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ECOLOGY AND MORPH TRAITS OF THE SWAMP EEL *MONOPTERUS ALBUS* (SYNBRANCHIFORMES: SYNBRANCHIDAE) ON THE RYUKYU ISLANDS, JAPAN

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Populations of the swamp eel (*Monopterus albus*) in the Nara Basin Japan may originate from fish introduced from the Korea Peninsula. The origin and current ecology of this fish in other areas in Japan are not examined in detail. We investigated current distribution and some morphological traits of swamp eel on seven islands in the Ryukyu Archipelago, Japan. We confirmed the presence of swamp eel at half of 63 selected study sites, which had a slow current or still water where the fish were expected to inhabit. Morph-measurement indicated that relative size of mouth or buccal cavity of fish from the Ryukyu Islands was significantly smaller than fish from the Nara Basin: the latter performs paternal mouth-brooding, whereas such care behavior was not evidenced in the former. Most captured fish that were <30cm long were substantially smaller than individuals in the Nara Basin or in Shanghai, China. The body condition index of captured fish, however, did not differ from that of the same-sized fish in the Nara Basin, suggesting that the small body size of fish from the Ryukyus might not be induced by food shortage. Swamp eels in the Ryukyu Islands had dark brown body coloration and did not have stripes on the body, whereas those in Nara and in Shanghai have yellow-brown bodies occasionally with stripes. These morph traits of swamp eel in the Ryukyu Islands may suggest that they will not be derived from an artificially introduced population, but rather, be native. We discuss the importance of conserving swamp eel in the Ryukyu Islands.
Key words: Conservation, *Monopterus albus*, Morphological traits, Native population, Ryukyu Islands

Introduction

The swamp eel *Monopterus albus* (Zuiew) (Order: Synbranchiformes) is a freshwater fish that is widely distributed across eastern Asia from southeastern China to the Korean Peninsula, including the western part of the Japanese Archipelago (Okada, 1966; Masuda et al., 1988; Imatani, 1989). Although populations of swamp eel in western Japan were

considered native to the area, those in the Kinki district in Honshu Island are documented descendants of fish introduced to the Nara Basin from the Korean Peninsula in the early 1900s (Imatani, 1958; Matsumoto et al., 1998). After the release of this fish in the Nara Basin, its distribution steadily expanded into areas of the region where native conspecific fish did not occur (Imatani, 1958; Matsumoto et al., 1998). Because this fish can breathe in air, it could have easily survived long-distance transport; thus, it is unknown whether other local populations of swamp eel in western Japan are native or are derived from introduced fish.

Swamp eel has been documented in the Ryukyu Islands, i.e., the southwestern part of the Japanese Archipelago (Kuroiwa, 1927; Ogawa, 1938; Okada & Ikeda, 1938; Aoyagi, 1948; Okinawa Prefecture, 1996a, 1996b). In the Ryukyu Islands, as well as in China, swamp eel has traditionally been consumed for food and medicinal purposes (Kinjyo, 1993, 1995). Thus, it is possible that in the Ryukyus, this species originated from fish introduced from the Asian continent. In this report, we focus on the current ecological situation and the origin of this fish in the Ryukyu Islands. If swamp eels in the Ryukyus have unique morphological traits that differ from those of swamp eel from other regions, these differences may suggest the possibility that the fish are native. However, a comparative examination of swamp eels between the Ryukyus and other regions has not been conducted. Therefore, we examined external morphological traits (body form, body size and body coloration) of swamp eel in several of the Ryukyu Islands and compared them to those of swamp eel from Honshu Island and Shanghai. We then discuss the possibility that swamp eel in the Ryukyu Islands is native to this area.

