicating that the larger maternal females are capable of carrying larger litters (Fig. 3.3-2).

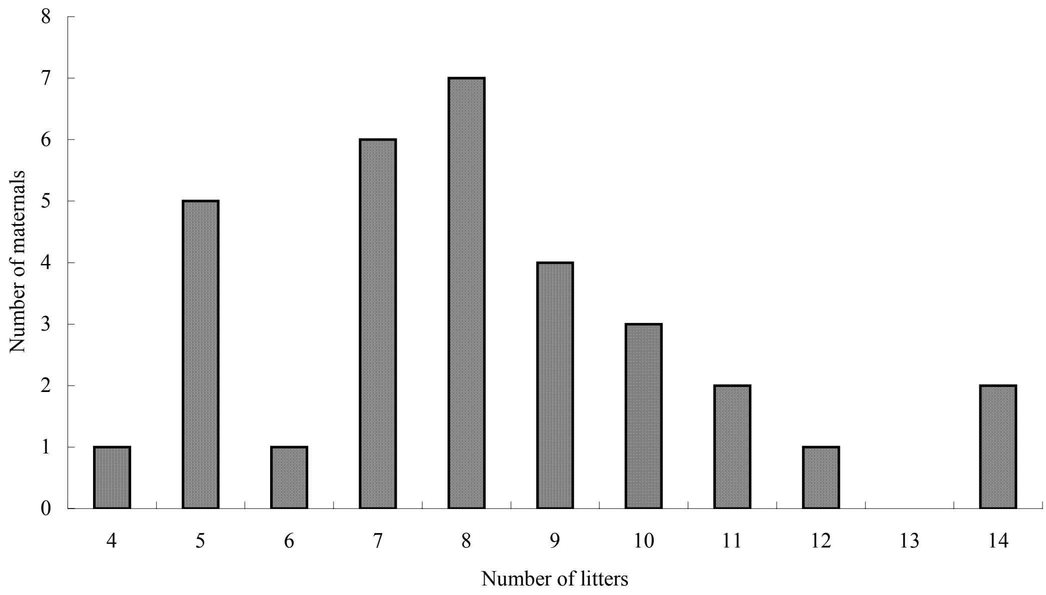

Fig. 3.3-1: Litter size distribution of *Sinonatrix annularis* in the Chutzuhu swamp (1998, 2000 and 2001)

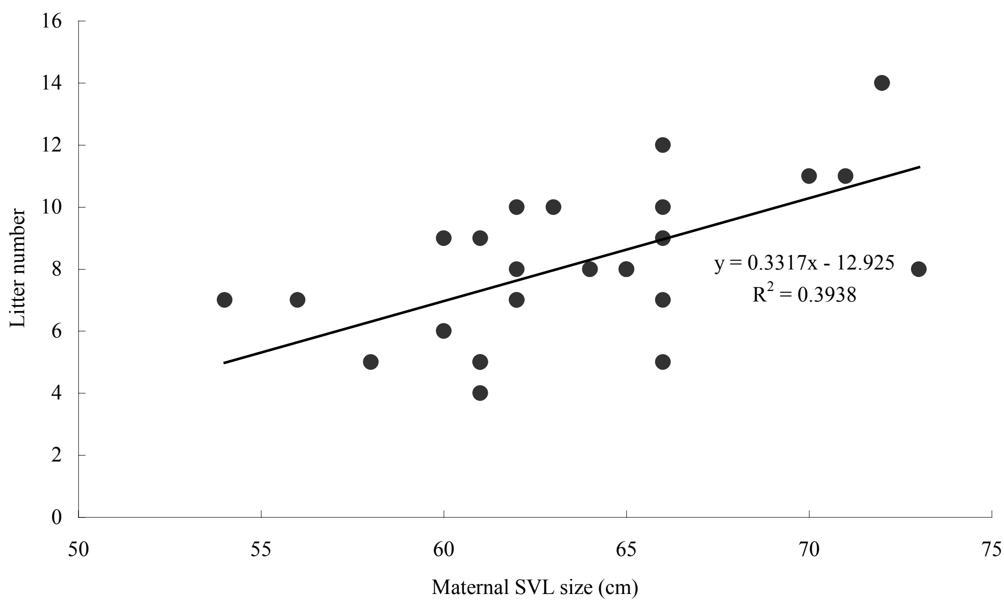

Fig. 3.3-2: The correlation of maternal size and litter number of *Sinonatrix annularis* in the Chutzuhu area (1998, 2000 and 2001)

Neonatal sizes were based on 14 litters, obtained in 1998 (n=5), 2000 (n=4) and 2001 (n=5). The range of total-body length (TBL) was 18-26.8 cm (n=113, mean±SD=

22.57±1.77); snout-vent length (SVL) was 14.6-21.2 cm (n=113, mean±SD=18.08±1.34); tail length (Tail-L) was 3.4-5.7 cm (n=113, mean±SD= 4.52±0.45) and body mass (BM) was 2-6 g (n=113, mean±SD= 4.51±0.92; Tab. 3.3-4). There was no correlation between the SVL of the offspring and that of the maternal female (r=0.191, P=0.253). Litter sizes also showed no significant statistical correlations with the offspring of SVL (r=0.164, P=-0.283).

Tab. 3.3-4: Average litter and offspring size comparison of *Sinonatrix annularis* in 1998, 2000 and 2001

	1998 (Mean ± SD)	**2000 (Mean ± SD)**	**2001 (Mean ± SD)**
Litter size	**8.6 ± 4.58**	**9 ± 1.83**	**6.8 ± 1.79**
TBL (cm)	**22.26 ± 1.13**	**22.4 ± 1.47**	**23.16 ± 2.38**
SVL (cm)	**17.83 ± 0.91**	**18.07 ± 1.22**	**18.47 ± 1.82**
Tail-L (cm)	**4.43 ± 0.31**	**4.37 ± 0.38**	**4.69 ± 0.59**
BM (g)	**4.72 ± 0.7**	**4.67 ± 0.63**	**4.08 ± 1.23**
Body condition (BM/TBL)	**0.2114±0.025**	**0.2082±0.023**	**0.1735±0.038**

***The sample size of litters were 1998 (n=5), 2000 (n=4), 2001(n=5), and in TBL, SVL, Tail-L, BM and Body condition respectively 1998 (n=43), 2000(n=36) and 2001(n=34).**

3.4. Resource utilization

3.4.1. Food

Dietary condition was detected in 30 stomach contents of *S. annularis* (male=10, female=20), which involved 52 diet items, and were recorded in 1998 (2♂, 2♀) and 2000 (8♂, 18♀; Tab. 3.4-1). The percentages of diet items were as follows, loach (*Misgurnus anguillicaudatus*; 92.31%, n=48), Asian snakehead fish (*Channa asiatica*; 5.77%, n=3) and rice paddy frog (*Rana l. limnocharis*; 1.92%, n=1; Fig. 3.4-1). This indicated that *S. annularis* more specifically foraged on loaches than other fish and amphibian species (x^2=81.52**, df= 2, P>0.05). In addition to that, no *S. annularis* foraging and dietary condition were detective in 2001, which may indicate an insufficient food resource in that year.

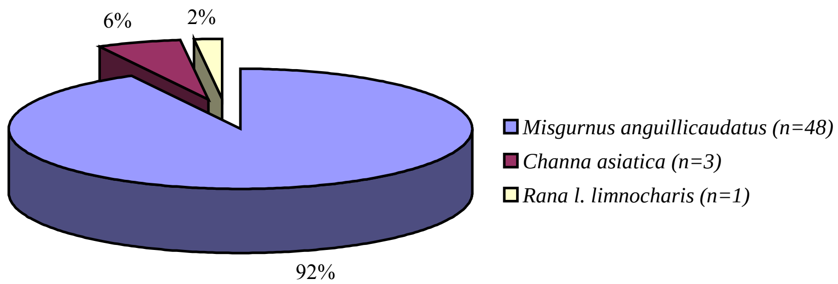

Fig. 3.4-1: Stomach contents items and their percentages, taken from *Sinonatrix annularis* in the Chutzuhu swamp

The principal foraging localities of *S. annularis* were marshland (73.3%, n=22), ditch (20%, n=6) and paddy field (6.7%, n=2). In addition to that, it was found that

40% of the foraging occurred in the central cover ratio sites (37.5-62.5%; n=12), 30% in low cover ratio sites (0-25%; n=9) and 16.7% in high cover ratio sites (87.5-100%; n=5). The remaining 13.3% data was lost (n=4) due to unrecorded microhabitat in August 1998.

Tab. 3.4-1: Monthly frequency of stomach contents of *Sinonatrix* snakes in the Chutzuhu swamp from March to November in 1998 and 2000

	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Total
S. annularis	**0**	**1**	**3**	**13**	**0**	**3**	**5**	**4**	**1**	**30**
S. percarinata suriki	**1**	**1**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**4**

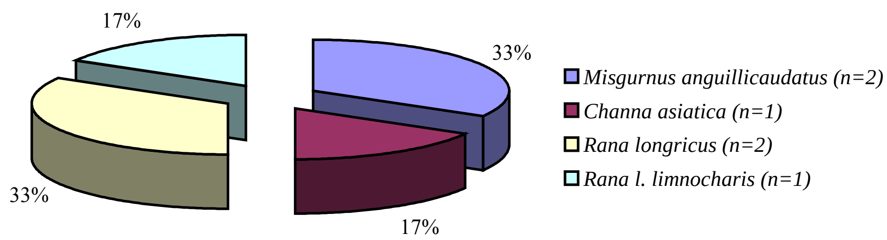

Fig. 3.4-2: Stomach contents items and their percentages, taken from *Sinonatrix percarinata suriki* in the Chutzuhu swamp

Another 4 stomach contents, 6 diet items of *S. percarinata suriki* were detected in 2000, and it appears, without particular affinity, that it included long-legged frog (*Rana longricus*; n=2), loach (*M. anguillicaudatus*; n=2), rice paddy frog (*R. l. limnocharis*; n=1) and Asian snakehead fish (*C. asiatica*; n=1). The dietary preference of *S.*

percarinata suriki indicated no specific tendency (Fig. 3.4-2). In addition, the foraging localities of *S. percarinata suriki* included two sites, in a creek and another two in a ditch, and all were collected from low ground cover ratio (12.5%) sites (Fig. 3.4-3).

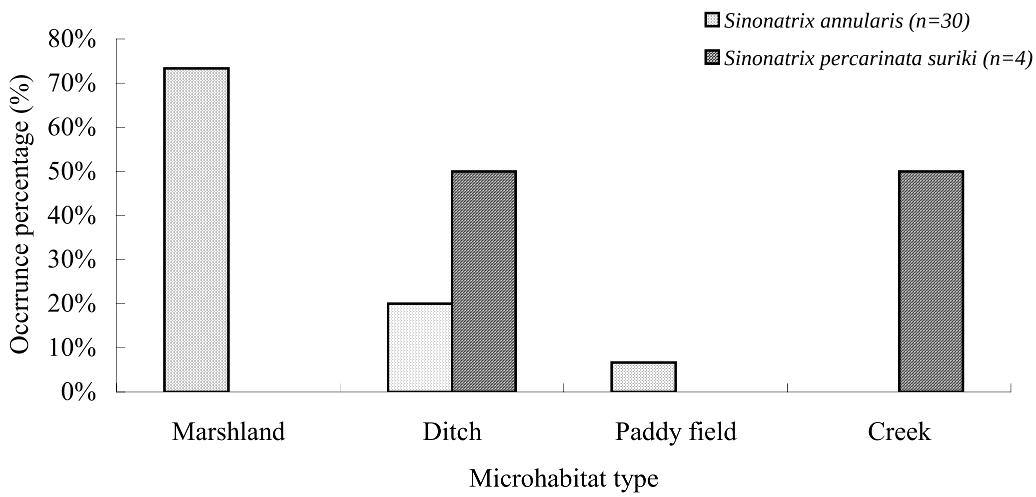

Fig. 3.4-3: Foraging sites and their percentages, as utilized by *Sinonatrix* snakes in the Chutzuhu swamp

3.4.2. Habitat and spatial distribution

According to preliminary studies and field observations in 1997 and 1998, we recognized four principal microhabitats utilized by *Sinonatrix* snakes in Chutzuhu, paddy field, grass-marshland (=marshland), creek and ditch. From November 1999, a focus was placed on the principal microhabitats and data was accumulated about habitat utilization by *Sinonatrix* snakes. The condition of the four principal habitats were as follows, no observable water flow in both the paddy field and the marshland, only a difference in ground cover ratio existed, fast flowing water in the creek and average to slow flowing in the ditch. Based on our observations, the presence of water is a key factor and was reflected in the trapping efficiency at each site, it was nearly 99% at microhabitats that had water. The average water temperature, from highest to lowest, were as follows, creek (20.28), rice paddy (20.26), marshland (19.76) and ditch (18.96 ; Tab. 3.4-2).

Tab. 3.4-2: The average water temperature of different habitats in different seasons in the Chutzuhu swamp (2000-2001)

Periods	Spring	Summer	Autumn	Winter
	Feb.-Apr.	May-Jul.	Aug.-Oct.	Nov.-Jan.
Creek ( )	17.00	21.90	22.63	16.42
Ditch ( )	17.05	19.89	20.52	16.42
Paddy field ( )	17.13	21.13	23.45	16.40
Marshland ( )	16.03	21.46	22.57	15.46

The marshland tended to be the main habitat utilized by *S. annularis*, irrespective of the capture probability (CP= 3.57%) or absolute value (AV= 77.76%, n=416). The remaining habitats were as follows, ditch (CP= 1.51%; AV= 14.02%, n=75), paddy field (CP= 1.04%; AV= 6.73%, n=36), creek (CP= 0.22%; AV= 0.94%, n=5), others (including embankment, and trap wash out by water; 0.56%, n=3). Habitat type and existence of ground cover ratios showed a close relation. High ground cover ratio tended to be the favorite choice of *S. annularis*, irrespective of the habitat type (Tab. 3.4-3). In addition, ground cover ratio was negatively correlated with the SVL of the snakes (r=-0.152**, P=0.01). This indicated that larger individuals were more willing to expose themselves in low cover ratio site than smaller individuals.

Tab. 3.4-3: Percentage of *Sinonatrix annularis* capture proportion within different microhabitats and their cover ratios (November 1999-September 2001)

Cover ratio	Low			Average			High			
	1	2	3	4	5	6	7	8	9	N
Marshland (%)	0.5	10.1	6.7	12.7	19.2	16.1	13.4	20.9	0	416
Ditch (%)	1.3	14.7	12	9.3	24	21.3	6.7	10.7	0	75
Paddy field (%)	5.6	22.2	30.6	22.2	16.7	2.8	0	0	0	36

Notation for cover ratio: 1, 0%; 2, 12.5%; 3, 25%; 4, 37.5%; 5, 50%; 6, 62.5%; 7, 75%; 8, 87.5%; 9, 100%.

Habitat utilization by *S. percarinata suriki* is obviously distinct from *S. annularis*, which utilized the habitats as follows, creek (CP= 1.3%; AV= 36.59%, n= 30), ditch (CP= 0.76%; AV= 46.34%, n= 38), paddy field (CP= 0.37%; AV= 15.85%, n=13) and marshland (CP= 0.0086%; AV= 1.22%, n=1). The habitat utilization of *S. percarinata suriki* may reflect its linear distribution pattern (Tab. 3.4-4, Fig. 3.4-4).

Tab. 3.4-4: Percentage of *Sinonatrix percarinata suriki* capture proportion within different microhabitats and their cover ratios (November 1999-September 2001)

Cover ratio	Low			Middle			High			
	1	2	3	4	5	6	7	8	9	N
Creek (%)	3.3	43.3	3.3	13.3	10	10	10	3.3	3.3	30
Ditch (%)	5.3	63.2	15.8	5.3	7.9	2.6	0	0	0	38
Paddy field (%)	0	35.7	28.6	28.6	7.1	0	0	0	0	13

Notation for cover ratio: 1, 0%; 2, 12.5%; 3, 25%; 4, 37.5%; 5, 50%; 6, 62.5%; 7, 75%; 8, 87.5%; 9, 100%.

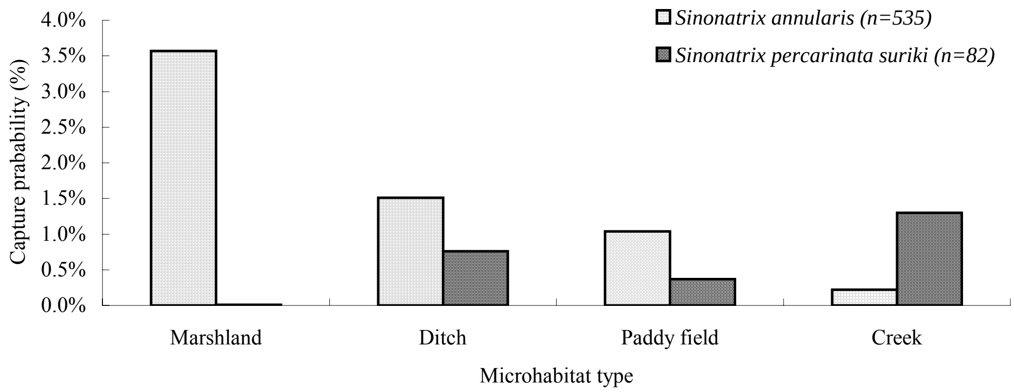

Fig. 3.4-4: Capture probability of *Sinonatrix* snakes within different microhabitats in the Chutzuhu swamp

3.5. Population condition

The population condition of *S. annularis* in the Chutzuhu area was determined by body the condition index (BCI), and was recorded from November 1999 to September 2001. Due to the fact that the BCI may be over-estimate in yearling juvenile snakes and gravid female, we exclude these two classes from calculations for monthly and annually population condition comparisons. The body fitness of yearling juveniles was determined by the ratio of BM/TBL. In addition, due to a lack of neonatal size for *S. percarinata suriki*, the BM/TBL ratio was also applied on this species for body condition determination.

