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Growth, Maturity and Population Structure of the Bagrid Catfish, *Pseudobagrus ichikawai*, in the Tagiri River, Mie Prefecture, Japan

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Abstract A small population of the bagrid catfish, *Pseudobagrus ichikawai*, was investigated during the period from April 1988 to December 1989 in the Tagiri River, Mie Prefecture, Japan. The catfish were nocturnally active from spring to autumn, especially from June to September. During the daytime and in winter, they hid in crevices along the vegetated river shores or under boulders on the river bed. Analyses of seasonal changes in size distribution and growth patterns of 202 individuals revealed that the fish grew mainly in summer. New recruits, which appeared first in autumn, attained about 40 mm in standard length (SL) by July of the following year. At age 2 years, some females exceeded 60 mm SL, being mature, whereas males probably mature at 3 years, reaching about 100 mm SL. The maximum sizes recorded were 93.5 mm SL for females and 108.0 mm SL for males. Sexual size dimorphism was apparent in immature, 1 year-old, becoming pronounced in older fish. The sex ratio of adults was largely female-biased. Although it appeared that spawning took place in July of both years, no recruits representing the 1988 year-class were captured. Differences occurred between 1988 and 1989 in growth rates, maturation of 2-year-old females, and population structure. The possibility of the species having a polygynous mating system, with the population size and age structure being unstable owing to floods, is suggested.

The bagrid catfish fauna of Japan is represented by *Pseudobagrus aurantiacus* (according to Ueno [1974, 1985], this species probably comprises two different species), *P. ichikawai* (=*Coreobagrus ichikawai*), and *Pelteobagrus nudiceps* (Miyadi et al., 1976; Sawada, 1984). The distributions of the species are geographically separated, with each species being closely related to species in Korea and/or China (Nakamura, 1963; Ueno, 1985; Watanabe et al., 1992). *Pseudobagrus ichikawai* (nekogigi) is found only in the rivers flowing into the Ise and Mikawa bays (Okada and Kubota, 1957; Nakamura, 1963).

The life histories of the Japanese bagrid catfishes have not been studied in detail, with only a few reports on limited aspects of their ecology, e.g., the early life history of *P. aurantiacus* (Okada and Seiishi, 1938). *P. ichikawai* has been observed inhabiting pools in the middle to upper reaches of rivers, remaining hidden under rocks by day, but actively feeding on aquatic animals at night (Shimizu and Shimizu, 1982; Shimizu, 1988). In 1977, *P. ichikawai* was designated as a "natural monument" for preservation purposes, owing to the rapid decline in habitat and abundance of the species, largely due to intense human impact (Nagoshi, 1983).

This study was aimed at clarifying the life history of this rare catfish, *P. ichikawai*, especially its growth, maturity and population structure. Mark-recapture methods were used with the permission of the Japanese National Agency for Cultural Affairs.

Materials and Methods

Study area

This investigation was conducted in the Tagiri River (14 km long), Mie Prefecture, Honshu, Japan (35°10′N, 136°31′E). The river rises from the Yoro Mountains, flowing into the Inabe River. In the middle and lower courses, it is a Bb-type river (Kani, 1971), 5–20 m wide. Weirs built approximately every 200–300 m, have prevented upstream movement of fish at normal water levels.

Shimizu and Mori (1985) found *Pseudobagrus ichikawai* only in the lower reaches (about 2 km) of

the Tagiri River. A section including the backwater of a weir in the lower reaches was selected for the main part of this study, owing to a preliminary survey which showed the density of the species in that area to be relatively high. The study site, about 80 m long and 10–18 m wide (about 1000 m^2 in surface area), was separated from other habitats of *P. ichikawai* by a weir of 80 cm height at the lower end and rapids about 100 m long at the upper end. The greatest water depth was 60–80 cm at normal water levels. The river bed was mostly covered with pebbles, along with some boulders and concrete blocks with the banks comprising a complex mix of boulders and dense vegetation, but not being protected by concrete. Although the velocity of the surface current at the center of the river was ordinarily about 30 cm/sec, flow along the shores was negligible. A detailed description of the area was given by Watanabe (1990).

Methods

Mark-recapture investigations were carried out one to three times a month (2–7 days each) from April 1988 to December 1989.