In the Ryukyu Islands, conservation of swamp eel may be an urgent problem (Okinawa Prefecture, 1996a, 1996b; Japanese Ministry of the Environment, 1997). If swamp eel in the Ryukyus is not of introduced stock, but represents native populations or a subspecies of *M. albus*, their conservation warrants further attention. However, there are no detailed studies of the current ecological situation of swamp eel on these islands. Therefore, we also report on the current distribution and habitat use of swamp eel in the Ryukyus based on field observations and information obtained from local residents.

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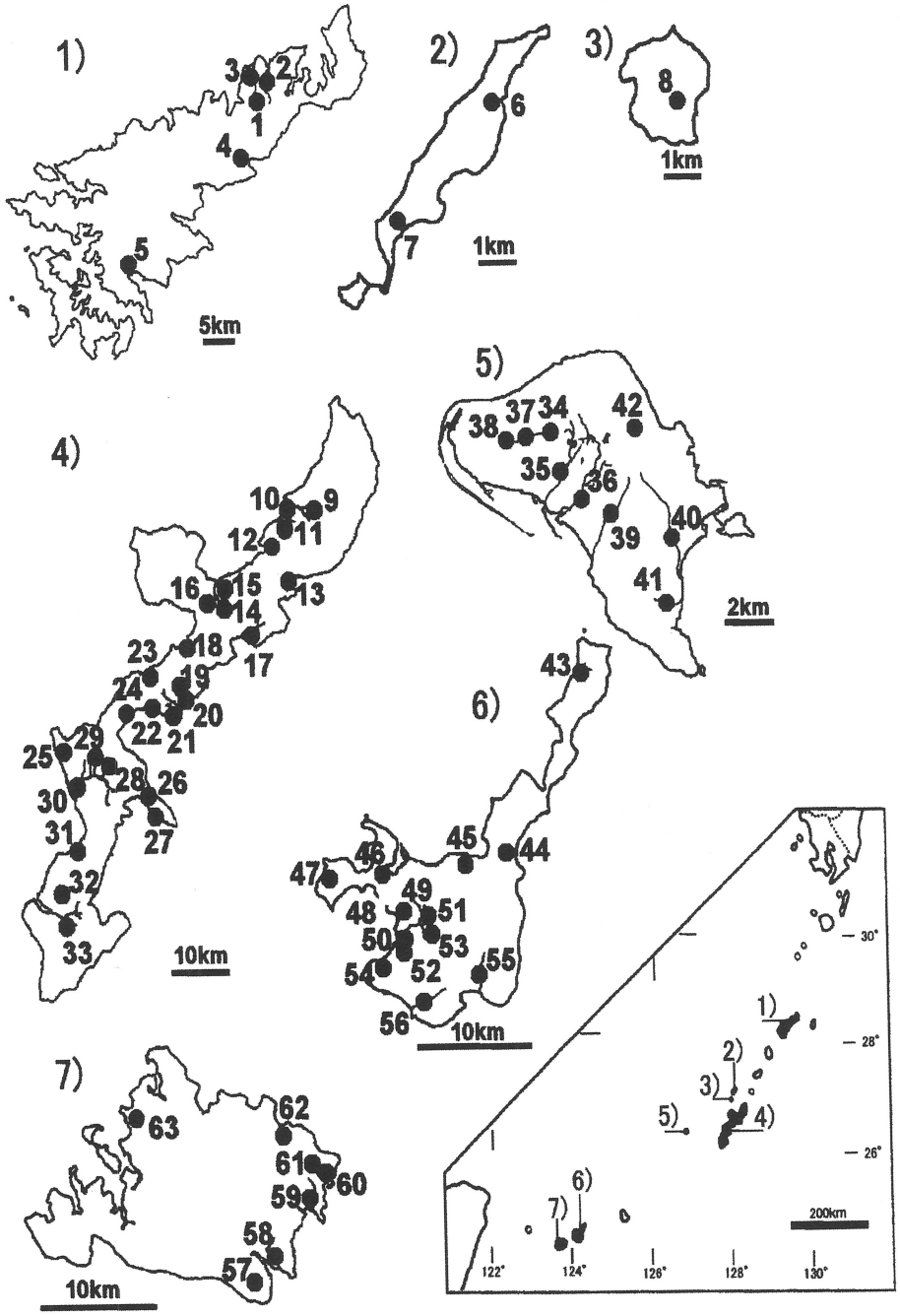


Fig. 1. Location of study sites on seven islands in the Ryukyu Archipelago: 1) Amamioshima, 2) Iheyajima, 3) Izenajima, 4) Okinawajima, 5) Kumejima, 6) Ishigakijima, and 7) Iriomotejima.