The mean value of BCI in *S. annularis* was 0.5518±0.111 (mean±SD) for males, 0.6479±0.156 (mean±SD) for non-gravid females, and 0.9226±0.140 (mean±SD) for gravid females. The energy storage capability of females was observably better than that of the males ($r=-0.421^{**}$ $P<0.01$) and may reflect the differentiation of reproduction output. The BCI value of gravid females was distinct from the other classes and may offer further data for reproductive prediction and fecundity determination. In addition, the differentiation was also exhibited monthly, annually and in the two genders. Spring and autumn seemed to be the peak BCI period in the annual cycle of *S. annularis* males. Except for November 2000, females showed no observable trend and no observable BCI peak period through out the whole study period. Furthermore, from late winter to early spring appeared to be the annual weakest body condition period, irrespective of the gender, and may be an indication that stored energy is consume during the cold seasons in the Chutzuhu area. Focusing on the annually population body condition, an identical pattern is obvious in both genders of *S. annularis*, there was a conspicuous body fitness decreasing in 2001, when compared to 2000, and reminds us to be attentive to and to monitor the future evolution of the *S. annularis* population in the Chutzuhu area (Fig. 3.5-1, Fig. 3.5-2). The body condition of yearling juvenile snakes was determined by BM/TBL and the total mean value was 0.1801±0.0412(mean±SD). But when we compare the annual differences in the juvenile class with that of the adults, the same pattern is reflected, 0.1836±0.045 (mean±SD) in 2000, which is higher than 0.1726±0.031(mean±SD) in 2001.

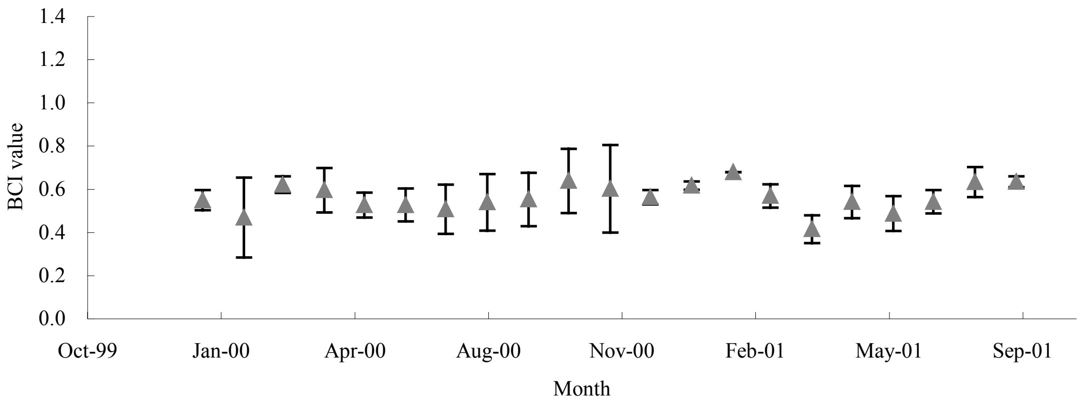

Fig. 3.5-1: Monthly BCI dynamic of *Sinonatrix annularis* males in the Chutzuhu swamp (November 1999- September 2001)

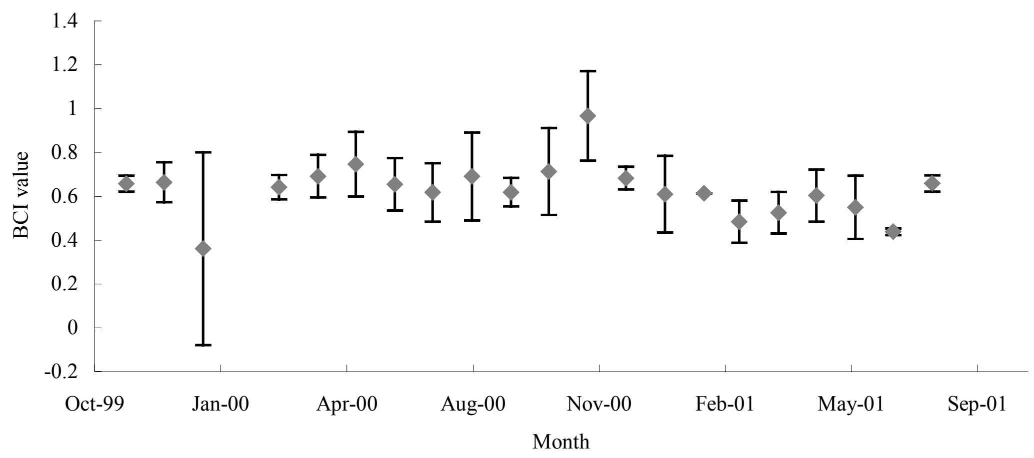

Fig. 3.5-2: Monthly BCI dynamic of *Sinonatrix annularis* females in the Chutzuhu swamp (November 1999- September 2001)

In addition, the body condition of non-juvenile *S. annularis* correlated with the microhabitat condition and snake occurrence. The interaction of cover ratio and BCI of *S. annularis* indicated that higher BCI value enabled individuals to be exposed in the low vegetation cover habitats (r=-0.166**, P<0.01). Moreover, it also correlated with microhabitat type and statistical analysis was significant (r=0.191**, P<0.01), and expressed that individuals with a good body condition had a greater option of microhabitat utilization.

Body condition of *S. percarinata suriki* was determined by BM/TBL, during November 1999 to September 2001, and was, from high to low, as follows, 1.1897±0.621 (mean±SD) in non-gravid females, 0.8657±0.226 (mean±SD) in males and 0.2066±0.005 (mean±SD) in juveniles. In addition to that, the value of one gravid female was 2.411, double that of non-gravid females and triple that of males. The values for non-gravid females were higher than that of males, but both without any annual differences in the Chutzuhu area and may indicate that when marshland evolves into a dry grassland, that the impacts on the *S. percarinata suriki* population in Chutzuhu is smaller than that on the *S. annularis* population.

The evolution of the marshland into a dry land may increase the risk of *S. annularis* being discovered and preyed upon by predators. The decreasing water level and aquatic area also exposes the tracks of the snakes. KING (1985) found that tail stubs and scars might indicate failed predation attempts by fish, reptiles, avian or mammals. When the signs of possible failed predation attempts, on *S. annularis*, in 1997, 1998 and 1999 to 2001 were compared, a slight increase, nearly double the initial value (4% in 1997, 1998; 7% in 1999 to 2001), was observed, but it showed no statistical significance (x^2= 0.574, df=1, P>0.05). In addition, there was no evidence to suggest how many snakes were lost due to successful predation.

3.6. Interaction with other species

3.6.1. Mammals and avian

Four small mammals species were collected by the funnel traps, brown rat (*Rattus norvegicus*), Formosan mouse (*Mus caroli*), Tanaka's gray shrew (*Crocidura attenuata tanakae*) and Formosan mole (*Mogera insularis*). We eyewitnessed a brown rat (*R. norvegicus*) predation on a medium-sized *S. annularis* in cold weather November 2000.

In September 2000, a small indigenous carnivore, the Formosan gem-faced civet (*Paguma larvata taivana*), was found at the north edge of this basin, but there was no evidence to prove that this animal preyed upon organisms in the marshland and on *Sinonatrix* snakes. In addition to that, a feral dog was found in the marshland-trapping site in August 2001, and more dog tracks were usually found around the *Sinonatrix* snakes study site. The influence of wild dogs on *Sinonatrix* snakes shall be evaluated in a future study.

Cattle egret (*Bubulcus ibis*) and little egret (*Egretta garzetta*) seemed to be the dominant avian predators of small to medium-sized *Sinonatrix* snakes and were also food competitors, by preying on loaches, snakehead fish and frogs in the Chutzuhu area. It must also be noted that in 1998 a crested serpent eagle (*Spilornis cheela*) nest was found in the northern side of this basin, which indicated the presence of a species that could probably utilize *Sinonatrix* snakes as a food resource, but due to lacking supportive data, this is still only a hypothesis and speculation.

3.6.2. Reptiles

Movements of ectothermic animals will be limited temporally and spatially, to some degree, by the thermal regimes of the environment (MACARTNEY ET. AL., 1988). *S. percarinata suriki* lives in an obvious close relationship, genetically and ecologically, with *S. annularis* in this study site. They even co-exist in same locality, but some ecological properties are ingenious discriminates in the two species.

Several snakes species, that are known to prey on other snakes, were also captured or observed by us, *E. carinata*, *D. r. rufonzonatum, Bungarus m. multicinctus, Naja atra, Zaocys dhumnades*. These animals may also increase the predation pressure on *Sinonatrix* snakes. In fact, two *S. annularis* died because of failed predation attempts of large *E. carinata* inside the funnel traps. *D. r. rufonzonatum* was also usually present in the study site. It had been identified before as a *Sinonatrix* predator in Taiwan (LEE AND LUE, 1996a).

Stejneger's grass lizards (*Takydromus stejnegeri*) and elegant skinks (*Eumeces elegans*) were collected in the center of the studied marshland from October 2000. The former is a dominant lizard in dry grassland environments of Taiwan, and the occurrence of Stejneger' s grass lizard may indicate that this highland swamp is in a process of evolving into a dry grassland environment.

3.6.3. Amphibians, fish and invertebrates

Thirteen amphibian species were recorded in this study area (Appendix 7.2). According to the food resource utilization of *S. annularis* and *S. percarinata suriki*, in this study, it is clear that the former species include fewer amphibians in their diet than the latter species. But, the larval stage and post-metamorphism stage of amphibians may be an absolutely different situation with respect to the diet of these snakes. In captivity, juvenile *S. annularis* and *S. percarinata suriki* took tadpoles as their food frequently. It is probably an important food resource of neonatal and juvenile snakes in the field, but because tadpoles easily digest faster, no stomachs were proven to contain such prey items. It is also presumed that yearling *Sinonatrix* snakes may also became prey items of three large Amphibians that occur in the Chutzuhu area, *Rana tigerina regulosa*, *R. guentheri* and *Bufo bankorensis*.

Fish tended to be the major food resource of both *Sinonatrix* species. Five species were recorded in this study area, loach (*M. anguillicaudatus*), Asian snakehead fish (*C. asiatica*), eel fish (*Monopterus albus*), domestic carp (*Carassius auratus*), tin fish (*Zacco barbatus*). The former two were found in the stomach contents analysis of the snakes. In addition to that it must be noted that due to the ferociousness of the snakehead fish, and considering the size of the largest individual of this species that was found in this study site; approximately 30 cm in length, 5 cm in head diameter and body mass of more than 300 g; it is most likely a powerful predator in the marshland that preys on small, and even medium-sized, *S. annularis* and *S. percarinata suriki*.

Invertebrates were also abundant in this study site, three carnivorous aquatic-insects, predacious diving beetle, water scorpion and naiad, were recorded in this marshland and it is supposed that they are not of any threat to juvenile *Sinonatrix* snakes. Crayfish had been identified as a minor food resource of the genus *Nerodia* in American (FONTENOT ET AL., 1993). Two shrimp species, *Macrobrachium* sp. and *Caridian* sp., were also recorded in this area. The latter is a small sized species (ca. 2

cm) and is abundant after the occurrence of *S. annularis* neonates every year, but no evidence has been found to prove that this organism is a food resource and utilized by young *Sinonatrix* snakes.

Chapter 4. Discussion

4.1. Environmental changes in Chutzuhu swamp — an epitome of the Taipei basin

Chutzuhu, which means Bamboo Lake in Chinese, is a pure and closed swamp, isolated by a natural fence, which excludes exotic semi-aquatic animals (e.g. *Rana catesbiana*, *Oreochromis hybrids*, *Tilapia* spp. and *Ampullarium insularum*) that have invaded and become naturalized in surrounding areas. Since 1997, we have observed a series of changes and a succession process in this highland swamp. Environmental changes in this ancient volcanic lake are like an epitome of the Taipei basin, which now houses a prosperous and huge Asian city. Chutzuhu have been utilized for agricultural activities for more than one century and a paddy field landscape has been perpetually maintained until recently.

Taipei City evolved in a great basin, which was created by a volcanic eruption in ancient times. Based on the specimens in the collections of the Zoology Department of National Taiwan University and Biology Department of National Taiwan Normal University, it is very apparent that *Sinonatrix* snakes must have been an abundant species in the Taipei basin. Following the eradication of malaria in the area and the development of the city, the environment was drastically altered, wetlands and swamps were being drained, so they disappeared rapidly. Some inconspicuous species most likely disappeared, due to environmental changes and urban developed by human, without anyone noticing. The occurrence of the semi-aquatic snakes *Sinonatrix* in Taiwan may have been the result of accidental incidents that provided some geological and biogeography means for dispersal. Following the wetland succession and transformation into dry land, the semi-aquatic snake fauna was also replaced by some terrestrial species and became only a historical record. But before that, how much was known about those semi-aquatic snakes in Taiwan—an extremely isolated population from its mother population?

4.2. Overview of the *Sinonatrix* snakes population in Taiwan — historical and present

In 1863, SWINHOE was first person to record *Tropidonotus annularis* (=*S. annularis*) in Taiwan, which was also the earliest recorded reference of the snake fauna from this island. The specimen was, based on the record data, collected from Tamsuy(= Tamsui, Taipei County), without any further detail description on it. OSHIMA (1914) reported two snakes damaged in fishery operations, *S. annularis* and *Enhydris plumbea* respectively, but until now, ninety years later, both species have almost disappeared from the Taiwanese environment. MAKI (1931) described a new species *Natrix suriki* (=*S. percarinata suriki*) from Makazayazaya (=Macha district, Pingtung County). MAO (1965) revised the report reconfirmed that *N. suriki* should be a subspecies of *N. percarinata* and revised to be *N. percarinata suriki* (=*S. percarinata suriki*). In addition to that, he briefly described some behavior, habitat and distribution of *S. percarinata suriki* in his paper. In 1998, MAO first realized that the ventral scale numbers of *S. percarinata* are distinct from northern and southern populations and that the population in Taiwan appears to be a branch of that series (MAO, 1998). Phenotype variation of *S. percarinata suriki* in Taiwan presented a geological difference and indicated that this subspecies partition consisted of two groups or two subspecies, from Northeast Taiwan and Southwest Taiwan, which are distinct in color patterns and molecular data (MAO, UNPUBL.).

OTA (1991) had analyzed the distributional patterns of Taiwanese endemic taxa and their relatives. He classified them into five groups for possible closest relatives, outside of Taiwan, as follows: group A) characterized by the occurrence of the closest relatives in Ryukyu Archipelago; group B) characterized by the occurrence of the closest relatives in the Philippines; group C) characterized by the occurrence of the closest relatives in Fujien Province of China, the eastern coast of the continent and neighboring Taiwan; group D) characterized by the occurrence of the closest relatives in the continent but not Fujien Province; and group E) relationships wholly unknown. According to the former definitions, *Sinonatrix* snakes in Taiwan were classified into group C by OTA (1991). In my study and judging on specimens examined, there is no doubt about the fact that *S. annularis* and the northern population of *S. percarinata suriki* should be classified as group C, but the southern population of *S. percarinata suriki* is quite distinct from the northern population, based on scale numbers, color patterns, behavior, breeding season and molecular phylogenetic analysis. We suppose that the southern population of *S percarinata suriki* in Taiwan may have come from a different ancestor than the northern population. In our specimen comparisons, the color pattern and ventral scale count of individuals in Chutzuhu area were quite similar to the specimens and descriptions of this species from Fujien and Zehjiang, especially the color patterns. The closest ancestor of the southern Taiwan population may be related to Guandong Province of China or Vietnam and must be classified under group D, as described by Ota (1991). This pattern also occurs in phylogeny studies done on freshwater fish of Taiwan and had been proven by molecular evidence (CHENG, 2001; POH, 2001).

The taxonomy of the genus *Sinonatrix* evolved from *Natrix* (sensu lato) and had been reorganized and discussed by MALNATE (1960) and have been partitioned into four genera by ROSSMAN AND EBERLE (1977) as follows: 1) genus *Natrix*, distributed over Europe and west Eurasia; 2) genus *Nerodia*, distributed over North American; 3) genus *Sinonatrix*, distributed over Southeast continental China, the Indochinese

Peninsular and Taiwan; and 4) genus *Afronatrix*. distributed over North Africa. These four genera have been proven to come from a natural assemblage and they belong to a monophyletic group in phylogenetic relationship studies (SCHWANER AND DESSAUER, 1982).

Except for some taxonomical descriptions (STEJNEGER, 1907; MAKI, 1930; POPE, 1935; WANG AND WANG, 1956; KUNTZ, 1963; MAO, 1965; RAO AND YANG, 1998), phylogenetic (MAO AND DESSAUER, 1971; LAWSON, 1986; MAO, 1998) and brief observations (HE, 1983), no systematical ecological studies have been conducted on *Sinonatrix* snakes in Asia. Therefore, compared to its sister groups *Natrix* and *Nerodia*, it is a genus of which the life history and ecology is still poorly understood.

4.3. Population estimation of *Sinonatrix* snakes in Taiwan

Our study results of snakes captured in Chutzuhu swamp showed that *S. annularis* was the dominant species, irrespective of numbers and snake-times. Compared to population estimations from other studies on other species, it seams that this species in this area is a large natricine snake population (Tab. 4.3-1). This is most likely due to the abundance of nutritional materials that washes into and accumulates in this swamp from out of the forested areas that grow around the edges of the basin. These nutritional factors offer high abundances of food for detrivores, like the loaches and shrimps, and support the entire ecosystem of this highland swamp.