During the day, *Pseudobagrus ichikawai* hiding under boulders were caught by hand net following removal of the latter. At night, fish swimming actively, but not quickly, were sought by flashlight and similarly captured. Search and capture efforts were kept as consistent as possible. Column net-traps (30 cm diameter by 80 cm long) were baited with earthworms or fishing paste and set near boulders along the shores from April to July, 1989.

Standard length (SL) and body weight (BW), measured to the nearest 0.5 mm and 0.1 g, respectively, sex, external characters, and capture location were recorded for all fish collected. Subsequently, the fish were marked, kept in a container for one or more hours, and then returned to the river near their capture point. As a common mark, a small V-shaped notch was cut in the adipose fin of each fish. Although the notch could be recognized throughout the study period, it was re-cut at each recapture for easier recognition. From June 1988 to August 1989, all fish larger than 50 mm SL, 142 females and 60 males, were also individually marked by the injection of red or blue liquid latex by hypodermic syringe at two points on the body sides. The influence of latex injection on survival and growth rates has been shown to be negligible (Riley, 1966; Yusa, pers. comm.). The rate of disappearance of the injected latex, based on recaptured specimens with a notched adipose fin, was estimated to be less than 2%.

Males larger than 50 mm SL were identifiable by the prominent genital papilla posterior to the anus. The smaller fish were grouped together, because of the difficulty of determining their sex in the field.

The age of each marked fish was estimated at the time of capture as follows: 1) when the size distribution was apparently polymodal, the age of a fish was determined by considering each mode to represent an age group; 2) if age groups could not be determined from the size distribution, a fish was considered to be the same age as similar length (SL) fish of known age. Spawning season and individual yearly growth were also taken into consideration. Age was taken as the number of winter seasons experienced.

The condition factor (CF) is used herein as the index of female maturity, being calculated as follows:

$$CF = \left[\frac{\text{Body weight (g)}}{\{\text{Body length (cm)}\}^3} \right] \times 1000.$$

Locomotor activity (expressed as an activity index) was indicated by the mean number of fish captured per hour during night investigations.

Results

Diurnal and seasonal changes in activity

From April to October, *Pseudobagrus ichikawai* individuals were observed swimming in the open at nighttime only, with no obvious fluctuations in nocturnal activity. During the daytime, only a few catfish were found under boulders which could be moved by hand. By contrast, under and around a concrete block of about 2 m length and around crevices among shore vegetation, groups of 10–15 individuals were observed even in the daytime, during the summer season.

Seasonal changes in locomotor activity of the catfish under study are shown in Figure 1. Relatively high activity was observed from June to September, when the water temperature was above 15°C. No catfish were observed from November to March (water temperature below 10°C).

Growth

Total numbers of fish marked are shown by sex

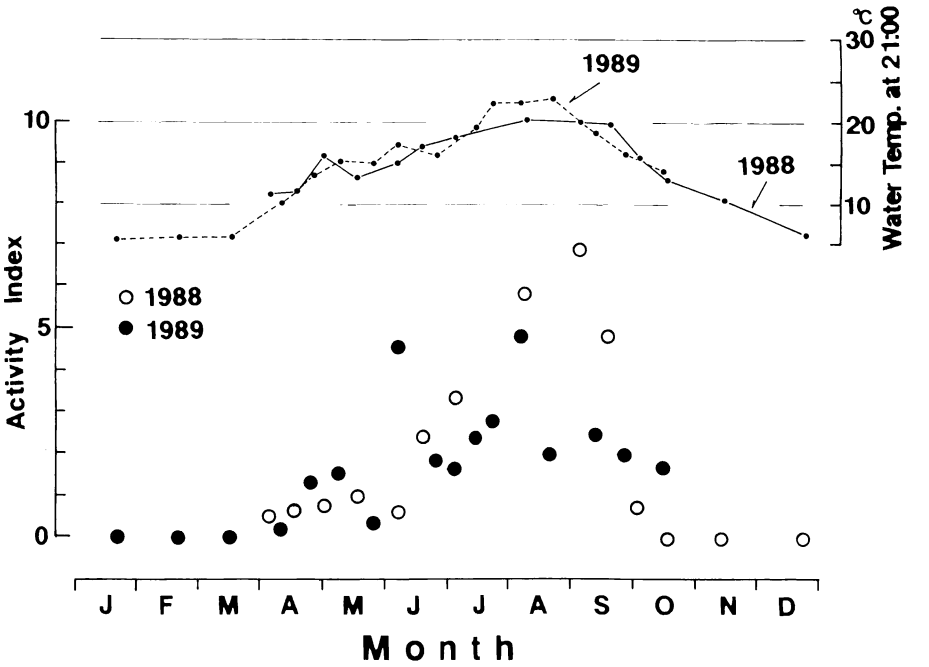

Fig. 1. Seasonal changes in locomotor activity of *Pseudobagrus ichikawai*, in the Tagiri River at night. See section of Methods for explanation of activity index.