Table 1. Results of interviews and field observations regarding the presence of swamp eel *Monopterus albus* at 63 study sites on seven Ryukyu Islands. MS: maximum size (cm), C: body coloration (DB: dark brown, B: black)

Island and study site	Capture or observation[a]	Interview[b] (MS & C)	Habitat type	Reference[c]
Amamioshima				
1	No	>5 (30, DB)	Stream	–
2	No	Present (25, DB)	Rice[e]	–
3	No	>20 (30, DB)	Stream, Marsh	–
4	–	Present (30, B)	Rice field	–
5	–	Present (20, B)	Marsh	–
Iheyajima				
6	No	Present (25, B)	Rice	–
7	No	Present (20, B)	Rice	–
Izenajima				
8	Yes	Present (30, B)	Rice	–
Okinawajima				
9	–	No	Stream	–
10	–	No	Rice	–
11	No	Present (25, DB)	Marsh	1
12	–	>20 (20, B)	Rice	–
13	–	Present (30, B)	Marsh	–
14	–	Present (30, B)	Stream	2
15	–	Present (30, B)	Rice, Taro[e]	–
16	–	Present (20, B)	Rice, Taro	–
17	–	No	Stream	–
18	–	No	Rice	–
19	No	No	Stream	–
20	No	No	Rice	–
21	Yes	Present (25, B)	Stream, Rice, Taro	–
22	No	Present (15, B)	Rice	–
23	–	No	Rice	–
24	–	>10 (20, B)	Rice	–
25	–	>10 –	Marsh	3
26	Yes	Present (25, B)	Marsh	–
27	Yes	Present (30, DB)	Marsh	–
28[d]	–	>5 –	Marsh	1
29[d]	–	>5 –	Marsh	1
30	–	Present (20, B)	Stream	3, 4
31	Yes	Present (25, DB)	Taro	5
32	Yes	Present (30, DB)	Pond	4
33	–	Present (30, DB)	Stream	4
Kumejima				
34	Yes	Present (25, B)	Pond, Marsh	6

Table 1. Continued

35	Yes	Present (20, DB)	Stream	6
36	Yes	Present (25, DB)	Stream	6
37	Yes	Present (30, DB)	Rice	−
38	Yes	Present (20, DB)	Stream	−
39	−	Present (25, DB)	Stream	−
40	−	Present (30, DB)	Stream	−
41	−	No	Stream	−
42	−	Present (30, B)	Pond	−
Ishigakijima				
43	No	No	Stream	−
44	−	No	Rice	−
45	No	−	Rice	−
46	−	No	Rice	−
47	−	Present (25, B)	Rice	−
48	No	>10 (20, B)	Rice	−
49	−	Present (20, B)	Rice, Marsh	7
50	−	Present (20, B)	Stream, Rice, Marsh	8
51	−	No	Rice	−
52	Yes	−	Stream, Rice	−
53	−	No	Rice	−
54	No	Present (25, B)	Rice	−
55	No	No	Stream, Rice	−
56	−	No	Stream, Rice	−
Iriomotejima				
57	No	No	Rice	−
58	No	No	Rice	−
59	No	No	Stream, Rice	−
60	No	No	Rice	−
61	No	No	Stream, Rice	−
62	No	No	Rice	−
63	No	>20 (20, B)	Rice	−

a : Yes and No mean the current presence of fish was confirmed and not. - indicates that research was not conducted.