Tab. 4.3-1: Comparison of density and population estimate of natricine snakes

Species	Population estimate (±SE)	Density	Locality	Resource
Sinonatrix annularis	988±326	-	Taipei, Taiwan	Present study
S. percarinata suriki	129±78	-	Taipei, Taiwan	Present study
Natrix natrix	299±75	3-4/ ha	Marburg, Germany	MERTENS, 1995
Thamnophis radix	1093	342/ acre	Chicago, USA	SEIBERT, 1950
Nerodia sipedon insularum	552±402.7*	381/ km*	Lake Erie Island, USA	KING, 1985

***: There were several study localities and estimation, we take the largest site and highest estimation for this comparison.**

MADSEN (1984) mentioned that low recapture rates reflect the great mobility (very large home range) of adult specimens of *Natrix natrix*. The snake recapture rate of *S. annularis* was 4 % during the entire sampling period from 1997 to 1998 (n=112; trapping nights= 2,508). But rapidly reach values more than 50 % during every sampling during the period 1999-2001 and the monthly relative abundance became obviously lower than during the same seasons in 1997 and 1998. Comparing the recapture rates of *S annularis* in 1997, 1998 and 1999 to 2001, it may become apparent that the minor marshland environment is in a process of succession and is turning into a dry grassland, the fragmentation of the marshland habitat is most likely forcing the snakes to concentrate in relatively high densities in some remaining wetland patches where habitat requirements are still met. The utilization of the swamp was monitored from 1997 to 2001, and it was found that in 1997 and 1998 most of the swamp was manipulated and utilized as paddy fields, but as of 1999 many of the farms have been abandoned. The water level of this swamp was maintained and manipulated by the local farmers. We had some brief interviews with some of the farmers, who were working in the Chutzuhu swamp, about their attitudes towards the water snake activities in their farmlands. Most of them responded in such a way that it appears that they simply ignored the snakes and considered them harmless. Thus the situation of the snake population in the Chutzuhu swamp seems unlikely to be due to anthropogenic activities, aimed at the water snakes.

Like other ectoderms, the activity of snakes is strangely dependent on environmental temperatures (MAY ET AL., 1996). Seasonal dynamics of *S. annularis* showed a unimodal, and otherwise also indicated that the population in Taiwan was without an exact hibernation period, but February tended to be the lowest activity period, the environmental temperature appeared to be the manipulating factor of monthly dynamics and this also correlated with the reproductive activities (Fig. 4.3-1). We presume that mating and courtship occurrences in during the period mid April to early June, which was substantiated by a relatively higher abundance of male during that time. This presumption also based on the fact that gravid females were being detected from late May during the study year. Annual dynamics peaked in June, which may be due to mating behavior combined with foraging activities, which were reflected in the higher proportion of stomach content items (43.33%; n=13) individuals contained**.** In addition to that, June is also the high temperature (mean=23.5 ^{o}C) and rainfall season (mean=294.7 mm) in Taiwan, and sufficient thermal requirements and the extension of the aquatic area may explain the increased activity of *S. annularis*. From April to November were the major activity months for all size classes and was also correlated to temperature. *S. annularis* live bearing was indicated by the appearance of neonatal snakes and was most abundant during September and shifted to October, which most likely indicated that these are the principal breeding seasons. Compared to literature based on populations from Mainland China, this population seems without obvious distinctions, except for the no exactly hibernation behavior, earlier courtship and slightly longer breeding periods (POPE, 1935; HE, 1983; ZHAO ET AL., 1998), which most likely are due to differences in the climate. Seasonal dynamic and movement different had been reported in some conspecific but different population snakes (MAY ET AL., 1996)

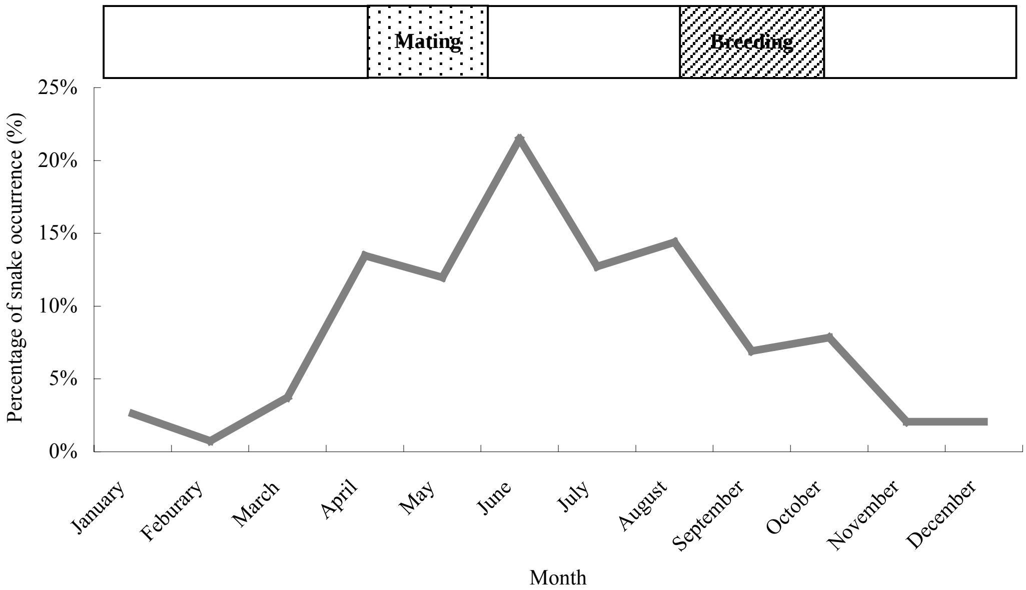

Fig. 4.3-1: Monthly activity of *Sinonatrix annularis* in the Chutzuhu swamp

Seasonal dynamics of *S. percarinata suriki* represented a similar mode, as observed in *S. annularis*, but we supposed that mating most likely occurs, and may be concentrated, in May. Annual activities were concentrated during the period April to October, and a period of dormancy existed for one or two months during the coldest months of winter (Fig. 4.3-2).

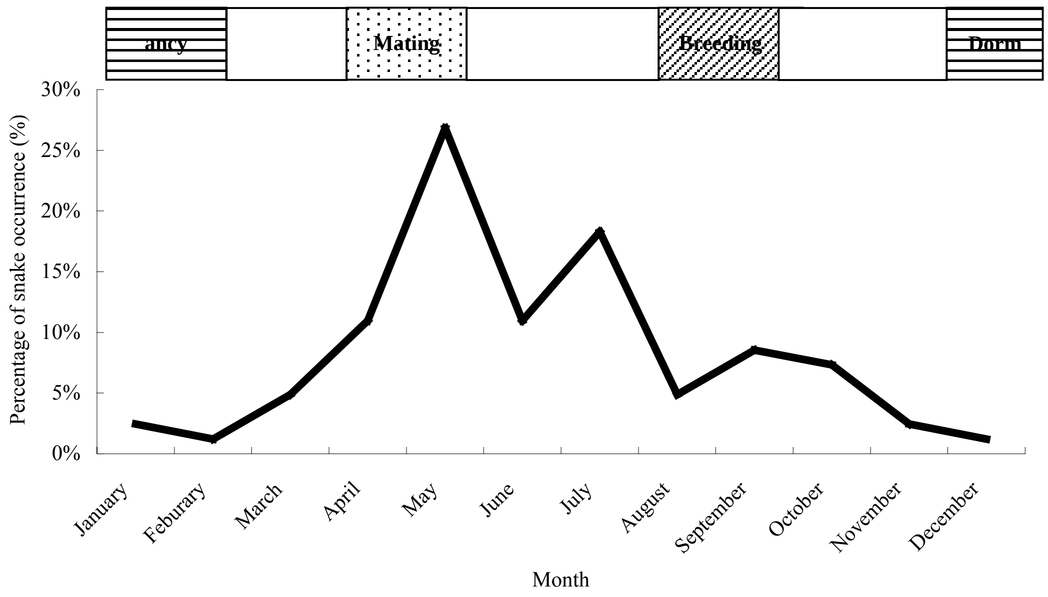

Fig. 4.3-2: Monthly activity of *Sinonatrix percarinata suriki* in the Chutzuhu swamp

In spite of the fact that the mean movement area and straight-line distance per day of non-gravid females were higher than that of males, the home range on average, of each individual was higher in males than that of non-gravid females and juveniles. Males often moved greater distances than females, when searching for mates during spring, and females sometimes made extensive journeys in search of oviposition sites (GREGORY ET AL., 1987). In some snakes spatial relationship studies of FITCH AND SHIRER (1971): snakes seldom returned to specific points, which was contrasted in our trapping records, in which we frequently recaptured an individual in the same area or nearby the previous trapping location, several months or more than a year earlier. This may be due to snake activity in a relatively small home range. IVERSON (1990) found that males are more active during the mating season, but after that their activity were no longer that apparent. The different kinds of activities associated with reproduction, most likely in turn influence their movement patterns at certain times of year (MACARTNEY ET AL., 1988). Movement of *S. annularis* showed to be restricted and concentrated in marshlands, irrespective whether they were studied based on straight-line distance or activity grids number. In addition, when the recapture intervals of males were extended, no correlation between activity grid numbers were noted and may indicate that *S. annularis* males occupied certain home ranges. *Natrix s. sipedon* (= *Nerodia s. sipedon*) were studied by Brown in 1940 and his findings supports the idea that water snakes usually occupy small home ranges (FRAKER, 1970; Tab. 4.3-2).

Several literature sources indicated that fluctuating aquatic environments affect dispersal rates, movement or home ranges of semi-aquatic or aquatic snakes (HOUSTON AND SHINE, 1994; WHITING ET AL., 1997). Some local farmers mentioned that *S. annularis* was always active along the water trail and were never observed to attempt to cross the embankment or open dry land. In our observations, after heavy rains or following a typhoon, the probability of new individuals captured was conspicuously higher. It is presumed that the movement and home range of *S. annularis* in the Chutzuhu swamp may fluctuate according to the rise and fall of the water level. Therefore, we suppose that when the swamp had a higher water level, a different situation might have occurred (Tab. 4.3-3).

Tab. 4.3-2: Mean movement of *Sinonatrix* snakes in straight-line distance, mean movement area per day and home range in the Chutzuhu swamp

Species	Sex	Straight-line distance (meter/day)	Daily movement area ($meter^2$/day)	Home range ($meter^2$)
Sinonatrix annularis	**Male**	**0.70±0.75**	**9.42±13.02**	**796.2±959**
	Female	**0.95±1.94**	**12.36±32.8**	**589.7±350.8**
	G-Female	**0.45±0.34****	**6.14±5.04****	**562.5±385.2****
	Juvenile	**0.48±0.42**	**9.79±6.15**	**180±130.4**
S. percarinata suriki	**Male**	**1.34±2.34**	**17.68±33.71**	**722±678***
	Female	**0.57±0.61**	**11.38±7.61**	**300±235***

***: Linear spatial utilization pattern**

****: Involved partial postpartum movement data.**

Gravid females *S. annularis* movement appeared to be relatively lower compared to that of males and non-gravid females. The low movement of gravid females were noticed and reported in several literature sources (WEATHERHEAD AND PRIOR, 1992; CHARLAND AND GREGORY, 1995). Gravid females of *Thamnophis* snakes moved little, and spent much of the gestation period in very restricted areas and were significantly closer to water than non-gravid females (CHARLAND AND GREGORY, 1995). High predation by king snakes and racers on gravid green snakes (*Opheodrys aestivus*), were observed by PLUMMER (1990); which might have been due to low movement of gravid females. *E. carinata* and *D. r. rufozonatum* are two snake species, occuring in this swamp, that are well known to prey on other snakes, and may prey on *Sinonatrix* snakes and increase the mortality of gravid females (LEE AND LUE, 1996a, 1996b).

Tab. 4.3-3: Movement comparison within different natricine snakes

Species	Movement (±SD)	Method	Locality	Resource
Sinonatrix annularis	M: 0.70±0.75 m/d F: 0.95±1.94 m/d GF: 0.45±0.34 m/d	MR	Taipei, Taiwan	Present study
S. percarinata suriki	M: 1.34±2.34 m/d F: 0.57±0.61 m/d	MR	Taipei, Taiwan	Present study
Rhabdophis tigrinus	67.5 m	MR	Yokohama, Japan	MORIGUCHI AND NAITO, 1983
Thamnophis sirtalis	F: 17.4±14.8 m/d GF: 2.7±2.1 m/d	RT	British Columbia, Canada	CHARLAND AND GREGORY, 1995
T. sirtalis	10 m/d	RT	USA	FITCH AND SHIRER, 1971
T. radix	M: 0.72 m/d F: 1.05 m/d	MR	Illinois, USA	SEIBERT AND HAGEN, JR., 1947
Natri natrix	54.8±16.8 m/d	RT	Southern Sweden	MADSEN, 1984
Nerodia harteri paucimaculata	M: 41.6±7.1* m/d F: 31.3±6.9* m/d GF: 24.1±4.5*m/d	RT	Texas, USA	WHITING ET AL., 1997
N. sipedon	4 m/d	RT	USA	FITCH AND SHIRER, 1971

Notation: MR= Marking and recapture; RT= Radio tracking.

4.4. Population structure of *Sinonatrix* snakes

The sex ratio of the two *Sinonatrix* snakes was slightly higher in males than in females but did not skew away from the equal sex ratio, that skewed towards the female gender in 1998, which might have been related to a difference in seasonal sexual activity. Seasonal sexual activity differences were reported in several species (GREGORY ET AL., 1987; IVERSON, 1990).

MADSEN AND SHINE (1994a) pointed out that growth rates slowed dramatically after maturity in *S. annularis* males and females, and was also consistent with the description of the former situation. Compared to other natricine snakes, the growth rates of the two *Sinonatrix* snakes seemed to be lower in males, but females appeared indistinct from other species (Tab. 4.4-1). Snakes may reduce the population size of their prey to such an extent that they themselves become food stressed and thereby suffer reduced growth rates at high population densities (LINDELL AND FORSMAN, 1995). Food abundance and efficiency of food digestion might explain some differences in growth rates between two snakes in manipulated studies (GREGORY AND PRELYPCHAN, 1994). Because we manipulated the study by providing sufficient food throughout the study period and by eliminating predators, two factors for the growth rate determination in neonates, the variance that remains can be concluded to be due to environmental affects. The growth rate of captive *S. annularis* neonates showed the following: 1) the principal growth period of neonatal snake was from June to September and correlated with the actual relatively high abundance of juveniles in the field at same time; 2) temperature was an obviously higher trigger factor, compared to sufficient food resource, in neonatal growth; 3) growth rates of males and females were indistinct prior to being yearlings, but after that female growth was more rapid than that of males; 4) with the absence of predation pressure and loss of habitat, male neonates took three years to reach sexual maturity, and females took four years; and 5) neonates experienced a ventral color change when the yearling size is attained, which may be due to an anti-predator response.

Tab. 4.4-1: Growth rate comparison within different natricine snakes

Species	Mean growth rate (cm/day; ±SD)	Locality	Resource
Sinonatrix annularis	**M: 0.0055±0.0044**	**Taipei, Taiwan**	**Present study**
	F: 0.0176±0.015		
	JM: 0.022±0.02		
	JF: 0.025±0.023		
S. percarinata suriki	**M: 0.007±0.0053**	**Taipei, Taiwan**	**Present study**
	F: 0.0113±0.0048		
Nerodia sipedon insularum	**M: 0.012**	**Lake Erie Island, USA**	**KING, 1986**
	F: 0.014		
Natrix natrix	**F: 0.0016***	**Alps, Italian**	**LUISELLI ET AL., 1997**

***: Indicate that was estimated from SVL in 76.66 cm.**

Compared to Temperate natricine snakes, the proportion of mature to immature individuals was without conspicuous differences in females of the two *Sinonatrix* snakes, but higher in the males of both species, in particular in *S. percarinata suriki* males. Since some sources pooled the proportions of the two genders, it is not possible to recognize the detail ratios and comparisons (Tab. 4.4-2). The higher proportion of male *S. percarinata suriki* might be due to two aspects, first, although minor it might be because of some spatial or temporal sampling insufficiency; and secondly, it might be possible that it was due to environmental selection forces that restricted *S. percarinata suriki* juveniles and sub-adults. The latter, compare to sympatric species, may represent a reproduction strategy. Low immature proportions may also reflect high mortality before young snakes reach sexual maturity.

Tab. 4.4-2: Size and age structure comparison of natricine snakes

Species	SVL range (cm; mean)	Mature/immature ratio	Climatic zone/ Locality	Literature
Sinonatrix annularis	**M: 27.1-64 (44.8)**	**2.9 : 1**	**Sub-Tropical**	**Present study**
	F: 29-76 (52.6)	**1.8 : 1**	**Taiwan**	
S. percarinata suriki	**M: 25.8-64.6 (50.1)**	**9 : 1**	**Sub-Tropical**	**Present study**
	F: 26.8-73.9 (53)	**1.9 : 1**	**Taiwan**	
Nerodia sipedon insularum	**M: 44-85 (62.5)**	**1.3 : 1**	**Temperate**	**KING, 1986**
	F: 60-110 (82.1)	**1.5 : 1**	**Lake Erie Island**	
Rhabdophis tigrinus	**M: 55.6-69 (62.3)**	**3.8 : 1**	**Temperate**	**PARKER AND PLUMMER,**
	F: 54.8-86.1 (70.5)		**Japan**	**1987**
Regina septemvittata	**M: 35.2-64.2 (49.7)**	**3.6 : 1**	**Temperate**	**PARKER AND PLUMMER,**
	F: 45.9-69.5 (57.7)		**Kentucky**	**1987**
Thamnophis butleri	**M: 32.1-41 (36.6)**	**0.88 : 1**	**Temperate**	**PARKER AND PLUMMER,**
	F: 34.5-48 (41.3)		**Michigan**	**1987**
T. elegans	**M: 30-55 (42.5)**	**2.4 : 1**	**Temperate**	**PARKER AND PLUMMER,**
	F: 40-65 (52.5)		**California**	**1987**
T. sirtalis	**M: 30-71 (57.3)**	**3.5 : 1**	**Temperate**	**PARKER AND PLUMMER,**
	F: 45-80 (62.5)		**California**	**1987**

The SVL size and body mass relationship exhibits some correlation and represents on the size differentiations between the two genders of the two *Sinonatrix* snake species. The body mass and snout-vent length equation in *S. annularis* males is y=2.4833x – 68.242 (R^2=0.8163); in females is y=4.1541x – 135.59 (R^2=0.7763) and in gravid females is y=7.3946x – 301.19 (R^2=0.6491). All the regression equations indicated a strong correlation between body mass and snout-vent length in *S. annularis* (Fig. 4.4-1). It was also display in the size and weight relationship of *S. percarinata suriki*, y=2.7539x –77.976 (R^2=0.7772) in males, and y=3.8901x – 115.09 (R^2=0.8677) in females (Fig. 4.4-2). Populations of *S. annularis* in Taiwan appearances to exhibit a slight sexual difference in body size and this supports the observations of POPE (1935) and review of SHINE (1994). Meanwhile the largest female snout-vent length, in a series of 104 specimens examined, from Fujien and northeastern Kiangsi was 552 mm quite, which is distinct from the population in Taiwan (772 mm). The maximum-recorded sizes *S. annularis* from Zehjiang was 710 mm in females, 600 mm in males, which are also smaller than individuals measured in Taiwan. The size difference between the Taiwan population and the Mainland China populations may be due to the following reasons: 1) cool climate and relatively brief growth period each year (e.g. LUISELLI ET AL., 1997); 2) selection forces restrictions on larger sized individuals (e.g. water flow resistance); 3) sampling bias; and 4) characteristics of the island population (e.g. founder effect).