and year-class in Table 1. Recapture ratios of marked fish in samples attained 80% in the 1987 year-class and 70% in older year-classes in the investigations in June 1989 and subsequently.

Seasonal changes in size distribution of captured fish, and growth patterns of marked fish are shown by sex in Figure 2. Individual growth patterns are given only for those individuals recaptured relatively often.

In 1988, fish measuring ca. 30 mm SL in April growing to ca. 50 mm in August could not be sexed, and were recognized as belonging to the age-1 group (1987 year-class). Fish of the 1989 year-class were first captured on September 12, 1989 (range: 20.5–28.8 mm SL; mean ± SD: 24.8 ± 3.9 mm, $n = 5$). However, no fish of the 1988 year-class were found in 1988 and 1989.

Table 1. Total numbers of individually marked *Pseudobagrus ichikawai*

	Year-class			Total
	1985	1986	1987	
Female	91	28	23	142
Male	22	10	28	60

For the older year-classes, age-2 groups could be recognized from the size distribution between April and July in both 1988 and 1989, individuals reaching ca. 60 mm SL (females) and 75 mm (males) in July (Fig. 2). A mode in the size distribution, comprising larger fish, was considered to represent age 3 and older fishes. A few larger females were apparently referable to age-4 or older.

Based on the age determined for each marked individual, the size (SL) of each year-class in early July was calculated for both years (Table 2). Annual growth of females averaged about 10 mm SL at age 2, but less than 10 mm SL in older age groups. Annual growth of males was higher, about 25–35 mm SL for the age-2 group, with the result that during age 3, they exceeded 100 mm SL. Thus, the maximum size recorded in males (108.0 mm SL) was greater than that in females (93.5 mm SL) (Fig. 2, Table 2). On September 18, 1988, at which time the sex of age-1 fish could be first identified, males (56.3 ±4.3 mm SL, $n = 8$) were already larger than females (52.3 ± 2.9 mm SL, $n = 10$) (t-test, one tailed, $t = 2.41$, $df = 16$, $p < 0.05$). Rapid growth occurred from June to September, but rates decreased during the

