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Spawning Behavior and Early Ontogeny of a Pomacanthid Fish, *Chaetodontoplus duboulayi*, in an Aquarium

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Abstract Spawning behavior of *Chaetodontoplus duboulayi* was recorded for the first time in an aquarium. Dimorphic characters associated with sex were recognized in color pattern and caudal fin shape. From 14 March to 27 April 1992, a pair spawned almost daily. Spawning took place between about 50 min before and 70 min after the mercury lamps went out in the evening (18:40–20:40). A second spawning was observed on three evenings. The number of eggs per spawning ranged between 5,000 and 33,000. Compared with the courtship of other pomacanthid species, the male's rapid swimming, which was its only courtship display, and the female's active display, including soaring and rapid swimming, were unique to *C. duboulayi*. Eggs were pelagic and spherical, 0.92–0.97 mm in diameter, and had a colorless transparent chorion and a yellowish transparent oil globule of 0.22–0.24 mm in diameter. Hatching occurred 24–25 hrs after spawning at 25.0–25.4°C. The newly-hatched larvae, 2.40–2.63 mm in total length (TL) with 12+16=28 myomeres, had an elliptic yolk sac, which extended beyond the snout. The yolk was segmented. The oil globule was located at the rear end of the yolk sac. The larvae of *C. duboulayi* up to 48 hrs after hatching were generally similar to those of other pomacanthid species, but distinguishable by the pigmentation patterns.

Marine angelfishes (family Pomacanthidae) are among the most colorful of circumtropical fishes. In recent years, studies of social and reproductive biology or early ontogeny have accumulated for 39 pomacanthid species in seven genera (Moyer, 1990; Hioki, 1992). However, most of the studies were fragmentary or limited, except for the genera *Centropyge* and *Genicanthus*. In general, the larger the species, the less is known of its reproduction and early ontogeny, probably because of the difficulties of field observations due to low population densities and large home ranges, and also because of the difficulty in breeding such species in small aquaria (Moyer et al., 1983; Moyer, 1987). In this respect, studying pomacanthid reproductive biology in a large aquarium seems to be one of the most effective approaches.

Even for the medium-sized pomacanthids of the genus *Chaetodontoplus*, information is limited. Reproduction and early ontogeny of only two species, *Chaetodontoplus septentrionalis* and *C. mesoleucus*, have been reported (Fujita and Mito, 1960; Moyer, 1990; Hioki, 1992). Virtually nothing is known about *C. duboulayi*, which is distributed in northern Australia, southern New Guinea and the Aru Islands (Steene, 1978). This paper describes spawning behavior and early ontogeny of *C. duboulayi* observed in an aquarium.

Materials and Methods

In 1988, three adult *Chaetodontoplus duboulayi*, approximately 20–25 cm in total length (TL), were obtained from Underwater World Perth, a public aquarium in Western Australia. Since July 1991, two of them have been reared in an exhibition tank of about 7 m^3 ($3 \times 1.5 \times 1.5$ m), containing artificial coral, at Tokyo Sea Life Park (TSLP), a public aquarium in Japan. Observations were conducted on this pair from 11 March to 10 June 1992, through an acrylic window on the side of the tank. Their behavior was recorded for 2–3 hrs every evening between 11 March and 24 April. Spawning occurred from 14 March to 19 May. Terminology of motor patterns used in the descriptions of spawning behavior generally follows Moyer and Nakazono (1978). At the end of the spawning period, the male and female had attained about 28 cm and 26 cm TL, respectively.

Stocked natural sea water was recirculated in a closed system with ozone sterilization, the water

temperature in the tank being kept at 23.8–26.2°C. No sunlight reached the tank; mercury lamps above the tank were turned on between 07 : 30 and 19 : 30, fluorescent room lamps between 08 : 30 and 21 : 00, and a dim room light from 21 : 00 to 07 : 30. Thirty-three individuals of 17 species of chaetodontids, labrids and others were kept together in the tank during the study period. Fishes were usually fed on algae, spinach, polychaetes, shrimp, clams, squid and fish.