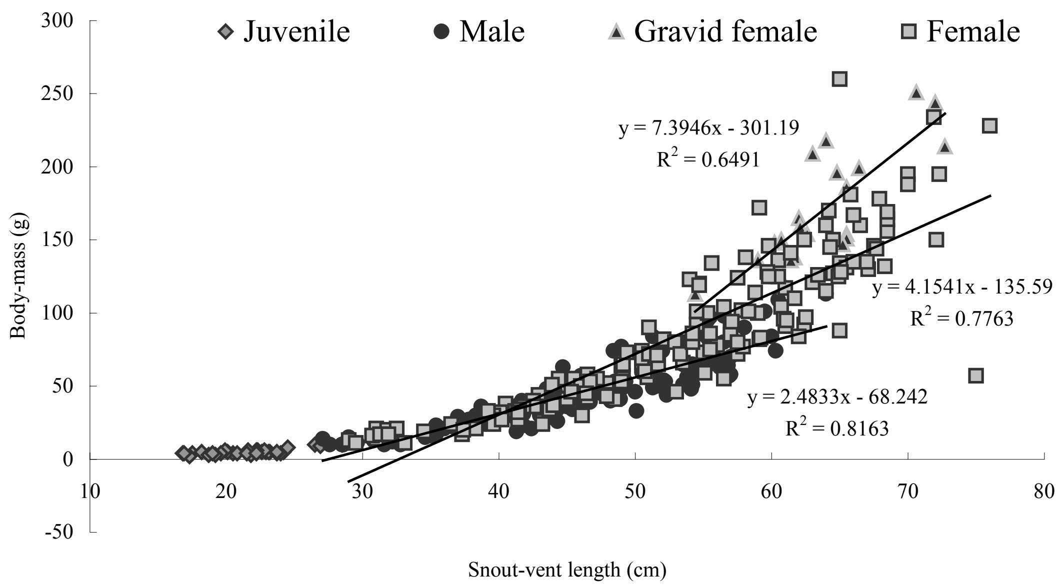

Fig. 4.4-1: The relationship between body mass and snout-vent length within different genders and conditions of *Sinonatrix annularis* in the Chutzuhu swamp

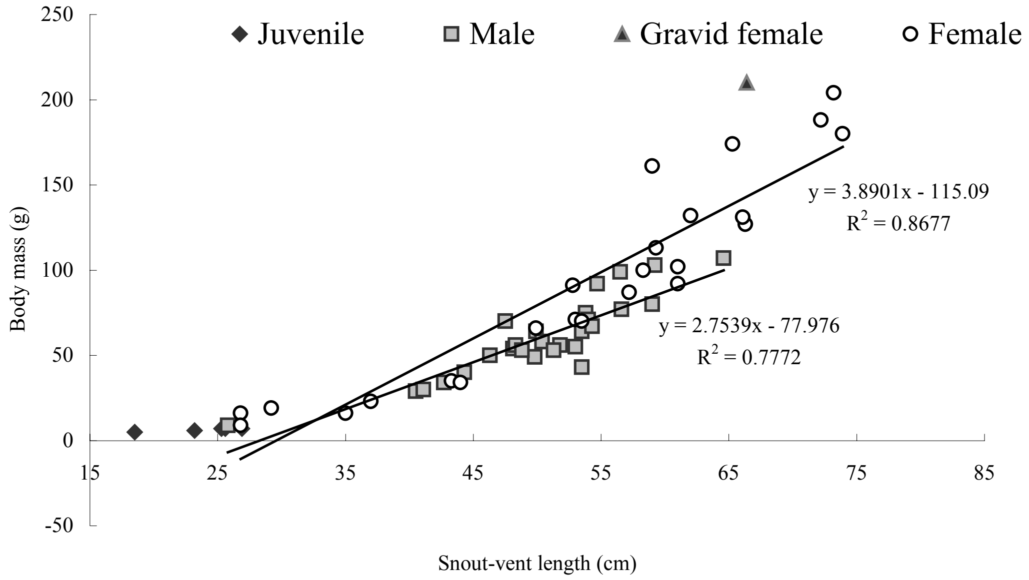

Fig. 4.4-2: The relationship between body mass and snout-vent length within different genders and conditions of *Sinonatrix percarinata suriki* in the Chutzuhu swamp

4.5. Characteristic of *Sinonatrix* snakes reproduction in Taiwan

According to POPE (1935), the smallest female who carried embryos was 413 mm and contained 5 embryos, observably smaller than that of the Taiwan population (544 mm and carried 7 embryos). Different climatic conditions and localities may influence results from a snake species with a wide distribution range because of delayed maturation or decreased growth rate in some areas (LUSELLI ET AL., 1997). Low growth rates and delayed maturation were reported in tropical aquatic snakes by HOUSTON AND SHINE (1994) in Australia. MADSEN AND SHINE (1992, 1994a,b) and LUISELLI ET AL. (1996, 1997) found that the reproductive output increased strongly with maternal body size, and indicated that larger female are able to breed frequently, produce larger litters and neonates, has a higher neonate survival-ship and lower stillborn frequency, but, natural selection forces may be a consideration that has to be considered. POPE (1935) stated that *S. annularis* also occurs in streams of Mainland China, but in our study similar patterns were observed in *S. percarinata suriki* and it is supposed that the size differentiation may related to water-flow resistance (see Discussion 4.6). In addition to that, HUANG ET AL. (1987) mentioned that the mean Tail-L/TBL of *S. annularis* in Zehjiang, was 0.207 in males and 0.193 in females, both relatively longer than that from the population character in Taiwan (0.196 in males and 0.186 in females). Whether it is due to a population divergence because of environment adaptations or whether it possesses any other ecological significance remains unclear and needs further investigation.

There is no conspicuous breeding seasonal differences between *S. annularis* breeding season results from the present study and literature records from Mainland

China (POPE, 1935; HE, 1983; ZHAO ET AL., 1998).

The reproductive season of *S. percarinata suriki* was described by MAO (1965), based on observations made on September 17, 18 and 28, 1962. The breeding season of *S. percarinata suriki* in Northern Taiwan is obviously later than that of southern populations (MAO, 1998). It was also noticeable in minor differences in the sizes of yearlings (Fig. 4.5-1). Temperature is a potentially important factor, affecting the reproductive characteristic of reptiles (BALLINGER, 1977; WHITTER AND LIMPUS, 1996). The climate of northern Taiwan is located in a subtropical region while southern Taiwan belongs to a more tropical region, annual average temperature difference was about 6.2 ^{o}C (e.g. Chutzuhu, northern Taiwan was 18.5 ^{o}C; Kaohsiung, southern Taiwan was 24.7 ^{o}C). A constant thermal theory was practically applied on the prediction of insect pest cycles, which was based on the assumption drawn from the total hatchling thermal requirement of insect eggs. That theory may also explain some intra-species reptile breeding seasonal differences, and could even predict the time interval of snake eggs hatching.

Fig. 4.5-1: The size difference of yearling *Sinonatrix percarinata suriki* between northeast population (upper) and southwest population (lower) collected in same season (right redline indicate 1 cm).

Female *S. annularis* produced neonates biennially or less frequently, but BELM (1982) pointed out that populations with larger females exhibited a higher ratio of reproductive activity in females than in populations with more balanced size distributions. In our observations, larger female BCI values fluctuated less than that of smaller individuals within the period that they are gravid and postpartum. Two females were also tested in 2001, they were offered sufficient dietary items in postpartum periods, but until the following spring (2002) the BCI value of both snakes were still lower than that of the minimum gravid level. Reproductive output increased strongly with maternal body size (LUISELLI ET AL., 1996) and clearly explains the correlation between maternal size and litter size in *S. annularis*. It also indicated that larger maternal individuals were able to carry larger litters under the same conditions as individuals with lower reproductive output and risks.

Oviparous snakes can achieve a much higher reproductive output, owing to a larger clutch size and more frequent reproduction (LUISELLI ET AL., 1997). The average clutch size of *S. percarinata suriki* was observably higher than that of sympatric viviparous species, and might be due to a reproductive strategy similar to that of egg laying species.

Maternal body size influenced offspring size as well as litter size (MADSEN AND SHINE, 1992). But in the Chutzuhu study, *S. annularis* maternal size correlated with offspring size but was not related to litter size. Some studies indicated that offspring size and litter size possessed a trade-off relationship (MADSEN AND SHINE, 1992). But, it seems to be an irregular reproductive rule of reptiles (ROOSENBURG AND DUNHAN, 1997). Annual offspring size differentiation may reflect food resource shortages and maternal fat storage insufficiency in the Chutzuhu swamp. BALLINGER (1977) pointed out that reduced prey availability explained lower reproductive frequency and lower clutch sizes. Similar conclusions were also drawn from a study on pigmy rattlesnakes (SEIGEL ET AL., 1998). In 2001, the average size of neonates was observably larger than of neonates from 1998 and 2000. According to LUISELLI ET AL. (1996), larger neonates retained their size advantage for at least 12 months, but did not have a higher survival probability. We suppose that in years of low food availability, reproducing females may reduce the clutch or litter size to trade-off a larger neonate size to increase the cohort competition ability of the neonates. But if the maternal female is suffering from an energy storage insufficiency, due to a food shortage, even if the offspring are of larger sizes, the body fitness condition will still be weak. Under conditions with low food resource availability, the neonatal mortality, before they become yearlings, may still be high.

4.6. Resource utilization, partitioning and differentiation of sympatric *Sinonatrix* snakes

Chutzuhu is a highly diverse swamp, which contains 14 amphibian species and 5 fish species that may be utilized as a food resource by *Sinonatrix* snakes (Appendix 7.2). Food resource utilization of *Sinonatrix* snakes in Chutzuhu swamp was examined in this study. Adult *S. annularis* appeared to forage more specifically on fish than on amphibians in the process of metamorphosis (Fig. 4.6-1). Even though juvenile snakes frequently accepted tadpoles as food in captive situations, so far tadpoles in dietary weight of *S. annularis* is still undetermined. ZHAO ET AL. (1998) reported that stomach contents of *S. annularis*, collected from Anhui and Zehjiang, contained some tadpoles. MAKI (1931) briefly described the usual prey of *S. annularis* in Taiwan as fish. POPE (1935) also mentioned that *Natrix annularis* (= *S. annularis*) showed a preference for fish over frogs, but he listed another stomach content item, *Fluta* (=*Monopterus*) eel. Eel fish (*M. albus*) frequently appeared in the Chutzuhu swamp, but in our tests on both *Sinonatrix* snakes, there were no responses to it. Anyway, *S. annularis* feeds more specifically on fish and this behaviour fits the descriptions in former literature. Some differentiation may be due to prey form or divergence because of geological conditions.

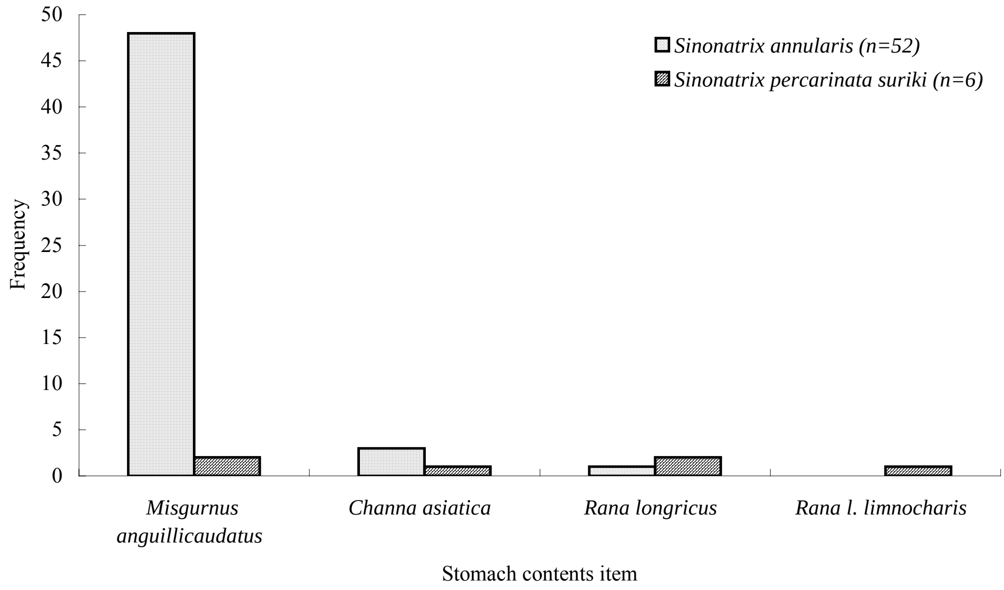

Fig. 4.6-1: Food resource utilization frequency of *Sinonatrix* snakes in the Chutzuhu swamp

Numerous references stated that the diet of *S. p. percarinata* in Mainland China consisted of frogs, tadpoles, fish (including loach, eel) and crayfish (POPE, 1935; ZHAO ET AL., 1998), the percentage of fish and frogs were about half and half. LEE AND LUE (1996b) listed tin fish (*Zacco barbata*), tadpole and frog as prey of *S. percarinata suriki*. Compared to *S. annularis*, *S. percarinata suriki* tended to be a wider foraging predator. Except for observations made in the population study in Chutzuhu, some observations were also made in Fushan botanical garden, Sanping and Gaoshu. In September 2000, a *S. percarinata suriki* was found in Fushan botanical garden at night preying on a large *R. guentheri*.

Some predation success probability may be strongly correlated to body color, especially in some sit and wait foraging strategy species. Caudal luring is one of the more famous mimicry behaviors, used by some juvenile snakes to increase their hunting efficiency, and requires a worm-like colorful tail and motion. In April 2000, a unique predation behavior was observed in Gaoshu district, Pingtung County. Three *S. percarinata suriki* were active in a creek at noon and one of them (about 65 cm in total body length) took a breath on the surface and dove to the bottom of the deep pool. The lower body was used just like an anchor to keep the animal fixed to the bottom of the pool and then it raised the front part of the body and displayed the white region of the neck under the sunlight, and it reflected just like a bright fishing lure would, as it tried to attract some fish closer to catch. We observed it for about one hour and fifty minutes, during which time it did not surface to take a breath. When we tried to frighten it by throwing some stones to its location, it just changed the locality and continued this particular fishing behavior. We never read about this behavior from any other available literature sources or saw it in any other *S. percarinata suriki* populations in Taiwan. The neck ventral color pattern is different, and may represent this special behavior, in some *S. percarinata suriki* populations in Taiwan and could possibly be due to microevolution of habitat adaptation or phylogenetic divergence

Fig. 4.6-2: Ventral color differentiation of adult *Sinonatrix percarinata suriki* between northeast population (left) and southwest population (right).

Habitat differentiation of *Sinonatrix* snakes was first notice in the nearby farmlands in the Chutzuhu basin in 1996 by the author. A four meters wide road crossing the semi-aquatic Calla lily field, partitions it into two parts. *S. percarinata suriki* only occurs in the western part and *S. annularis* only inhabits the eastern part. Environmental distinctions of the two sides are represented in ground-cover ratio, temperature and sunlight. REINERT (1993) listed three relevant cues in snake habitat selection, temperature, structure features and identification of relevant structure features. The differentiation of microhabitat utilization by *S. annularis* and *S. percarinata suriki* may be due to the following aspects: 1) evolution tendency for thermal niche and preference; 2) different morphological adaptation for an aquatic environment; 3) different foraging strategies and minor variations in food resource utilization.