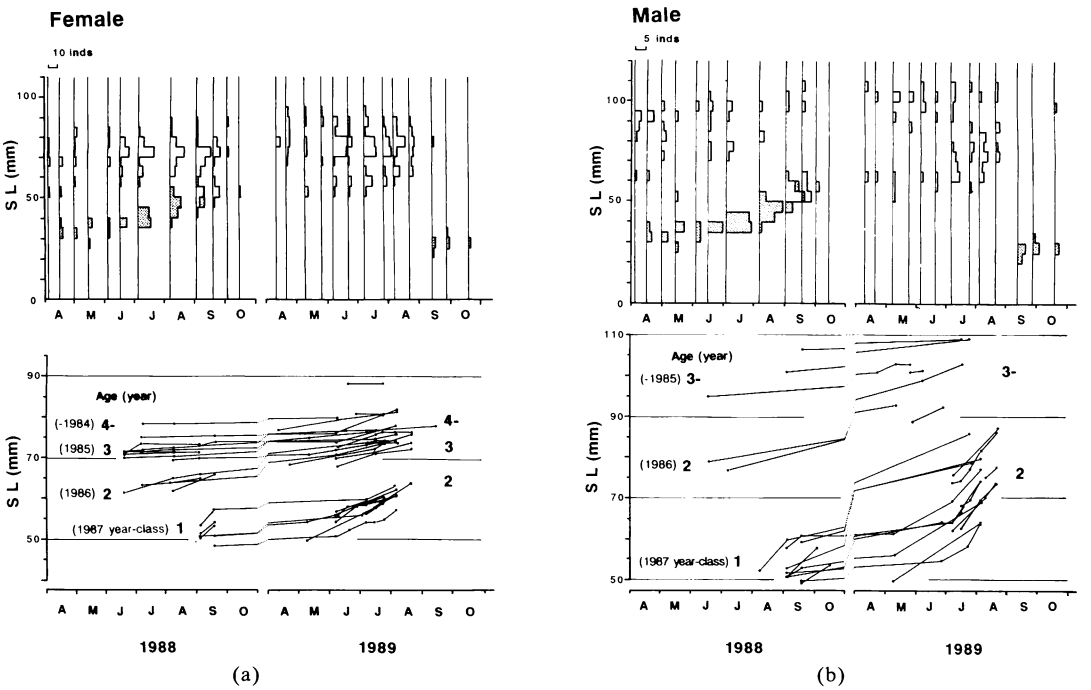

Fig. 2. Seasonal changes in size distribution (upper) and growth of marked individuals (lower) for female (a) and male (b) of *Pseudobagrus ichikawai* in the Tagiri River. Shaded area: sex undetermined.

winter (Fig. 2).

The mean standard length of the age-2 fish in 1989 was significantly shorter than in corresponding fish in 1988 for each sex (Table 2; female: t-test, one tailed, $t=3.83$, $df=11$, $p<0.01$, male: $t=2.96$, $df=8$, $p<0.01$).

Spawning season and age at first maturity

Seasonal changes in the mean condition factor were not significant in age-1 fish, irrespective of sex (Kruskal-Wallis test, 1988: $H=6.50$, $df=7$, $p>0.3$). The same was true in age-2 and older males (Fig. 3; Kruskal-Wallis test, 1988: $H=4.98$, $df=7$, $p>0.5$; 1989: $H=13.03$, $df=10$, $p>0.2$).

In age-2 and older females, however, seasonal changes were clearly recognized (Fig. 3; Kruskal-Wallis test, 1988: $H=97.62$, $df=6$, $p<0.001$; 1989: $H=101.78$, $df=10$, $p<0.001$). The condition factor in these females increased from June to early July and sharply decreased around the middle of July to August. Since the fluctuation was accompanied by expansion and subsequent contraction of the abdomen, it was considered to be caused by gravidity and

Table 2. Mean standard lengths (mm) of *Pseudobagrus ichikawai* in early July

Age	Female		Male	
	1988	1989	1988	1989
1	40.0 (35.5–44.5, 23[a])	—[b]		—[b]
2	62.3 (59.0–64.0, 6) >[c]	57.7 (54.5–60.0, 7)	75.5 (74.0–77.0, 4) >[c]	68.5 (62.5–76.0, 6)
3	72.1 (68.0–75.0, 18)	73.2 (70.3–75.0, 4)	96.2 (90.5–99.0, 3)	100.0 (92.0–108.0, 2)
4	76.9 (74.0–84.0, 8)	83.6 (76.0–93.5, 7)		

Numerals in parentheses: range, number of individuals. The highest age-group for each sex in each year includes all older fish. [a] Includes both sexes; [b] no recruitment; [c] t-test, one-tailed, $p<0.01$.