b : Yes means that current presence was informed. No means fish has not been observed and >5, >10, and >20 indicate that swamp eels were found >5, >10, and >20 years ago, respectively.

c 1 : Sato (1996) ; 2: Kochi (1986) ; 3: Sato (1994b) ; 4: Sato (2000) ; 5:Matsumoto (1997) ; 6: Sato (1994a) ; 7: Okinawa Prefecture (1996b) ; 8: Senou and Suzuki (1981) .

d : At sites 28 and 29, marsh habitat has been largely destroyed.

e : Rice and Taro mean rice field and taro-potato filed.

for the Protection of Endangered Animals.

Materials and methods

Study sites

The swamp eel *Monopterus albus* (Order: Synbranchiformes) generally inhabits muddy substrates in brooks, streams, marshes, ponds, and rice paddies (Imatani, 1989; Matsumoto et al., 1998). Swamp eel in the Ryukyu Islands occupies similar habitats (Okinawa Prefecture, 1996a, 1996b). The distribution of swamp eel has been reported for the islands of Amamioshima (Kuroiwa, 1927; Ogawa, 1938), Okinawajima (Kuroiwa, 1927; Okada & Ikeda, 1938; Aoyagi, 1948), Kumejima (Okinawa Prefecture, 1996b), and Ishigakijima (Kinjyo, 1995). In addition to these islands, we studied Iheyajima, Izenajima, and Iriomotejima (Fig. 1). We selected 14 sites at which the presence of swamp eel had been previously documented (see Table 1) and 49 sites at which swamp eel was expected to occur, based on historic (1919-1922) and current (1986-1995) habitat conditions using 1:50000-scale maps of the area (Geographical Survey Institute). In total, we selected 63 sites on seven islands: 5 on Amamioshima, 2 on Iheyajima, 1 on Izenajima, 25 on Okinawajima, 9 on Kumejima, 14 on Ishigakijima, and 7 on Iriomotejima (Table 1, Fig. 1). The study sites were located in streams, marshes, ponds, rice paddy fields, and taro-potato (taro) fields (Table 1).

Field observations and interviews of residents

The study was conducted between spring and late summer 2001-2003. We attempted to observe or capture fish at 33 sites using hand-net. As swamp eel is active in night, observations were also conducted in night. The field study was conducted over a total of 55 h on Amamioshima (8 h at night), 80 h on Okinawajima (20 h at night), 16 h on Kumejima (5 h at night), 48 h on Ishigakijima (6 h at night), and 32 h on Iriomotejima (8 h at night). After capturing fish, we recorded the body weight and total length, and recorded the body coloration and the presence or absence of stripes on the body (Swamp eels in the Nara Basin and around Shanghai have yellow to brown body coloration). Fish from Nara Basin has a black stripe on dorsal area of either body side (Fig. 2). The stripes varied in the shape and width (stripes consist of many dots in many fish as in Fig. 2, and some individuals lack the stripe (5 of 32 fish examined had no stripe, S. Matsumoto, personal observation)).

We calculated a body condition index (body weight/ total length^3 x 10000) in these captured fish, which will be compared with similar sized fish collected in the Nara Basin in summer season. Some fish were sampled at Okinawajima and Ishigakijima.