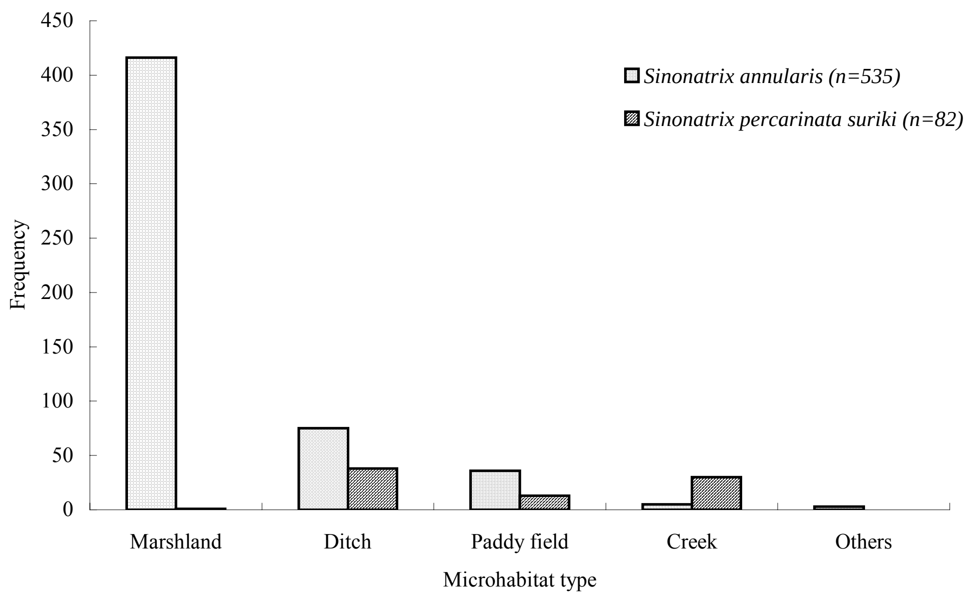

Fig. 4.6-3: Microhabitat utilization frequency of *Sinonatrix* snakes in the Chutzuhu swamp (November 1999- September 2001)

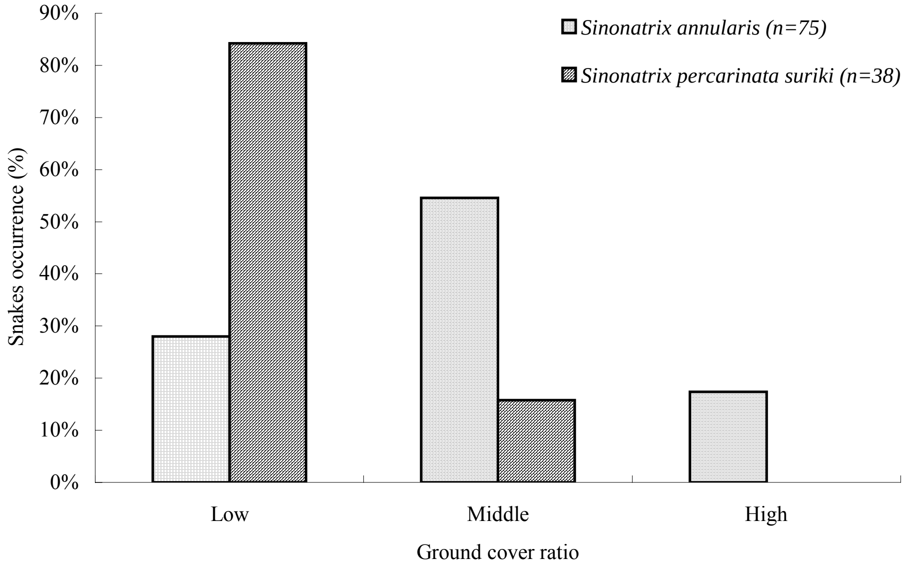

Fig. 4.6-4: Ground cover ratio differentiation of two sympatric *Sinonatrix* snakes occurring in a conspicuous overlapping habitat— ditch environment

Thermal niche, regulation and temperature preference of snakes have been widely studied and discussed in several American and Europe natricine species (MUSHINSKY ET AL., 1980; HAILEY AND DAVIES, 1986; HAILEY AND DAVIES, 1987; HAILEY AND DAVIES, 1988; LUTTERSCHMIDT AND REINERT, 1990; TU, 1993; NAGY AND KORSÓ, 1998). But due to some study resource limitations, most studies focused on a single reproductive mode, like the oviparous *N. maura* and *N, natrix* study by HAILEY AND DAVIES (1986, 1987 and 1988) and NAGY AND KORSÓ (1998), vivipary in *Nerodia rhombifera*, *N. cyclopion* and *N. fasciata* studied by MUSHINSKY ET AL. (1980) and *N. s. sipedon* by LUTTERSCHMIDT AND REINERT (1990). The origins, ontogenetic and evolution of reproductive mode (viviparity and oviparity) had widely discussed by various reports (LEMEN AND VORIS, 1981; SHINE, 1983; SHINE, 1987; SHINE, 1995). Several evidence support that the multiple origin of viviparity in snakes and lizard

(LEMEN AND VORIS, 1981). Cold climate hypothesis is one of well-know explanation for viviparous reproductive mode, which may evolve from cold climate adaptation of reptiles (ZHAO, 1988; SHINE, 1995). *Sinonatrix* snakes in this study may offer an excellent opportunity to examine this hypothesis, and might offer some explanations for microhabitat-utilization differentiation of *S. annularis* and *S. percarinata suriki*.

Microhabitat utilization of *S. annularis* indicated that this species tended to be more concentrated in marshlands than any other habitats (Fig. 4.6-5; Fig. 4.6-6; Fig. 4.6-7). Ground cover ratio was negatively correlated with the SVL of snakes, indicating the larger individuals were more willing to expose themselves in low cover ratio sites than smaller individuals (BONNET AND NAULLEAU, 1996). Based on the water temperatures recorded from 2000-2001, the marshland tended to have a lower water temperature microhabitat than that of creeks and paddy fields. We suppose that the occurrence of *S. annularis* in these habitats may be due to relative lower thermal requirements, as apposed to the requirements of *S. percarinata suriki*, and might slightly be influenced by the reproduction mode—vivipary. In overview, thermal requirement difference of two *Sinonatrix* snakes also minor on distribution pattern of both snakes, *S. annularis* more limit in temperate to subtropical zone but *S. percarinata* have more extensive distribution from lower temperate region to upper tropical climatic zone.

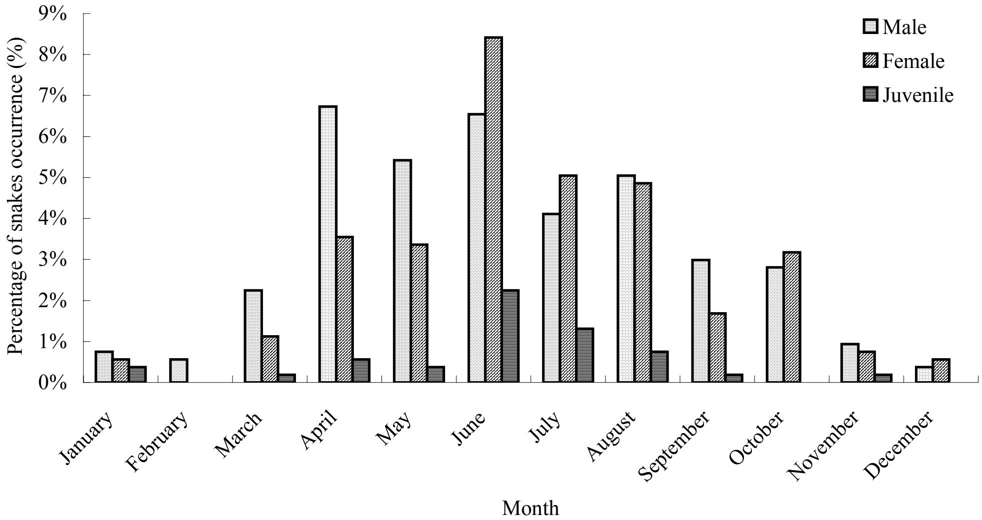

Fig. 4.6-5: Monthly dynamics of *Sinonatrix annularis* in a marshland habitat (November 1999-September 2001; n=416)

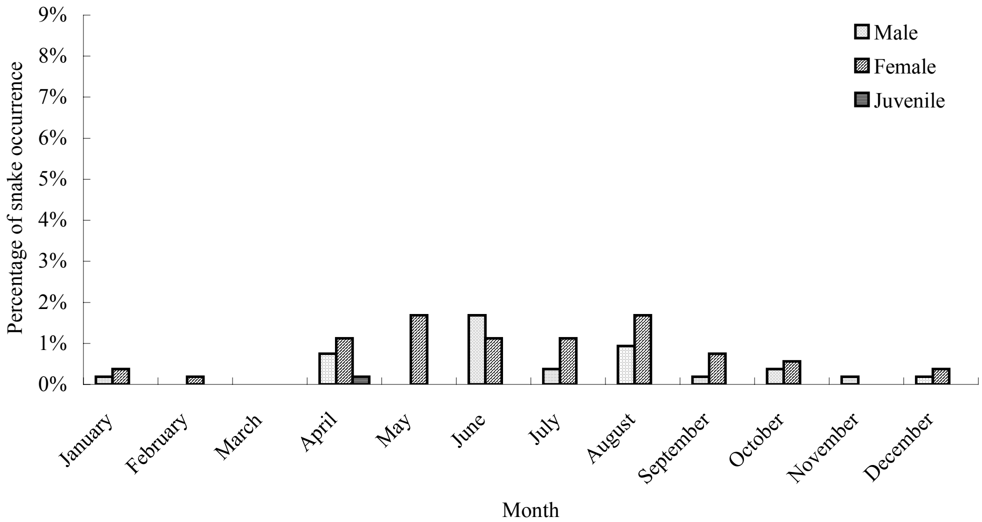

Fig. 4.6-6: Monthly dynamics of *Sinonatrix annularis* in a ditch habitat (November 1999-September 2001; n=75)

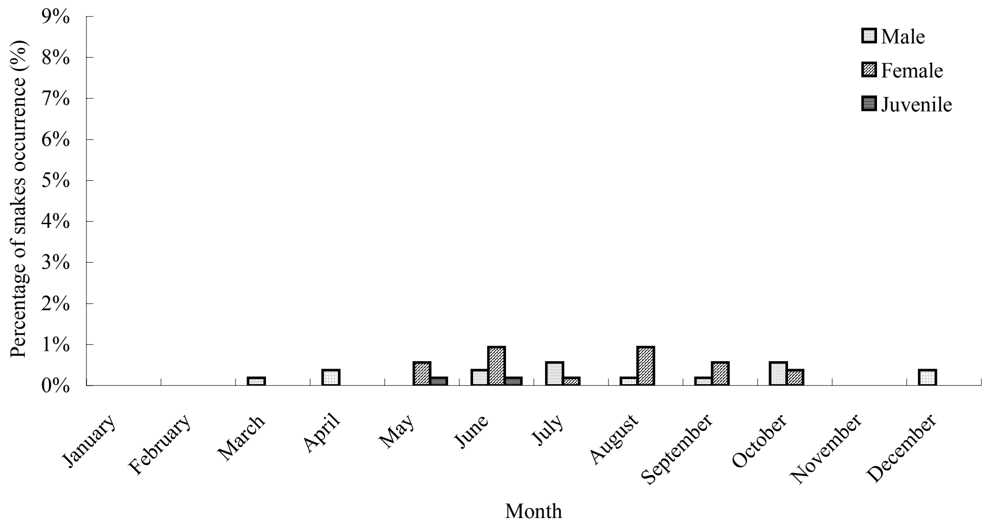

Fig. 4.6-7: Monthly dynamics of *Sinonatrix annularis* in a paddy field habitat (November 1999-September 2001; n=36)

Specific thermal requirements, in relation to vitellogenesis and pregnancy, probably explains the differences in basking behavior that reproductive females exhibit since they often require more specific thermal conditions to provide optimal temperatures for the development of follicles and embryos than non-gravid females (BONNET AND NAULLEAU, 1996). But, trapping localities of gravid *S. annularis* females are unavailable, so no particular affinity on microhabitat and cover ratio can be presented.

MAO (1965) mentioned that *S. percarinata suriki* was often seen in shallow water habitats that were not overgrown by vegetation. Compared to viviparous snakes, *S. percarinata suriki* more frequently occurs near the surface of relative higher thermal habitats, creek and ditch. Higher thermal intake may also reflective on its reproductive mode— oviparous. Two most ecologically similar species do not appear to be in competition for thermal niche space (MUSHINSKY ET AL., 1980) and this may offer one explanation for the microhabitat utilization divergence of *Sinonatrix* in Taiwan. Similar situations were also noticed in *N. natrix* and *N. maura*, studied by HAILEY AND DAVIES (1986), and this situation was stated as follows; both largely avoid competition by using different prey, and activity time and space give further separation.

Intra-species habitat utilization differences may be correlated to sex (SHINE, 1986), prey (CHANDLER AND TOLSON, 1990) and thermal requirements. MAO (1965) stated that *S. percarinata suriki* occur in rapidly flowing mountain streams, elevations from 100-560 meters high, and usually swarmed in open creeks that were not shaded by the forest. In our observations, without a doubt, *S. percarinata suriki* is a gregarious semi-aquatic snake, but the habitat preference is not only restrict to streams. Some populations were discovered in ponds or lakes, some at altitudes of approximately 1,200 meters, in mountainous areas in Taiwan. Usually, the individuals that occur in peaceful aquatic environments have large sizes, with a heavy body, and tended to be females. Differences in head size relative to body length may reflect sex-specific adaptations to reflect divergence in dietary composition or foraging habitats (SHINE, 1986; SHINE, 1993; SHINE ET AL, 1996). By comparing intra-species size differences and microhabitat utilization, *S. percarinata suriki* appeared to exhibit some microhabitat dimorphism and is supposedly correlated to body size (Fig. 4.6-8; Fig. 4.6-9; Fig. 4.6-10). Large female body size allows higher fecundity and can be attributed to sexual selection or natural selection (SHINE, 1986). In our observations, males appeared to be more dominant in fast flowing habitats (e.g. creek), while females, especially larger females, were more frequently encountered in slow flowing aquatic environments like paddy fields, ponds or lakes around Taiwan. It may be due to water-flow resistance of the female's heavy body and is reflected in the microhabitat utilization difference and may be attributed to a kind of natural selection. In addition, juveniles only appeared in creeks and ditches, which may indicate some minor physiological or anti-predation requirements. We suppose that may be due to the permutation of a white background and black blotches on the ventral sides of this animal, which could confuse predators when juveniles are active in the middle of the flowing creek or near the stream surface.

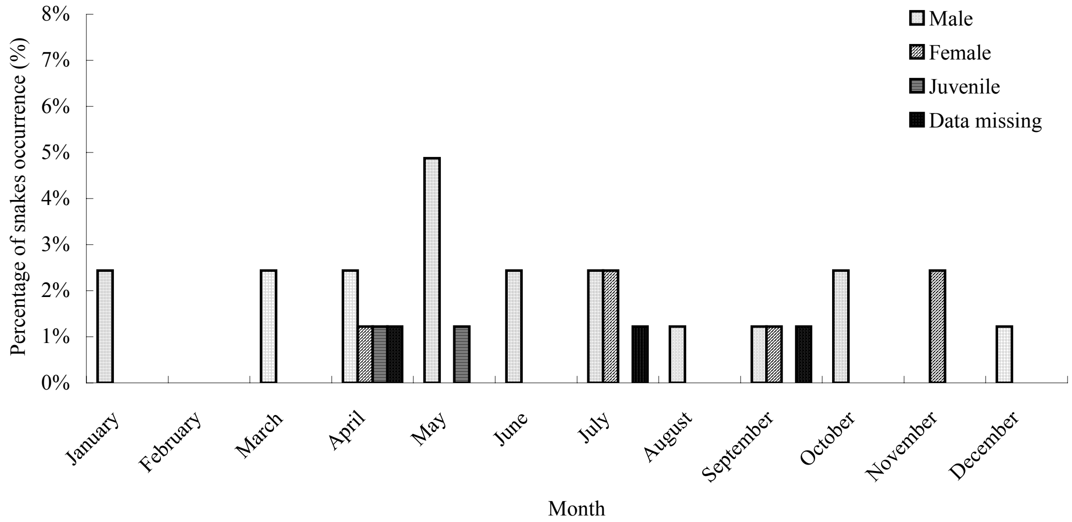

Fig. 4.6-8: Monthly dynamics of *Sinonatrix percarinata suriki* in a creek habitat (November 1999-September 2001; n=30)

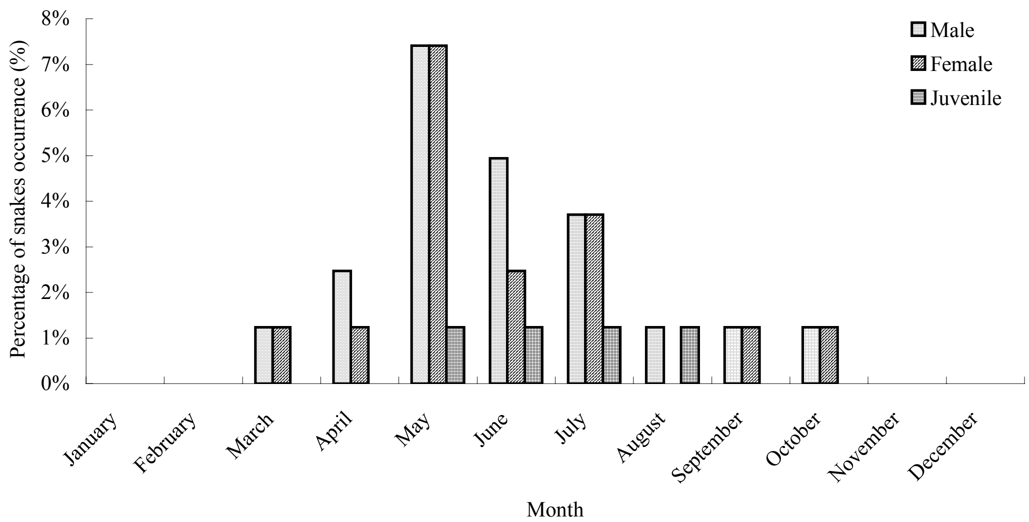

Fig. 4.6-9: Monthly dynamics of *Sinonatrix percarinata suriki* in a ditch habitat (November 1999-September 2001; n=38)

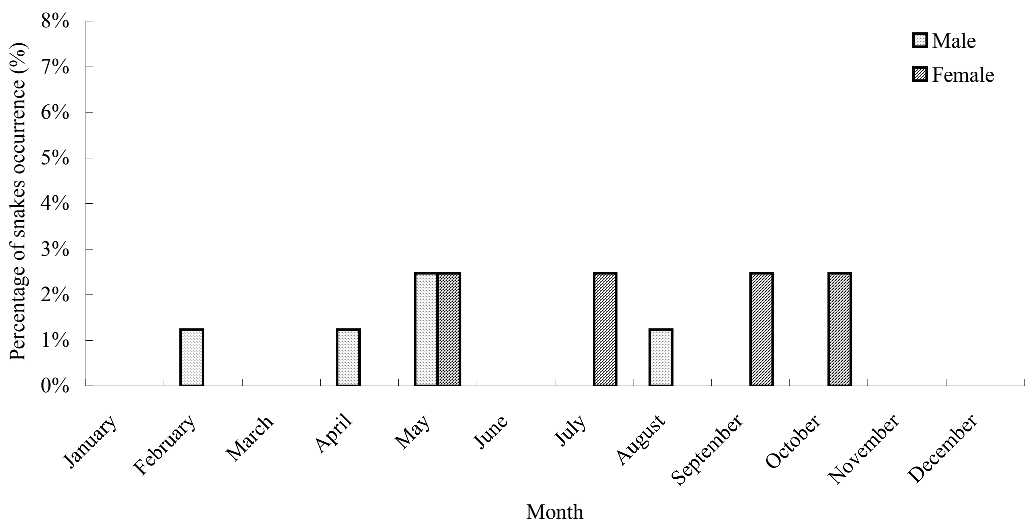

Fig. 4.6-10: Monthly dynamics of *Sinonatrix percarinata suriki* in a paddy field habitat (November 1999-September 2001; n=13)

Different morphological adaptations to microhabitat divergence may be another explanation to be considered for the locality differences of *Sinonatrix* snakes in the Chutzuhu swamp. Some interspecies differentiation within the two sympatric

Sinonatrix snake species, can be observed in the proportion of tail-length to total body length (Tab. 4.6-1), but it is only slightly distinct between both genders of con-specific population (Fig. 4.6-11).