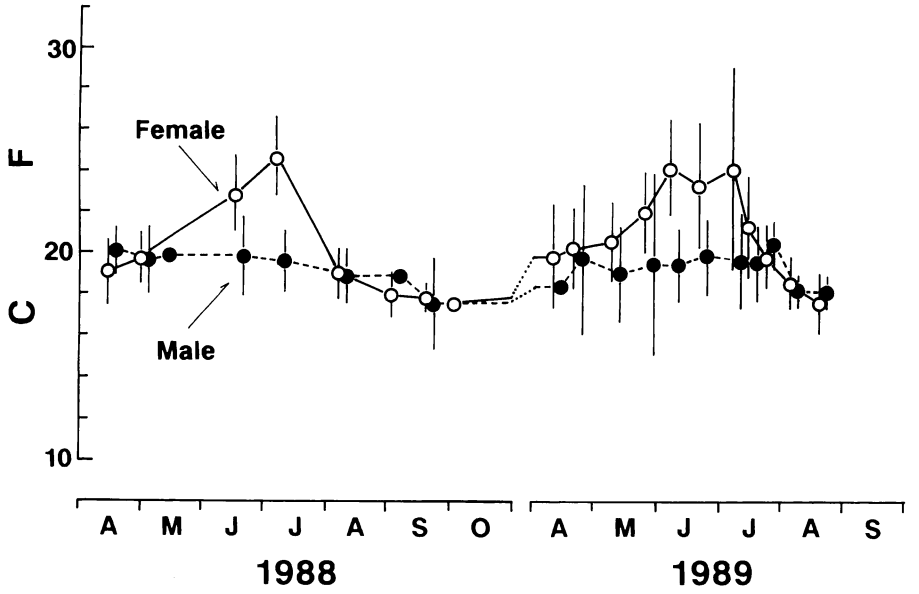

Fig. 3. Seasonal changes in the mean condition factor (CF) of *Pseudobagrus ichikawai* in the Tagiri River for each sex of age-2 and older fish. Vertical lines indicate standard deviation.

spawning, the latter taking place mainly in July. In fact, on July 22, 1989, a relatively large age-2 fish (63.0 mm SL) released about 120 adhesive eggs during handling (2.3±0.2 mm, longest egg diameter, 2.0±0.1 mm, shortest; $n=10$).

Although all age-3 and older females underwent abdominal swelling owing to gravidity, only a portion of the age-2 females did so. The proportion of such age-2 females was 73% (8/11) in 1988 and 6% (2/32) in 1989, indicating a highly significant difference in the proportion of sexually mature females in the two years (Fisher's exact test, $p<0.01$).

During the summer season, age-3 and older males (>ca. 90 mm SL) had a darker body color and swollen muscles about the head and nape. These appeared to be sexual characters, indicating that males attained maturity in their third year, one year later than females.

Sex ratio

Of the catfish captured by hand net, female num-

Table 3. Sex ratios in age-2 and older *Pseudobagrus ichikawai* collected with different sampling methods

									Age (years)	
1988		Apr.	May	June	July	Aug.	Sept.	Total	2	3–
Hand net	Female/male	3.0	1.0	2.8*	3.9**	11.3**	10.0**	4.8**	4.1**	5.2**
	Total number	4	10	23	39	37	44	157	46	111

								Age (years)	
1989		Apr.	May	June	July	Aug.	Total	2	3–
Hand net	Female/male	4.0	2.3	5.3**	4.7**	1.9**	3.2**	1.3	9.3**
	Total number	5	13	57	63	70	208	85	123
Trap	Female/male	2.5	0.3	1.5	1.4	——	1.4	0.5	1.8*
	Total number	7	4	5	29	——	45	9	36

*$p<0.05$; **$p<0.01$ (Female>Male).

bers exceeded those of males in both overall total (female/male=4.8 in 1988 and 3.2 in 1989) and in all months in which more than 20 individuals were captured (chi-squared test, one tailed, $p<0.01$, except in June 1988, $p<0.05$) (Table 3).

Considered separately, age-2 and older females also outnumbered the corresponding male groups in 1988 (age-2: female/male=4.1, $p<0.01$; older: 5.2, $p<0.01$), although in 1989, the sex ratio bias in age-2 fish (1987 year-class) was insignificant (female/male=1.3, $p>0.1$) (Table 3). The sex ratio of the 1987 year-class showed no significant bias neither at 1 year old in 1988 (September 3–4: female/male=0.8, $p>0.1$; September 18: 1.3, $p>0.1$), nor in the total number of marked individuals (female/male=0.8, $p>0.1$, Table 1).

For the trapped fish, the sex ratio bias for the overall total was insignificant (female/male=1.4, $p>0.1$), in contrast with those caught by hand net. Only in the age-3 and older group, was the proportion of females to males higher (female/male=1.8, $p<0.05$), but the bias was smaller than in the case of fish captured by hand net (chi-squared test, one tailed, $p<0.01$).

Discussion

Growth, sex ratio and maturity

As have some previous observations (e.g., Shimizu, 1988), this study indicated that *Pseudobagrus ichikawai* is nocturnal, apparently feeding actively in the open almost only at night, especially between June and September (water temperature $>15^{\circ}C$). During the day and other periods of inactivity (November to March), the species takes shelter, usually in crevices along the vegetated shore or under large boulders on the river bed. Growth occurred exclusively during the active, summer period.