Identification of sex based on external morphology is difficult in swamp eel. The reproductive season of *M. albus* spans late spring to late summer in the Nara Basin (Matsumoto & Iwata, 1997) . *M. albus* is a paternal mouth-brooder (Matsumoto & Iwata,

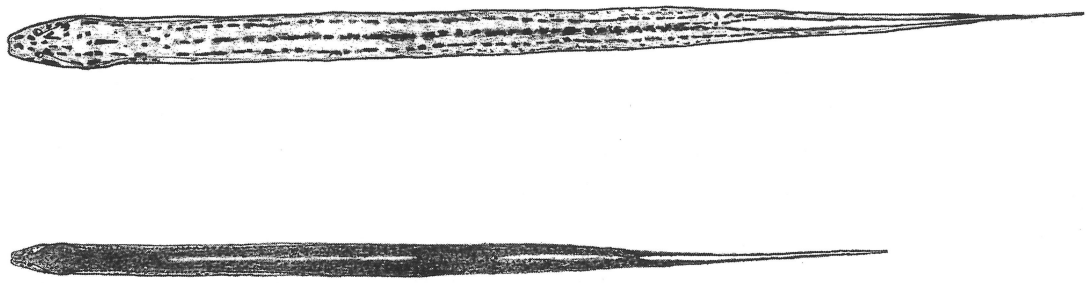


Fig. 2. Dorsal view of *Monopterus albus* from Okinawajima Island (lower) and from Nara Prefecture in Honshu Island (upper). Dark brown and yellow body coloration in the fish from Okinawa and from Nara, respectively. This fish from Okinawa was reared for ca. two years.

1997), and mouth-brooding males spit out the young when they are caught in nets (Matsumoto et al., 1998; Matsumoto, personal observation). When capturing fish, we carefully examined whether or not they were mouthbrooding. After examination, the fish were released at the capture site except for fish that were sampled.

We asked several residents (usually elderly farmers) at 60 study sites whether they had captured or seen swamp eel at or near the study site. If the fish were not currently present, we inquired about the last year(s) in which they had been observed. We asked respondents to provide an estimate of the maximum size of observed individuals. We also asked residents about the body coloration, the presence/absence of the stripes, and

Table 2. Relative length (length/ mouth-vent length x 100) of the 6 measurements on head in *M. albus*. Fish from the Ryukyus (n = 11) and Nara (n = 11). Mean ± SD and range are presented. See Fig. 3 for explanation of measurements (a - f). Statistic is by Mann-Whitney's U-test

Measurements	Ryukyu	Nara	P (U)
a	3.38 ± 0.28, 2.91 - 3.70	3.39 ± 0.33, 2.87 - 4.23	0.53 (51.0)
b	2.39 ± 0.24, 1.85 - 2.80	2.42 ± 0.31, 1.83 - 2.81	0.49 (50.0)
c	4.16 ± 0.46, 3.58 - 5.04	4.62 ± 0.29, 4.08 - 4.97	0.02 (26.0)
d	8.09 ± 0.56, 7.35 - 8.76	8.68 ± 0.49, 7.76 - 9.42	0.01 (22.0)
e	9.67 ± 0.70, 8.61 - 11.16	10.09 ± 0.45, 9.30 - 10.96	0.08 (33.5)
f	7.42 ± 0.50, 6.61 - 8.00	7.62 ± 0.90, 7.51 - 8.65	0.24 (42.5)

whether they had observed young in the mouths of adults. During the interviews, we showed photographs and formalin-preserved specimens of swamp eel (ca. 50cm long) obtained from the Nara Basin to avoid confusion with similar fish, such as eels (*Anguilla japonica* and *A. marmorata*) and loach (e.g., *Misgurnus anguillicaudatus*).

Measurements

The swamp eel has no pelvic and pectoral fins, and degenerated vertical fins that lack rays (Masuda et al., 1988). This fish lacks scales on body. For comparison of morphology of the swamp eel between the Ryukyu Islands and Honshu Island, we measured lengths of six parts (*a*-*f*) in head as shown in Fig. 3, partly because the size difference in mouth or head size will be expected between swamp eels in the Nara Basin with mouth-brooding in paternal care and in the Ryukyu Islands in which such care behavior was not evidenced (see results). Samples were from Okinawajima (n = 4) and Ishigakijima (n = 7) and the Nara Basin samples (n = 11) previously obtained, all preserved in 10% formalin solution. The body sizes of examined fish were not different between the Nara Basin (mean = 21.1cm, range = 16.8-24.0cm) and the Ryukyu Islands (19.9, 14.7-29.0) (Mann Whiteny *U*-test, $U = 38.0$, $P = 0.14$). For comparison, relative length (measured length/ mouth-anus length x 100) was used. Some samples were preserved in Osaka Natural History Museum, one from Ishigakijima, OMNH-P32081; 2 from Okinawajima, OMNH-P32082; OMNH-P32083; 6 from Nara Basin, OMNH-P362098, OMNH-P32099, OMNH-P32100, OMNH-P32101, OMNH-P32102, OMNH-P32103.