Tab. 4.6-1: Differentiation on Tail-L/TBL and SVL of sympatric *Sinonatrix* snakes in Chutzuhu swamp

Gender \ Species		***Sinonatris annularis*** **(mean±SD)**	***Sinonatrix percarinata suriki*** **(mean±SD)**
Male	**SVL (cm)**	**44.84 ± 8.57**	**50.08 ± 7.53**
	Tail-L/TBL	**0.196 ± 0.010**	**0.249 ± 0.009**
Female	**SVL (cm)**	**52.56 ± 10.86**	**53.04 ± 14.88**
	Tail-L/TBL	**0.186 ± 0.012**	**0.241 ± 0.014**

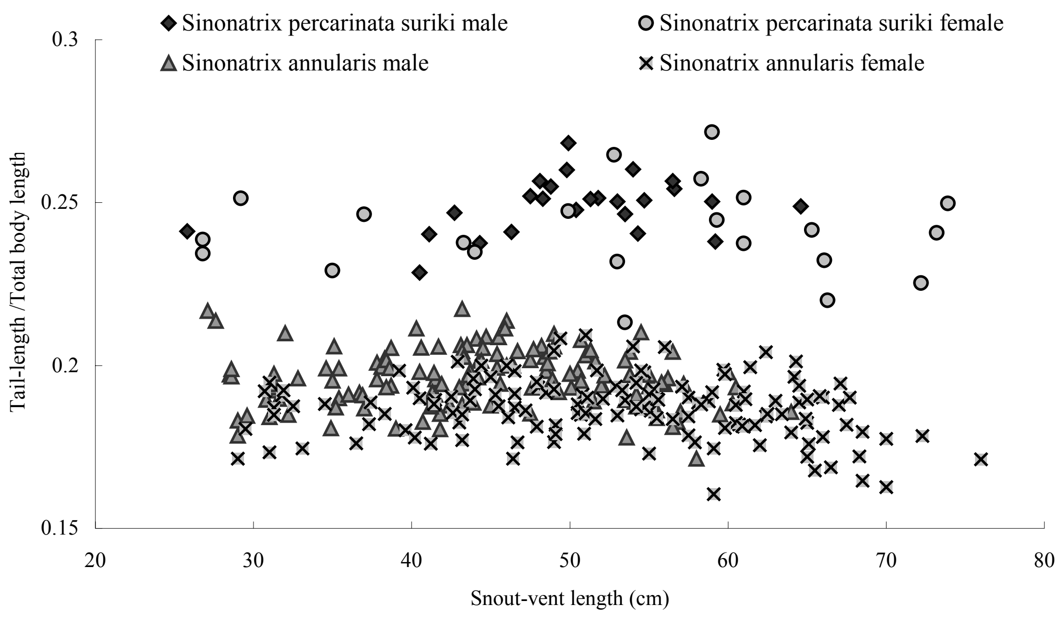

Fig. 4.6-11: Differentiation on proportion of tail length and total body length to snout-vent length between two genders of *Sinonatrix* snakes in Chutzuhu swamp

Head shape seems to be another consideration, *S. annularis* possesses a rounder and relativity shorter snout than *S. percarinata suriki*, whose snout is narrow and elongated. In our observations, semi-aquatic snakes that had a round and short snout usually preferred to live near the bottom of the water-body. On the contrary, the semi-aquatic snake species that possesses narrow and elongated snouts are usually active near the surface of fast flowing streams. MALNATE (1960) realized that two types of *Natrix* appeared to have developed in response to environmental differences. The first one was a heavy-bodied snake with a deep, narrow, relatively pointed head and was a denizen of semi-aquatic habitats. The second type was a terrestrial or forest-living snake, which had a more slender form, with a flattened head, a more truncate snout and lateral nostrils. But in our observations that semi-aquatic habitat species also displayed a head and snout shape divergence, which may be related to different water levels utilized. Surface semi-aquatic species (e.g. *Natrix tessellata* and *S. percarinata suriki*), have a narrow and elongated snout, with relatively longer tails and inhabit the medium to high-speed aquatic environments. Bottom semi-aquatic species (e.g. *N. maura* and *S. annularis*) possesses a shorter and rounder snout, with a slightly compressed body shape and relatively short tail for. Both adaptive types are direct responses to microhabitat and semi-aquatic environment utilization difference and are without strong genetic or phylogeny correlations. In addition, head size is also influential in several aspects of reptile life, sexual dimorphism (SHINE, 1986; SHINE, 1993), growth rate, survival (FORSMAN, 1994), and reproduction succession (BULL AND PAMULA, 1996). Swallow capacity of a snake's head has been shown to vary among species, populations and sexes and may depend on dietary items and sizes (FORSMAN, 1994).

The differentiations may also be due to the different foraging strategies of the two sympatric *Sinonatrix* snakes. In 1978, Regal assumed that foraging techniques appear to be associated with some important ecological and morphological characters, from the length of the tail to learning behavior (ANANJEVA AND TSELLARIUS, 1986). According to stomach contents analysis of in study, more than ninety-eight percent of the food items of *S. annularis* were loaches and snakehead fish. Both fish species are active near the bottom of the water body and are usually inactive, halting periodically, on the bottom of paddy fields or marshlands. Besides, based on the microhabitat and cover ratio analysis, the preferred habitats of *S. annularis* are average to high cover ratio marshland, and may offer an excellent opportunity for sit and wait predators. Dietary analysis of *S. percarinata suriki* showed the non-specific tendency of this species, fifty percent frogs and fifty percent fishes. The microhabitat analysis indicated that *S. percarinata suriki* prefer open aquatic environments, like creeks, ditches and paddy fields, moreover, movement analysis showed that this snake possesses a greater mobility ability, which appears to be the characteristics of an active predator.

The body color may be another factor, *S. annularis* is less conspicuous close to the muddy background of marshlands, while the gray body color of *S. percarinata suriki* camouflages them well among the rocks of the creek. According to CAMIN AND EHRLICH (1958), natural selection forces had an influence on the body color of *Natrix sipedon* (=*Nerodia sipedon*) in the Western end of Lake Erie. Some of the color differences between the two genders may partially be due to adaptations for thermal reflectance to facilitate the maintenance of high and relatively constant body temperatures (SHINE, 1993). It can also be seen in some close consanguinity sympatric snakes.

4.7. Population condition succession of *Sinonatrix* snakes

High mortality probability (34%-50%) during hibernation in three snake species was reported by HIRTH (1966). Annual dynamics of body condition in *S. annularis*, lowest in January and February, indicated fat consumption during the winter and might indicate possible mortality in low body condition individual during these periods of stress.

The correlation analysis between habitat type and snake body condition index (BCI) might indicate the following facts: 1) snakes with a good body condition occupied larger home ranges or were capable of extended movements; 2) anti-predation ability may be correlate to body condition; 3) individuals with a lower conditions may conserve their stored fat by reduced movement and avoiding exposure in open habitats until the next feeding.

Several sources indicated that human activities tended to have negative impacts on the life of snakes (BONNET ET AL., 1999). Contrary to that, this study illustrated that when humans disturbed and manipulated this swamp, they created an environment that was capable of maintaining a higher relative abundance snake population in Winter 1997 (CP= 2.41%) and Autumn 1998 (CP= 5.36%), but when human activities ceased, the capture probability decreasing to 2.75% in November 1999 to September 2001. This situation is due to the human activities that maintain the marshland environment and delays vegetation succession ratio in the swamp. It may also be the reason why the *Sinonatrix* snake populations were so abundant in the Chutzuhu swamp.

During the first stage of vegetation succession, some pioneer vegetation species invade the aquatic Calla lily farm, at that time the farm is still maintained as a marsh environment. Then, following several strong typhoons, the swamp habitat is drastically altered as follows: the heavy rains that accompany the typhoons cause extensive soil erosion in mountainous areas surrounding the swamp; then deposits the soils, rocks and silt in the basin. The swamp is thus filled in and since most farmlands have been abandoned or were transformed for the cultivation of terrestrial species, no one tries to clean up the damage cased by the typhoon or maintain the marshland environment. SEIGEL ET AL. (1998) pointed out that floods severely damaged snake habitats and could have reduced prey availability.

A series change reflects on the monthly relative abundance of *S. annularis* and different annual BCI values. The population condition of *S. annularis* neonates also decreased, with regards to annual body fitness. The mean body fitness and TBL in 1998 and 2000 were without observable differences, but in 2001 it tended to be lower. Larger neonates retained their size advantage for at least 12 months, but did not have a higher survival probability (LUISELLI ET AL., 1996). BALLINGER (1977) stated that highly fecund lizards might produce smaller clutches if resources were greatly reduced. Lower prey availability may reduce reproductive frequency in snakes and cause lower clutch sizes (SEIGEL ET AL., 1998). The longer neonates, TBL, and lower litter sizes might be an extreme environmental reproductive strategy to increase the survival rate of offspring, but insufficient energy storage in maternal females also decreases the body fitness of neonates (Fig. 4.7-1).

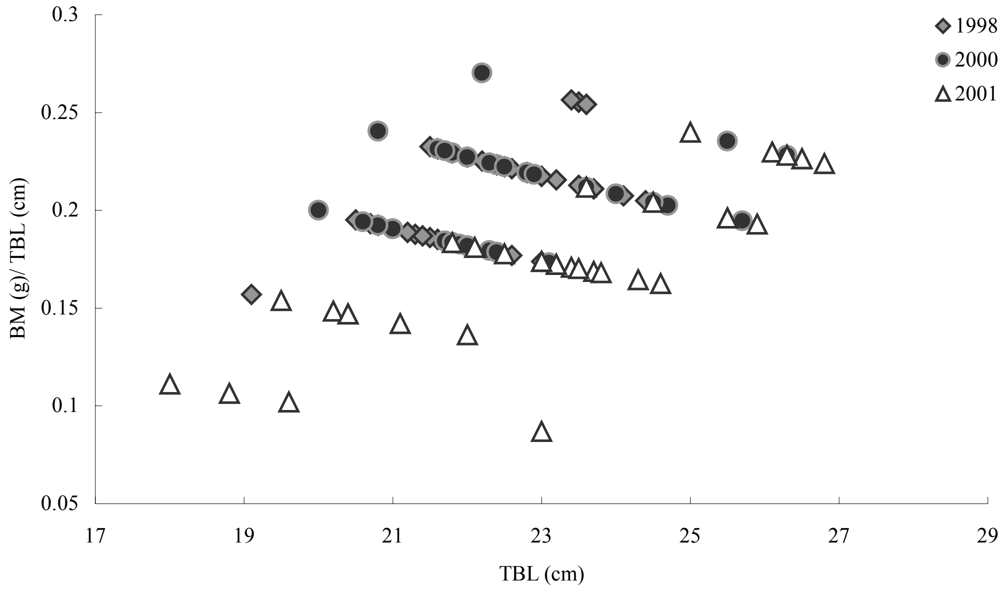

Fig. 4.7-1: Annual body-condition comparison of neonates of *Sinonatrix annularis* in the Chutzuhu swamp.

In April 2002, a dead *S. annularis* was found in the ditch in Chutzuhu swamp and since the body was still in an excellent condition it was sent for a pathological anatomization at the Division of Animal Medicine, Animal Technology Institute Taiwan. It was diagnosed with visceral gout, which was the cause of this snake's death. Visceral gout is a metabolic disease and has rarely been recorded in snakes from the Orient. This condition was likely due to excessive dehydration (LANCE AND LEUNG, 1974). Recently, the water resource shortage in Taiwan was continuously discussed and a reason for concern. It appears as a warning that we are losing the Chutzuhu swamp— a highland marsh eco-system.

Since 1992, a series of natural resource investigations have been executed by TESRI (Taiwan Endemic Species Research Institute) around Taiwan and more than 2/3 of the counties have been investigated, but up to date *S. annularis* have not been recorded in any of those areas. Therefore we have reason to believe that this population in the Chutzuhu swamp might be the last large *S. annularis* population in Taiwan. Except for water pollution, water resource shortage and habitat destruction; another potential factor, that may be causing the *S. annularis* population decline in Taiwan, and that should be considered, is global warming (The Green-house Effect). OTA (1991) studied the distribution ranges and patterns of *S. annularis* and *S. percarinata*, and compared to *S. percarinata*, *S. annularis* was found to occur in areas at slightly higher latitudes. *S. percarinata* appear to be distributed in more tropical regions, which might mean that *S. annularis* is more adapted for Temperate zones than *S. percarinata*. The last large population of *S. annularis* occurs and exists in the Chutzuhu swamp and this might not be a coincident. This area is the only area, in the whole of Taiwan that resembles a temperate climate swamp, at a low elevation. However, based on the present population condition of *S. annularis* in Taiwan, a conservation project should be put forth, focusing on *S. annularis* and its required habitat. Meanwhile, present population condition of *S. percarinata suriki* seems to be without immediately conservation requirements, but if water pollution and the impoundment of streams and creeks continue, this species' status may decrease to the point where conservation actions would be necessary, a problem that would become the responsibility of the government.

4.8. A presumable sequential change in semi-aquatic snake populations following environment succession in Chutzuhu

Based on four years practical field study and five years of observations on *Sinonatrix* snakes in Chutzuhu swamp, we have constructed a sequence model that most likely represents the series changes in the *S. annularis* population, following human activity and environment succession in the Chutzuhu area (Fig. 4.8-1, Fig. 4.8-2).

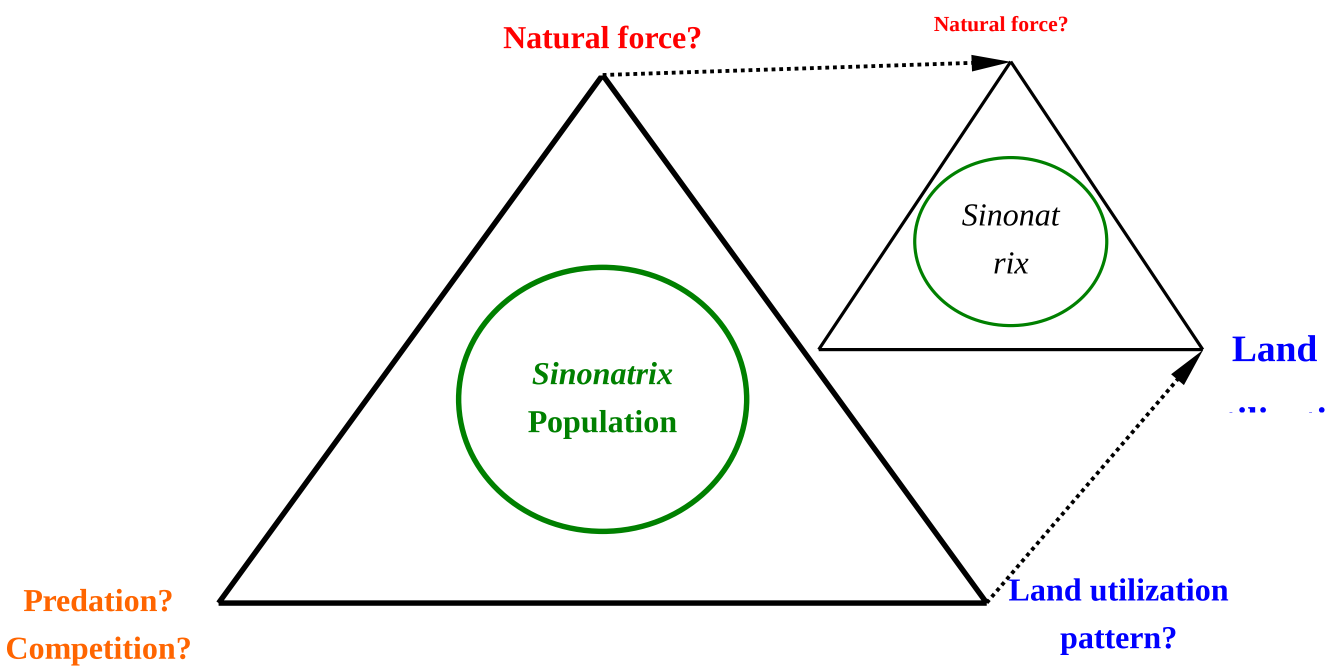

Fig. 4.8-1: The model of population succession of *Sinonatrix* snake in Chutzuhu swamp.