Sexual dimorphism in body size was clearly recognized, resulting mainly from the higher growth rate in males, especially in summer at age 2, at which time also, some females matured. The latter phenomenon, however, cannot be held solely responsible for the sexual size dimorphism, because males had already become larger than females during their first year. Other factors, such as physiological or behavioral differences between sexes (e.g., feeding activity), must also contribute to size dimorphism in this species.

Although the age-1 group had a sex ratio of about 1:1 in 1988, a larger number of females than males were captured of fish older than age 1 (1988) or 2 (1989). This sex ratio bias could be attributed to either actual bias and/or sampling error resulting from the capture method. The smaller bias in the sex ratio of trapped fish compared with that of fish captured by hand net suggests some behavioral difference between the sexes, e.g., older males captured less often by hand net, possibly because of their lower activity outside shelters. Nevertheless, because the total number of males marked was also much lower than that of females (Table 1), it can be concluded that more females actually existed than males, suggesting either a higher mortality rate or emigration of males. If the morphological changes in males at age 3 were a true indication of their sexual maturity, the sex ratio bias in mature fish overall, is even greater, due to the delayed maturation of males.

Although breeding details of this catfish remain unclear, the sexual size dimorphism, which results from the faster growth and longer growth period of the males, suggests the existence of a polygynous mating system in this species (Clutton-Brock and Harvey, 1984; Kozlowski, 1989), such being supported by the sex ratio bias in mature fish. Competition among males for reproductive resources likely exists, with the shelter being considered as a most important resource, owing to spawning being carried out in that of the male (Watanabe, unpubl. data). The possibility also exists that the sexual size dimorphism has resulted from female preference for larger males. In a related species, *Pseudobagrus fulvidraco*, which is widely distributed from Siberia to China, the larger males make burrows for spawning and subsequent protection of the eggs and offspring (Nikol'skii, 1954). Further studies are necessary to elucidate the reproductive ecology of *P. ichikawai* and its relatives.

Yearly changes

The growth rate, proportion of mature fish in age-2 females, recruitment of yearlings and age composition differed between 1988 and 1989. The lower proportion of mature females at age 2 in 1989 (1987 year-class), probably resulted from lower growth rates in the year-class. On the other hand, recruits representing the 1988 year-class were not caught from 1988 to 1989, even though breeding had obviously occurred in 1988. This might be attributable to the tremendous disturbance caused by three ty-

phoons in July, August and September, 1988, and the high frequency of changing river levels in May and June, 1989.

In a relatively stress-prone environment, such as a small stream, disturbances such as flooding strongly influence the population dynamics of some fish species and assemblages (Schlosser, 1985; Matthews, 1986). Differences in growth and recruitment between the two years of this study resulted in the size (age) distribution being biased towards larger (older) fish in 1989 than in 1988. The population structure of *Pseudobagrus ichikawai* in the study area therefore seems prone to instability. It should also be pointed out that the restricted distribution within areas confined by the many weirs in the river accentuates the effects of naturally-changing conditions.

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田切川（三重県）におけるネコギギ *Pseudobagrus ichikawai*（ナマズ目ギギ科）の成長，成熟および個体群構造

渡辺勝敏

1988年4月から1989年12月の間，三重県北部の田切川（員弁川水系）に生息するネコギギ個体群を標識採捕法を用いて調査した．本種は春から秋，特に6月から9月にかけて夜間に活動し，日中や冬期には抽水植物の繁茂する川岸部の横穴や河床の浮石の下に潜んでいた．体長分布の季節変化と合計202個体の標識魚の成長から，本種は主として夏に成長することがわかった．秋に最初に現われた当才魚は翌年の7月には標準体長約40 mmに達した．雌の一部は2才で体長60 mmを超え，成熟に達した．雄は体長が約100 mmに達する3才時に成熟すると推測された．最大体長は雌93.5 mm，雄108.0 mmであった．未成熟である1才時にすでにサイズにおける性的二型が現われ，高齢魚でより顕著になった．成魚の性比は大きく雌に偏っていた．両年とも産卵は7月に行われたと推測されたが，1988年級群については全く加入が認められなかった．本種が一夫多妻的婚姻形態をもつ可能性，および本個体群が洪水などによる攪乱に対して不安定であることが示唆された．

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