Results

Presence of swamp eel on seven islands

We attempted to capture fish at 33 sites using hand-net (Table 1). Fish were directly observed and/or captured at 12 of 33 sites on Izenajima, Okinawajima, Kumejima, and Ishigakijima. In total, we captured 31 fish at 11 sites.

We obtained interview information at 61 of 63 study sites: the current presence of swamp eel was informed at 31 sites on six islands, while non-presence at 30 sites (Table 1). At 14 of 31 sites where the current presence of the fish was informed, we found swamp eel at 12 sites (86%). At 11 of 30 sites where non-current presence of swamp eel was informed, we tried to collect or observe fish, but we were unable to find any specimens. Of the 30 sites at which the current presence of swamp eel was not verified, interview results confirmed the past presence of this fish at 9 sites (30%; Table 1).

Morphological and behavioral traits

Relative length of the six measurements in head of the samples of the Ryukyu Islands and the Nara Basin are shown in Table 2. Between the Ryukyu Islands and the Nara Basin, many values were not significantly different. However, means of *c* and *d* of fish

in the Ryukyu Islands were significantly smaller than those of fish in the Nara Basin.

The body coloration of all collected fish was in dark brown to black, and stripes along body axis were lacked (see Fig. 2). Interview results suggested that the body coloration of live swamp eel ranged from dark brown to black across our study sites (Table 1). Stripes along body axis were not reported in all 55 sites at which this information was obtained.

Of the fish captured at 11 sites, most individuals were <30cm in total length (TL), except for one fish at site 37 (43cm). Maximum sizes in TL were reported in the interviews as size range of 15-30cm with mean size 29.4±4.4 SD (n = 38 sites) (Table 1). The body condition index of fish with 17-30cm TL from the Ryukyu Islands (9.0±2.9 SD, n = 31 fish) did not differ from that of similar-sized fish from the Nara Basin (8.8 ±1.0, n = 8; Matsumoto, unpublished data, Mann-Whitney *U*-test, $U = 75.5$, $P = 0.82$).

Although our study period included the reproductive season, the 31 examined fish, which should have included some males, did not contain young in their mouths. The interview results from 44 study sites at which swamp eels were seen indicated that resident farmers never observe mouth-brooding in this fish.

Discussion

We chose study sites at which swamp eel was expected to occur. Field observations and interviews indicated that the fish were present at about half of the study sites. We did not find swamp eel at 11 sites for which there was no information on its current presence. In contrast, we found swamp eel at 12 of 14 sites where its presence was reported by residents. This suggests a high reliability of the interview results. Within the last one or last two decades, swamp eel may have been present at 30% of 30 sites at which their current presence was not confirmed by the present study. If swamp eel had previously occurred at these sites, it would indicate that local populations have drastically decreased or become extinct at about half of the study sites.

Of measurements on head, relative length of *c* (mouth-length) was different between the Ryukyu Islands and the Nara Basin: the mouth-length was larger in Nara samples than in the Ryukyu. The relative length of *d* was also larger in Nara than in the Ryukyus. Thus, mouth or buccal cavity may be larger in Nara swamp eel than that of the Ryukyus.