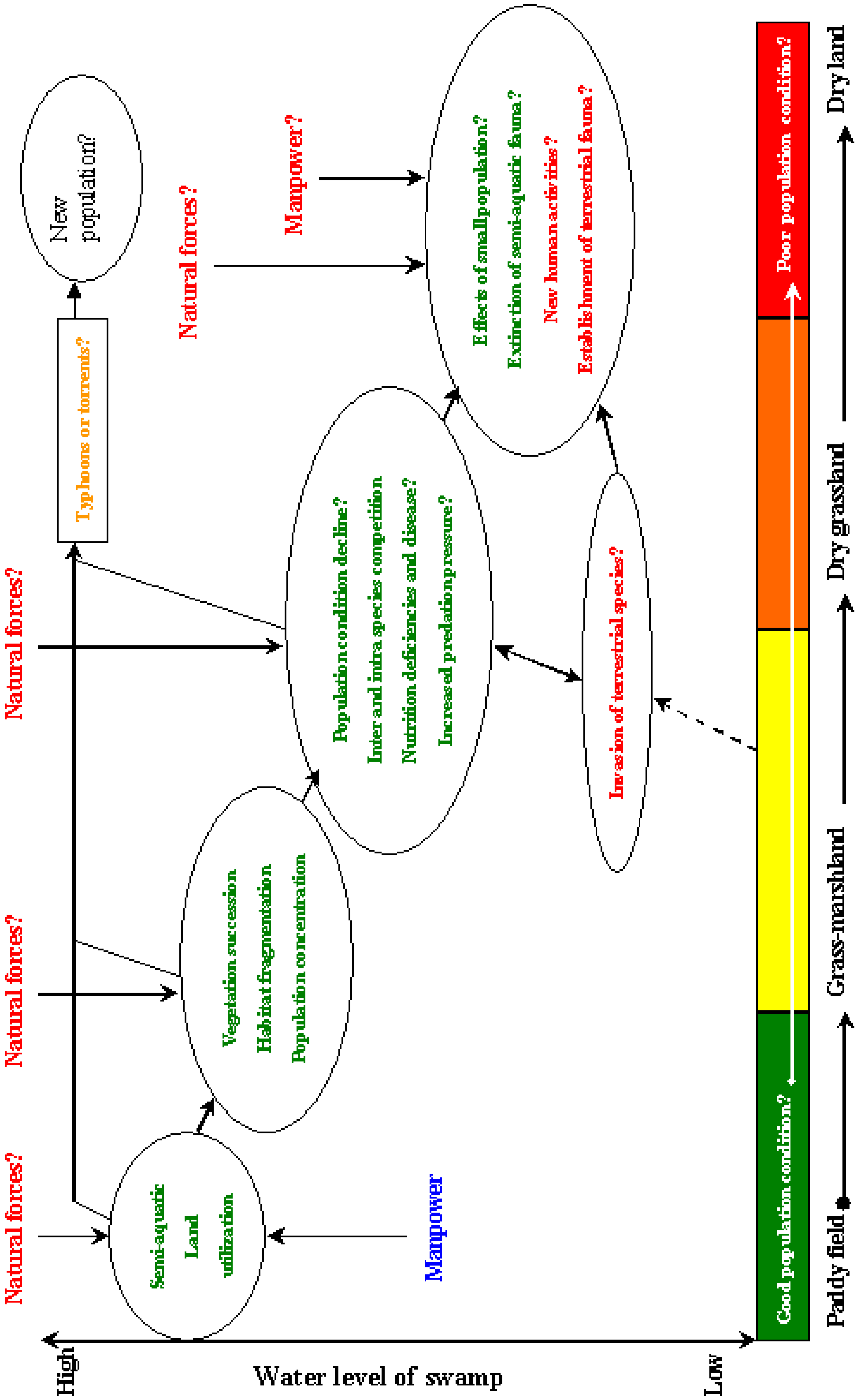

Fig. 4.8-2: Population and habitat succession series of semi-aquatic snakes *Sinonatrix annularis* in Chutzuhu swamp.

4.9. A conservation proposal for *Sinonatrix annularis*

Water tends to be the key factor and correlates with the life of the Chutzuhu swamp. All *Sinonatrix* snakes live in are dependant on water, for food supply, movement, reproduction, anti-predator response etc. In the past, farmers utilized this swamp and manipulated the water level, and at the same time also regulated the life of the wetland. Even though *S. annularis* were occasionally injured and sometimes killed by farmers as they constructed paddy fields and cut the grass, the negative impact of the farmers on the population was minute, on the contrary they ensured a complete wetland ecosystem that the snakes require, irrespective of environmental fluctuations. Following the influx of tourists and other visitors to the area for recreational purposes, the pressure on the area has increased. The roads and other infrastructure that have been developed cause extensive disturbances in the mountainous areas, which in turn cause serious soil erosion. Every time a typhoon hits the area huge amounts of soil, silt and rocks are deposited in the Chutzuhu swamp, reducing the life of the wetland.

Snakes are not popular animals in Taiwan, therefore the suggested conservation proposal focuses more on the habitat, landscape and wetland ecosystem. This way, a variety of species will benefit from the actions. To achieve this the conservation strategy should consist of and focus on several facets, water resource, land utilization patterns, an established *S. annularis* population monitoring system and recreation management.

4.9.1 Water resource

There is no doubt about the importance of water for the life of the Chutzuhu swamp. The water level should be maintained and regulated, the soil and other debris deposited by typhoons should be evaluated and decisions should be made about its removal. Any clearing and removal operations should only make use of manpower, not heavy machinery, to reduce the destruction of the remaining habitats and to minimize the possibility of injuring the snakes and other organisms that inhabit the area. In addition to that, the construction of a small dam should be considered for the manipulation and regulation of the water level of the whole swamp.

4.9.2 Land utilization pattern

The utilization of the area for paddy field farming has existed for more than 100 years. Even though this area belongs to Yangmingshan National Park, all the farmlands, located in the Chutzuhu area, belong to private individuals. Recently, the Calla lily has become a symbol of the Chutzuhu area due to introductions made by tour guides and television advertisements. Unfortunately, due to unknown reasons, the semi-aquatic Calla lily are suffering from blight and some farmers have changed their areas for the cultivation of terrestrial Calla lilies, which contributed to the rapid reduction of paddy fields. We had some brief interviews with some of the local farmers, about the semi-aquatic Calla lily and a comparison with the terrestrial one. Most farmers told me they prefer the semi-aquatic species due to the good flower quality, high productivity and ease of management. If we can resolve the semi-aquatic Calla lily blight problem, we most likely would also regain the paddy field landscape in the Chutzuhu swamp.

4.9.3 Monitoring system for *Sinonatrix annularis* and genetic evaluation

During the four years we studied S. annularis in the Chutzuhu swamp, we established a database for this species as well as for the fauna, flora, mark-and-recapture history of each individual, image data and ecological data (e.g. BCI, reproductive etc.). All future monitoring steps should follow the former procedures, and food resource dynamics should be incorporated into the future monitoring plan. Population genetic data should also be established and constantly monitored.

4.9.4 Recreation management

Some development and recreation proposals have been proposed (LIN ET AL., 1997), but most of them focus on recreation agriculture, farmlands, and restaurants. All of the above proposals may damage the Chutzuhu swamp ecosystem due to a huge influx of tourists and visitors, who would produce more water pollution, noise pollution and disturbance than the environment can carry. Recreation activities and patterns in Chutzuhu area should be reorganized and it would be better if it is limited to, and controlled by, Yangmingshan National Park.

4.10. Introduction and application of scanner methods in snake population studies

In 1946, Calström and Edelstam first described reptiles' natural markings. This finding was applied, and limited to only a few species, because earlier methods were based on color pattern permutation. However, "a snake's fingerprinting" digital system was developed by HAILEY AND DAVIES in 1985, and was based on the natural ventral scale markings of *N. maura*, that were photographed and combined with blotch patterns. Since then, MERTENS (1995) found that xerographic copies of *N. natrix* juveniles could be used for individual recognition. Nevertheless in our experience, photographs are some times ineffective in producing an accurate image of the snake's ventral pattern instantly, especially, when the individual is small. Although xerographic copies can improve this problem, the drawback is that this method is impossible to apply in the field, and is often difficult to use when counting ventral scales, and the monotone image is of little use in visual data preservation.

Measurements of snakes was discussed by FITCH (1987), and it was stated that stretching the snake to its full length for a SVL (=snout-vent length) measurement may damage delicate muscles and cause stunted growth and set back several weeks in their growth. In fact, it also happened in our *Sinonatrix* snakes study. To minimize risk and damage to man and snakes, to anesthetize the snakes appear to be a good choice for obtaining exact measurements, but it takes more time and there is always the danger of overdosing the animal. MATTISON (1995) illustrated an easy way of measuring snakes in his book, simply referred to as a squeezing box. It seems to be a good idea for the measurement of snakes and is widely applied on snake measurements in America. But can only be used for body length measurements. To eliminate or improve the disadvantages of previously stated morphological data collection methods, we developed a new way, which can offer good quality, safe, convenient and instant results of ventral characters of snakes, that can be utilized in dimension data accumulation.

A scanner is a computer image-input device, which is widely applied for photo-image editing, data transfer etc. In all the publications we reviewed, there are no references to indicate that scanners have been used in live reptile morphological studies. In 1999, due to our requirement for establishing a *Sinonatrix* snakes population morphological character database we used a modified scanner to accumulate partial morphological data of both *Sinonatrix annularis* and *Sinonatrix percarinata suriki*.

The practical application scanner is a Hewlett Packard (HP) Scan Jet 3300C. The maximum image analytical is 600 dpi (=dot per inch). For the smooth scanning of snakes on the scanner, we designed an A4 sized labyrinth (L x W x H =30.3 x 22.3 x 5 cm) to keep the snake's body completely extended. To prevent the snakes from moving, which will affect the scanning quality, the labyrinth contains a plastic cover, which has several lines of sponge that will prevent the snake from moving while the cover is being pressed down. All the image data were saved as "tiff" or "bmp" files and preserved in storage media such as USB flash drive, MO, CD or Zip disk. In practical applications, we have tested eight species of snakes, *Enhydris chinensis*, *E. plumbea*, *Pseudoxenodon s. stejnegeri*, *Rhabdophis tigrinus formosanus*, *S. annularis*, *S. percarinata suriki*, *Trimeresurus gracilis* and *Xenochrophis piscator*, in a laboratory and in the field without any problems.

The image quality of your snakes depends on your requirement. For instantce, a newborn *Sinonatrix annularis* may require a 600 dpi to produce an image on which each subcaudal can easily be counted. On the other hand a mature individual probability requires only 150 dpi to produce a satisfactory result. Three dimensions of length are available, which includes body length, snout-vent length and tail length. Arc View GIS 3.1 software can be utilized for calculating the dimensions of snakes on the screen or a proportional divider can be used measurements when the image is printed out.

Most ventral characters can be counted directly on the computer screen. Unclear or small characters can also be counted because the image can be enlarged. At least six available snake ventral characters can be clearly scanned from live snakes specimens and directly counted on the computer monitor. They are, ventrals, subcaudals, gulars, chin-shields, anal plate and fingerprinting patterns of ventral scales. We are trying to develop a computer program that will automatically do scale counts and individual fingerprinting recognition for future applications.

The only limitation in the application of this method is the size of the scanner, so this method can only be applied on small to medium sized snakes. Until now, there are only two scanner formats commercially available, A4 and A3. In other words, the length and body proportion of the snakes must be less than 150 cm or the body must be slander.

In our practical field tests, the adaptability of this method with notebook PC for fieldwork worked without any serious problems, the only consideration is climate. High humidity and rain may cause serious damage to the computer and scanner. A resolution of this limitation is a mobile platform, carried by or in a vehicle. Anyway, a scanner is an economical choice in present conditions and a resolution for efficient morphological data collection because it standardizes the whole image collect procedure.

Scanner methods for the population study of *Sinonatrix* snakes were practically executed for more than two years. Recently we started to focus on the other three semi-aquatic species in a pond and paddy habitat in northern Taiwan. All the hardware of this method was developed well, and at present, we can carry the whole system in a medium sized suitcase and continue to process morphological data accumulating for several hours with only notebook's battery as the power source.

The basic hardware requirements are as follows: a notebook PC, fitted with two or more USB ports; a scanner (600 dpi or more) with a CCD lens; power supply and data transfer by USB interface; an extra data storage media; a backup notebook battery and a labyrinth squeezing box. The basic software requirement must include an image acquisition and photo edit software, but due to the variety of available this will depend on the requirements of the user so it is not listed herein.

4.11. Preliminary proposed and standardized system for the establishment of fundamental snake population databases (FSPD)

A proposal for fundamental snake population databases (FSPD) focuses on long-term snake ecological studies and population monitoring. According to the criteria for the future population research of PARKER AND PLUMMER (1987), there are five selections for further studies; population density, geographic distribution and phylogeny, convergent species, late-maturing species and island populations. All of the above studies may require an efficient and standardized procedure for fundamental data accumulation and database establishment, especially for poorly known and rare or protect species. With regards to molecular aspects, how to collected sufficient snake DNA samples for phylogenetic analysis may become a key factor. Focusing on morphology, how to obtain enough data for species, subspecies and different population comparisons may become a challenge. In ecology, how to get accurate data, with minimum disturbance, is often an arduous problem. For long-term ecology studies and monitoring, a standard data accumulation procedure and methods can extend the data application and comparison. Due to former reasons, we would like to compile an efficient component and low sacrifice study procedure for FSPD and suggest its establishment.

The proposals of our fundamental population data accumulation are based on three facets, morphological, ecological and molecular. Morphological data focuses on weight and length measurements and surface structures, for example scale numbers. There are two methods applied in live snake morphological data collection; the scanner method (see Discussion 4.10) can collect measurement sources and most ventral view characters; and a digital camera or video camera can record horizontal and dorsal scale characters. Therefore, we would like to strongly suggest that the live individual image database be established by most Natural History Museums, which may replace and reduce the necessity for specimens collection, storage and management.

Marking and recapture is a well knows and widely applied method for demography (PLUMMER, 1985), life history (FITCH AND FLEET, 1970) and population ecology studies (KING, 1985). Three capture methods have been practically tested and compared by FITCH (1992) and live-trap and artificial shelters appear to be more efficient methods than random encounters. Marking protocols for snakes have been drawn up and reviewed by LANG (1992). The influences of some invasive marking techniques have also been tested and evaluated; PIT injection versus yearling snakes by KECK (1994). An improved surgical transmitter implantation was suggested by REINERT AND CUNDALL (1982) and with recovery determination by LUTTERSCHMIDT AND RAYBURN (1993). Snake invasion-marking procedures also offer a great opportunity for molecular sample accumulation. Non-invasion marking methods also can collect blood samples from veins that are located in the middle of the tail line or by ventral scale clipping.

Body condition index (BCI) applied for snake reproductive determination by BONNET AND NAULLEAU (1994) and extended with the application for population fitness determination in this study. Another population condition determinations propose for preliminary study stage is based on the proportion of BM/TBL, which has extensively been applied on rattlesnake population condition evaluations (SEIGEL ET

AL., 1998). A monitoring of population condition will evaluated by the average body condition index (BCI) and based on neonatal data of each population, and may also be applied for female reproductive condition examinations.

SEUTIN ET AL., (1990) described an efficient blood and tissue sample preservation method for avian DNA analysis and this method has been practically applied in some snake studies. Polymerase chain reaction (PCR) increases the possibility for analyzing low quantities of tissue material and samples. The whole system and FSPD procedure is as follows (Fig. 4.11-1):

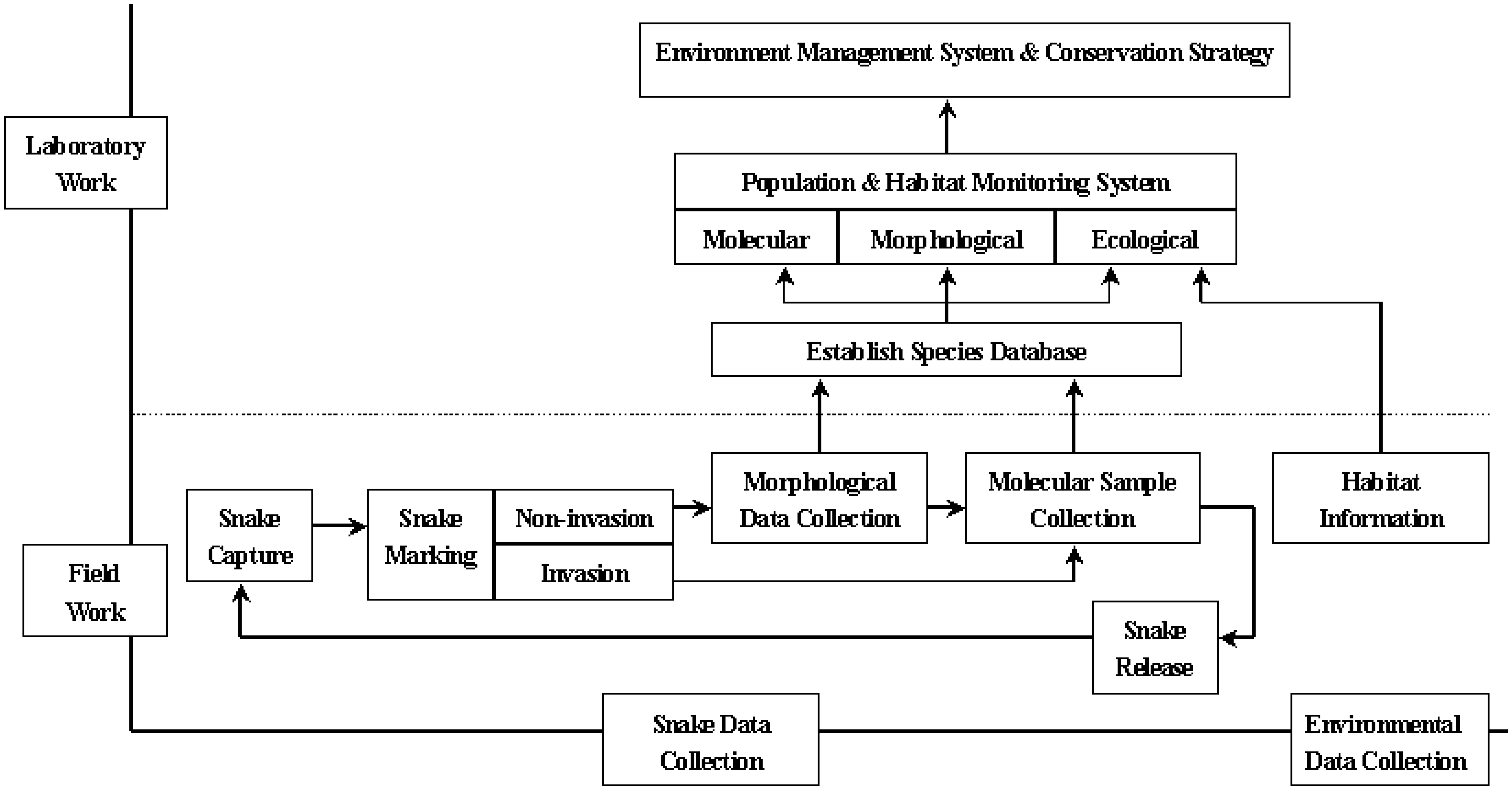

Fig. 4.11-1: The data collection procedure and systems of fundamental population database of snakes (FPDS).