In morph traits other than the relative length, body size and body coloration were largely different between the Ryukyus and the Nara Basin. Most of the fish captured in the Ryukyus were less than 30cm long regardless of habitat types, which corresponded well to the size estimates reported by resident farmers. The maximum size of swamp eel from multiple sites of different habitat types in the Nara Basin and from a population near Shanghai was 0.6-1 m (Matsumoto

et al., 1998, Matsumoto, personal observation). The body condition index during the summer season did not differ between similar-sized swamp eel from the Ryukyus and the Nara Basin, suggesting that animals in the Ryukyus did not suffer from food shortage. The small size of fish from the Ryukyu Islands, independent of the study sites, will not be explained by food restrictions.

Fish size will also be affected by environmental conditions such as water temperature, and in general, size of fish of the same species may increase in colder waters (Atkinson, 1994). As the latitude of the study regions in the Ryukyus (24.5-28.5° N) is lower than the Nara Basin (34.5-35° N), monthly mean water temperature of rivers where the swamp eels inhabit is higher in Ishigakijima (in Nagura River, mean = 26.5℃, range = 19.0-31.9℃) and in Okinawajima (in Kokuba River, 24.5, 14.5-32.0) (Okinawa Prefecture, personal communication) than in the Nara Basin (in Asuka River, 15.2, 3.0-24.0) (Nara Prefecture, personal communication). Thus, the general rule seems to apply to the swamp eels. However, the difference in maximum size between the Ryukyus (30cm except one sample of 43cm) and Nara or Shanghai (ca. 1m) is exceptionally great, if they belong to the same species (Atkinson, 1994).

Swamp eel in the Ryukyus lacked stripes on the body, whereas stripes sometimes characterize swamp eel from the Nara Basin and Shanghai (Matsumoto et al., 1998; Matsumoto, personal observation). The basic body color of swamp eel in the Nara Basin is of yellow to brown (Imatani, 1989, Matsumoto & Iwata, 1997; Matsumoto et al., 1998), whereas that in the Ryukyus was dark brown. Fish body coloration can be affected by circumstantial habitat conditions (Wootton, 1998). However, both the Ryukyu Islands and the Nara Basin contain various types of habitats, and this habitat variety may not account for the differences in coloration or the presence/absence of stripes. Thus, the color patterns of these fish are likely to be largely based on genetic differences.

We did not find evidence of mouthbrooding. Local farmers never observed small young in the mouths of adult fish. Even several farmers who had often eaten this fish (two sites on Amamioshima) had not noticed mouthbrooding. During the course of similar interviews at various locations in the Nara Basin, many farmers pointed out that this fish spit out small young (several cm long) upon being captured or killed (Matsumoto et al., 1998). This strongly suggests the possibility that swamp eel in the Ryukyus may not perform mouthbrooding.

Exactly, measurements on fish head indicate that mouth size or buccal cavity will be proportionally larger in swamp eels in the Nara Basin, where males perform mouthbrooding (Matsumoto & Iwata, 1997), than in the Ryukyus (See also heads of fish from Okinawajima and Nara Pref. in Fig. 2). The large buccal cavity will be effective in the paternal care with mouthbrooding, and the relatively small buccal cavity in the Ryukyus

will be understandable, if they may not conduct mouthbrooding. This fish in Nara is a protogynous sex changer (from female to male) and the subject fish from the Nara Basin in the present study should be female (Okada, 1996, Matsumoto et al., 1998). Females will become to be large paternal males, thus, large buccal cavity in females will be related to habit of mouth brooding. If swamp eel in the Ryukyus does not do mouthbrooding, such great behavioral difference between the two regions will be beyond variation within a species.

Differences in some characteristics of swamp eel from the Ryukyu Islands and the other regions suggest that the fish in the Ryukyus were not introduced from the surrounding regions, but may represent native populations that have been isolated for considerable geological time. Mitochondrial DNA analyses are currently underway to determine the genetic distances among swamp eel from the Nara Basin, Shanghai, and the Ryukyu Islands (Matsumoto et al., in preparation). Our preliminary results imply that the genetic distance between fish from the Ryukyus and other areas will be as large as between different species.