Chapter 5. Conclusion

OTA (1991) analyzed the distribution patterns of endemic taxa in Taiwan and classified them into five closest biogeography distribution patterns, *Sinonatrix* snakes was sorted into group C, of which the closest relatives are in Fujien Province of China. Based on our specimen examination, reference and literature comparisons, and observations, there is no doubt about the fact that *S. annularis* and the northern population of *S. percarinata suriki* in Taiwan belong to group C. Southern Taiwan populations of *S. percarinata suriki*, though, seems closest related to individuals from Guandong Province of China or Vietnam (group D) and this hypothesis is supported by some phylogenetic studies that were conducted on freshwater fish. In these studies it was found that the phylogeny of some conspecific freshwater fish in northern Taiwan were most closely related to individuals from Fujien but individuals from southern Taiwan population were more closely related to Guandong or Vietnam. Except some reference to taxonomy, phylogeny and brief biological observations, the genus *Sinonatrix* is a snake species that is poorly understood and has seldom been thoroughly studied, compared to its sister group genera *Natrix* and *Nerodia*.

The average population numbers of the two *Sinonatrix* snakes is, *S. annularis* is 998 snakes and *S. percarinata suriki* is 129. Irrespective of captures probability or capture snake-times *S. annularis* is absolutely the predominant species in the Chutzuhu swamp. Seasonal dynamics of both sympatric *Sinonatrix* shows an unimodal, in which courtship and mating occur primarily in May and breeding also frequently occur in September. *S. annularis* is the only viviparous snake of all the Old World *Natrix* tribes, and *S. percarinata suriki* is an oviparous snake. *S. annularis* is active in all months of the year but the activity of *S. percarinata suriki* is more concentrated in April to November and these snakes may remain dormant for one or two months.

Movement of *S. annularis* represents a restricted home range and short movement patterns, compared to *S. percarinata suriki*, which indicated great mobility and a linear distribution. Gravid *S. annularis* females are more restricted in movement than males and non-gravid females and are supposedly because of possible predation that may occur on the low mobility gravid females.

The sex ratio of the two *Sinonatrix* snakes is toward to an equal value, but monthly sex ratios revealed that male numbers are higher in spring to early summer, while female are more dominant in late summer to winter. Growth rates were no different in interval neonates to yearlings in both sexes, after they became yearlings females grew more rapidly than males. If without predation and food shortage, males become sexually mature after three years, and female take four years. Ambient temperature tends to be a priority factor in snake growth and the second is food intake.

Reproductive characteristics of *S. annularis* snakes in Taiwan are quite distinct compared to literature based on populations from Mainland China (POPE, 1935; HE, 1983), represented in maturity size, size distribution and litter size. Courtship and mating behavior is similar to that of *Natrix natrix* in Europe and also forms mating balls (LUISELLI, 1996). We presume that the reproductive frequency of *S. annularis* is biennially to triennially and *S. percarinata suriki* perhaps annually. The average litter size in *S. annularis* is 8.19, the litter size positively correlated with maternal SVL size. Offspring condition of *S. annularis* was found to be regressing rapidly in 2001 and may indicate that the Chutzuhu swamp is changing.

PARKER AND PLUMMER (1987) classified three groups of snake species based on characteristics of growth patterns as described by Feaver (1977). The growth pattern of *S. annularis* appears to fit group 3, male grow up slower than females in post maturity growth; females attain a larger body size; males engage in combat behavior; fecundity related to female SVL approximate 5.4 eggs/ 10cm female SVL; late maturity; and high adult survivorship.

Dietary composition is distinct in the two sympatric snakes, *S. annularis* feeds mainly on fish (98%) and frogs (2%); *S. percarinata suriki* feeds on fish (50%) and frogs (50%). Dietary differences may be related to foraging strategy, the *S. percarinata suriki* is a wide foraging species and we presume that *S. annularis* is sit and wait predator.

Microhabitat utilization in *S. annularis* is more concentrated in medium to high cover ratio marshland than any other habitats. *S. percarinata suriki* prefers more low cover ratio creeks and ditches. The microhabitat utilization divergent, observed in these two species, may be due to the following differentiations, 1) thermal requirement differences; 2) different morphological adaptations for distinct microhabitats; and 3) different foraging strategies reflected on habitat utilization differences.

Thermal requirement differences tend to be the strongest explanation and reflect on the different reproductive modes of the two *Sinonatrix* snakes. Cold climate hypothesis is an alternative explanation in viviparous snakes and indicates that *S. annularis* may be relative to low thermal requirements compared to the sympatric oviparous snake *S. percarinata suriki*. Water temperature in the four principal habitats were measured and are reported here from lowest to highest, marshland, ditch, paddy field and creek.

Different morphological adaptations to aquatic environment may be correlated to head shape, relative tail length (Tail-L/TBL) and body color. Head shape is determined by water-flow resistance and prey intake, round and relative short snouted snakes may have an advantage in low speed aquatic environments and during bottom activity and foraging (e.g. *S. annularis*), whereas species with a more pointed and elongated head (e.g. *S. percarinata suriki*) is more suited for fast flowing streams and feeding and activity near the surface.

Foraging strategy is another consideration in the two sympatric *Sinonatrix* species and also a minor determent of dietary composition, body shape and mobility. We suppose that *S. annularis* is a sit and wait predator due to microhabitat selection, restricted home range and relative short and slightly compressed body shape. There is no doubt that *S. percarinata suriki* is a wide foraging predator due to its great mobility, relatively varied food composition, relatively slender body with long tail and frequent occurrence in open aquatic environments.

In overview, microhabitat utilization represents sexual dimorphism situations in *S. percarinata suriki*. Male snakes are more active in medium to fast water-flow habitats (e.g. stream, creek and ditch), but females are more dormant in peaceful aquatic environments (e.g. paddy field, pond and lake). Microhabitat dimorphism may be due to water resistance and different thermal requirements.

We observed a unique foraging behavior in the southern Taiwan population of *S. percarinata suriki* and suppose that that behavior relates to its body color divergence. In addition to that the breeding season of *S. percarinata suriki* in southern Taiwan is about in July to August, more or less a one-month shift compared to northern populations and may be correlated to different climate regions (northern Taiwan is subtropical but southern Taiwan is tropical), and is also represented in juvenile sizes that were collected in the field.

Body condition index (BCI) represents the seasonal dynamics of *S. annularis* and showed a tendency, in which the population condition is in a constant decline. Population condition decline was also evident in the body fitness reduction of neonates and a case of a dehydration metabolic disease. The life of the Chutzuhu swamp is closely correlated to human utilization patterns, and is invaluable for the survival of *S. annularis*. A conservation strategy shall be formulated and will focus on the continued existence and conservation of the highland swamp eco-system.

We want to formulate a conservation proposal for *S. annularis* and the Chutzuhu swamp. There are four points that will be addressed in this proposal, the water resource; land utilization patterns; monitoring system for *S. annularis* and genetic evaluation; and recreation management. Water resource tends to be the soul of the whole conservation strategy and is related to the life of the entire Chutzuhu wetland ecosystem.

During the population study of the *Sinonatrix* snakes in Chutzuhu, we also developed an efficient method and practical application of this method in this study as of from November 1999. We are quite convinced that this is a non-damaging method to snakes for the collection of morphological data. It has been practically used in the laboratory and the field for five species population studies in Taiwan, *S. annularis*, *S. percarinata suriki*, *Enhydris chinensis*, *E. plumbea* and *Xenochrophis piscator*, and brief tests on three species, *Pseudoxenodon s. stejnegeri*, *Rhabdophis tigrinus formosanus* and *Trimeresurus gracilis*. Without a doubt it is a new technique that is harmless and suitable for long-term snake population and conservation projects.

According to some experiences gained in this study, the development of a new technique, population and conservation requirements, we would like to propose to establish a standardized procedure for collecting and accumulating fundamental population data for snake databases (FSPD). This system contains three sub-subjects, morphological data, molecular data and ecological data. Morphological data collections are base on our new technique, combined with digital imaging acquiring media. The data can be applied in taxonomy, phylogeny and ecology studies. Molecular resources collected from snake invasion marking, tail-vein blood sampling or scale clipping, combined with PCR methods to duplicate certain DNA fragments for phylogeny and to evaluate the quality of genetic conditions of snake populations. Ecological data collection is mainly based on marking and recapture procedures combined with body condition indexes for long-term monitoring of snake population changes and to offer suitable management suggestions or conservation strategies.

Chapter 6. Literature

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Chapter 7. Appendix

7.1 Flora and checklist of Chutzuhu swamp

Species
Dicotyledon
Justicia procumbens L.
Alternanthera philoxeroides (Moq.) Griseb.
Impatiens walleriana Hook. f.
Anredera scandens Moq.
Callitriche japonica Engelm. ex Hegelm.
Sambucus formosana Nakai
Cerastium ianthes Will.
Drymaria cordata (L.) Willd. subsp. *diandra* (Blume) I. Duke ex Hatusima
Stellaria alsine Grimm. var. *undulata* (Thunb.) Ohwi
Chenopodium ambrosioides L.
Adenostemma lavenia (L.) Ktze. var. *parviflorum* (Blume) Hochreut.
Ageratum houstonianum Mill.
Artemisia princeps Pamp. var. *orientalis* (Pamp.) Hara
* *Cirsium japonicum* DC. var. australe Kitam.
* *Conyza canadensis* (L.) Cronq. var. canadensis
* *Pluchea sagittalis* (Lam.) Cabera
* *Bidens chilensis* DC.
* *Bidens tripartita* L.
Crassocephalum rabens (Juss. ex Jacq.) S. Moore
Dichrocephala bicolor (Roth) Schlechtendal
Eclipta prostrata L.
Emilia sonchifolia (L.) DC.
Erigeron sumatrensis Retz.
Gnaphalium affine D. Don
Ixeris laevigata (Blume) Schultz-Bip. ex Maxim. var.
oldhami (Maxim.) Kitamura
Soliva anthemifolia R. Br.
Sonchus arvensis L.
Cardamine flexuosa With.
Mallotus japonicus (Thunb.) Muell.-Arg.

Hypericum japonicum Thunb. ex Murray
Clinopodium umbrosum (Bieb.) C. Koch
Melastoma candidum D. Don
Ludwigia octovalvis (Jacq.) Raven
Oxalis corniculata L.
Oxalis corymbosa DC.
Plantago asiatica L.
Polygonum chinense L.
Polygonum perfoliatum L.
Rumex japonicus Houtt.
Clematis gouriana Roxb.
Ranunculus sieboldii Miq.
Prunus campanulata Maxim.
Rubus corchorifolius L. f.
* *Rubus sumatranus* Miq.
* *Rubus parvifolius* L.
Rubus croceacanthus Levl.
Paederia scandens (Lour.) Merr.
Datura suaveolens Hamb. & Bonpl. ex Willd.
Solanum nigrum L.
Centella asiatica (L.) Urban
Oenanthe javanica (Blume) DC.
Boehmeria densiflora Hook. & Am.
Boehmeria frutescens Thunb.
* *Oreocnide pedunculata* (Shirai) Masam
Gonostegia hirta (Blume) Miq.
Pilea microphylla (L.) Leibm.
* *Pilea peploides* (Gaudich.) Hook. & Arn. var. major Wedd. *Elatostema lineolatum* Wight var. majus Wedd
Clerodendrum cyrtophyllum Turcz.
Cayratia japonica (Thunb.) Gagnep.
* *Lonicera acuminata* Wall.
* *Machilus japonica* Sieb. & Zucc.
* *Hydrocotyle batrachium* Hance
* *Neanotis hirsuta* (L. f.) W. H. Lewis
* *Eurya leptophylla* Hayata
* *Begonia formosana* (Hayata) Masam.
* *Lindernia cirdufikua* (Colsm.) Merr.

* *Alternanthera philoxeroides* (Mart) Griseb.
* *Rhynchotechum discolor* (Maxim.) Burtt
* *Mazus miquelii* Makino
* *Viola arcuata* Blume

Monocotyledon

Sagittaria trifolia L.
Colocasia escutenta Schott
Zantedeschia aethiopica (L.) Spreng
Murdannia keisak (Hassk.) Hand.-Mazz.
Fimbristylis aestivalis (Retz.) Vahl.
Schoenoplectus mucronatus (L.) Palla subsp. *robustus* (Miq.)T. Koyama
Alopecurus aequalis Sobol. var. *amurensis* (Komar.) Ohwi
Cyrtococcum accrescens (Trin.) Stapf
Dactyloctenium aegyptium (L.) Beauv.
* *Bambusa multiplex* (Lour.) Raeusch
Dendrocalamus latiflorus Munro
Echinochloa crus-galli (L.) Beauv. var. *formosensis* Ohwi
Eleusine indica (L.) Gaertn.
Isachne debilis Rendle
Leersia hexandra Sw.
Miscanthus floridulus (Labill.) Warb. ex Schum. & Laut.
Panicum repens L.
Paspalum conjugatum Berg.
Paspalum distichum L.
Polypogon fugax Nees
Setaria palmifolia (Koen.) Stapf
Sinobambusa kunishii (Hayata) Nakai
Sphaerocaryum malaccense (Trin.) *Pilger*
Juncus effusus L. var. *decipiens* Buchen.
Juncus leschenaultii J. Gay ex Laharpe
Hedychium coronarium Koenig
* *Lemna aequinoctialis* Welw.
* *Eleocharis acicularia* (L.) Romer & Schultes

Pteridophyte

* *Cyathea lepifera* (J. Sm. ex Hook.) Copel.

***** *Dennstaedtia scabra* (Wall. ex Hook.) Moore
***** *Thelypteris beddomei* (Bak.) Ching
***** *Nephrolepis auriculata* (L.) Trimen
***** *Selaginella leptophylla* Bak
***** *Azolla pinnata* R. Brown
Microlepia speluncae (L.) Moore
Sphenomeris chusana (L.) Copel.
Lycopodium cernuum L.

***: Checklist was mainly based on Chang and Chen (1999), star indicated out of their list and recorded by our survey in 2001.**

7.2 Wildlife fauna and checklist of Chutzuhu swamp

	Species	Remark
Mammal		
	Paguma larvata taivana	p.-predator
	Rattus norvegicus	predator
	Mus caroli	p.-predator
	Crocidura attenuata tanakae	p.-predator
	Mogera insularis	p.-predator
Avian		
	Bubulcus ibis	p.-predator
	Egretta garzetta	p.-predator
	Spilornis cheela	p.-predator
	Urocissa caerulea	
Reptile		
	Amphiesma sauteri	
	Bungarus m. multicinctus	predator
	Dinodon r. rufonzonatum	predator
	Elaphe carinata	predator
	E. porphyracea nigrofasciata	
	E. taeniura friesei	
	Zaocys dhumnades.	predator
	Sibynophis chinensis chinensis	p.-predator
	Sinonatrix annularis	
	S. percarinata suriki	
	Trimeresurus stejnegeri	
	Ovophis monticola makazayazaya	
	Protobothrops mucrosquamatus	
	Naja atra,	predator
	Eumeces elegans	
	Japalura swinhonis	
	Japalura polygonata xanthostoma	
	Sphenomorphus indicus	
	Takydromus stejnegeri	
	Mauremys mutica	

Fish		
	Channa asiatica	prey (juvenile) and p.-predator
	Carassius auratus	prey
	Misgurnus anguillicaudatus	prey
	Monopterus albus	prey
	Zacco barbatus	Prey

p.-predator=potential-predator; Indicate that this species high probability to prey on *Sinonatrix* snakes but without any directly evidence.

Species	*Breeding season	Remark
Amphibian		
Bufo bankorensis	Sep.-Feb.	prey (tadpole), p.-predator
Hyla chinensis	Mar.-Jun.	prey
Microhyla ornate	Apr.-Aug.	prey
Rana guntheri	Apr.-Aug.	prey and p.-predator
Rana latouchii	Feb.-Nov.	prey
Rana l. limnochris	Apr.-Sep.	prey
Rana longicrus	Nov.-Feb.	prey
Rana rugulosa	Mar.-Aug.	prey (tadpole), p.-predator
Buergeria joponicus	Feb.-Sep.	prey
Buergeria robustus	Apr.-Sep.	prey (tadpole)
Chirixalus eiffingeri	Feb.-Sep.	
Chirixalus idiootocus	Feb.-Sep.	prey (tadpole)
Polypedates megacephalus	Apr.-Aug.	prey (tadpole)
Rhacophorus taipeianus	Nov.-Feb.	prey (tadpole)

*: Breeding season of amphibians based on Yan (1991) and indicated that occurrence month of tadpoles.

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English Publications (1998-2003)

Mao, J.-J., H.-P. Chu, U.-C. Chen and K.-C. Yeh. (2003): The first description of *Elaphe frenata* Gray, 1853 (Colubridae□Squamata), from Taiwan. Bulletin of the National Museum of Natural Science, in press.

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