We conducted the present research at habitats in which swamp eel were expected to occur, but found swamp eel at only half of these locations. The interview results suggest that some populations of swamp eel went extinct within the last 20 years. In addition, habitat destruction may be a problem. Indeed, the preferred habitat in which the occurrence of swamp eel was reported has largely been destroyed at two sites (Table 1). A decrease in swamp eel habitat in the Ryukyus will reduce or eliminate local populations at many locations. For example, the total area of rice field on Amamioshima was reduced from 2214 ha in 1960 to 13 ha in 2002 (Kyushu Agricultural Administration Bureau, 2002). If swamp eel in the Ryukyus is in fact a different species from *M. albus*, the conservation of this fish is even more crucial. Thus, the conservation of local populations of swamp eel in the Ryukyus is an urgent necessity.

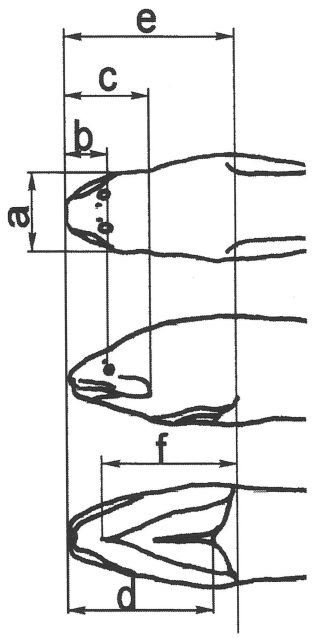


Fig. 3. Six meaured parts (a-f) on head of swampeel. Top vertical view, middle, horizontal view and bottom : underside.

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要　約

琉球列島におけるタウナギの形質特性および現在の生息状況．松本清二（橿原市立畝傍中学校），藤本治彦（沖縄県立八重山農林高校），嵩原健二（沖縄県立博物館），佐藤文保（久米島ホタル館），西田睦（東京大学海洋研究所），幸田正典（大阪市立大学大学院理学研究科）

近畿地方のタウナギ（*Monopterus albus*）は，朝鮮半島からの移入個体がその起源であると考えられているが，他の地域での詳細は明らかではない。また本種は琉球列島にも分布しているが，そこでの生息状況はほとんど調査されていない。琉球列島の７つの島で，本種の生息地である水田・池・沼・小川など63地点において，地元の方々からの聞き取りも含め，タウナギの生息状況の調査を行った。63地点のうち，生息が確認されたのは約半数の31地点であった。今回生息が確認できなかった30地点のうち，少なくとも９地点では最近まで生息していたと思われ，これらの場所ではタウナギは絶滅した，あるいは生息密度が急激に小さくなったと考えられる。調査したタウナギは，体色が黒っぽいことや概ね全長が30㎝までであることの点で，奈良県や上海でのタウナギ（共に最大１m，体色は黄褐色から茶色）と大きく異なった。全長15-30㎝の個体の肥満度（体重／全長３x 10000）は，琉球産と奈良県産の個体の間に差異はなく，栄養状態の悪さが琉球産タウナギの小型化の要因ではないことも示唆された。頭部の計測値から，琉球産タウナギの口腔の相対サイズは，

奈良産のものよりも有意に小さかった。奈良産のタウナギでは，雄による稚魚の口内保育が知られているが，琉球産のタウナギではそのような証拠は得られなかった。このことと，琉球産タウナギの口腔サイズの関連について議論した。これらの形質や行動の差異を考慮すると，琉球産タウナギは，大陸や日本本土から移植されたものが起源なのではなく，この地域に固有のものである可能性が高いことが示唆される。その由来及び沖縄県でのタウナギの現在の生息現状から，琉球列島に於ける本種の保全は急務な課題である。