Eggs of *C. duboulayi* were collected with a net set on the water outlet of the tank. The sea water containing the eggs was diluted and the total volume of sunken eggs measured using a graduated cylinder. The number contained in 5.0 cc of eggs spawned on 14 May was counted to obtain a relationship between volume and number ($N=3767/5\,V$, where N and V are total number and volume in cc, respectively). For subsequent spawnings, the number of spawned eggs was estimated from the total volume using this relationship. Eggs and larvae were reared in a 30 liter container using water from the parents' tank. A small portion of eggs and larvae were sampled at various time intervals and preserved in 5% sea-water formalin. The fertilization rate was calculated as the ratio of the number of eggs at the 2 or 4-cell stage to the total number of eggs examined. The sizes of eggs and larvae were measured using an ocular micrometer. Descriptions and measurements were made mainly on fresh material. No attempt was made to feed the larvae.

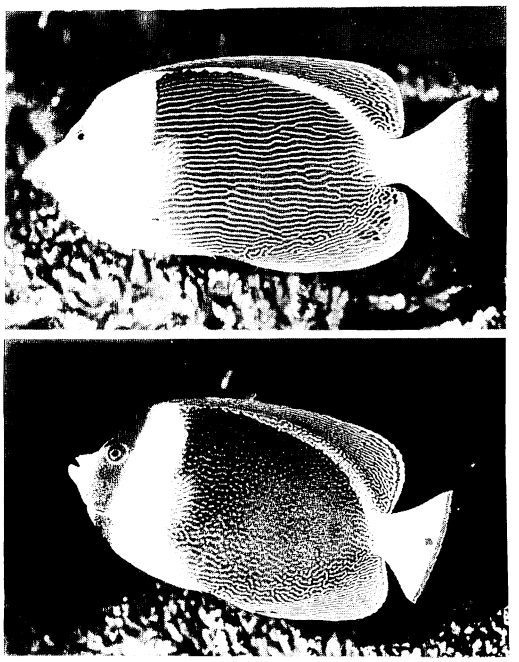

Fig. 1. *Chaetodontoplus duboulayi. Top*—male; *bottom*—female.

Results

Courtship and spawning

The rear margin of the caudal fin had pointed upper and lower lobes in the male, but was rounded in the female. The male had many fine, pale, longitudinal lines on the body, whereas the female had many fine spots, partly connected to one another (Fig. 1).

Spawning was recorded on 38 evenings from 14 March to 27 April. In most cases, it occurred between 18 : 40 and 20 : 40, i.e., between 50 min before and 70 min after the mercury lamps went off (Fig. 2). Spawning usually occurred once an evening, but on 10, 12 and 18 April a second spawning was witnessed. On 10 and 12 April, the second spawning was confirmed by the occurrence of two different stages in developing eggs, which were consistent with the time lag between the two spawnings. Seven spawnings were recorded from 28 April to 19 May at irregular intervals. Spawning did not occur from 20 May to 10 June. The number of eggs released per spawning varied from 5,000 to 33,000, and the fertilization rate, between 32 and 85%.

Approximately 3 hrs before the mercury lamps went off, the female's abdomen became noticeably swollen. About 2 hrs before spawning, the male began a courtship of rapid, horizontal swimming around the female for several seconds with the body inclined to one side (rapid swimming). During the courtship, the male used mainly its caudal fin for propulsion. At the same time the head became pale. The male repeated this courtship display until spawning occurred. The frequency of the display increased until 17 : 40 (from 16 : 50 to 17 : 40, Kendall's rank correlation, $\tau=1.00$, $n=5$, $p<0.01$), but then progressively decreased from 17 : 40 to 20 : 30, ($\tau=-0.60$, $n=18$, $p<0.001$; Fig. 2). The female also began to court, soaring ahead or alongside of the male with all fins extended (soaring). The frequency of the female display progressively increased from 16 : 50 to 20 : 30 ($\tau=0.80$, $n=22$, $p<0.001$; Fig. 2). The intensity of the display also increased as the

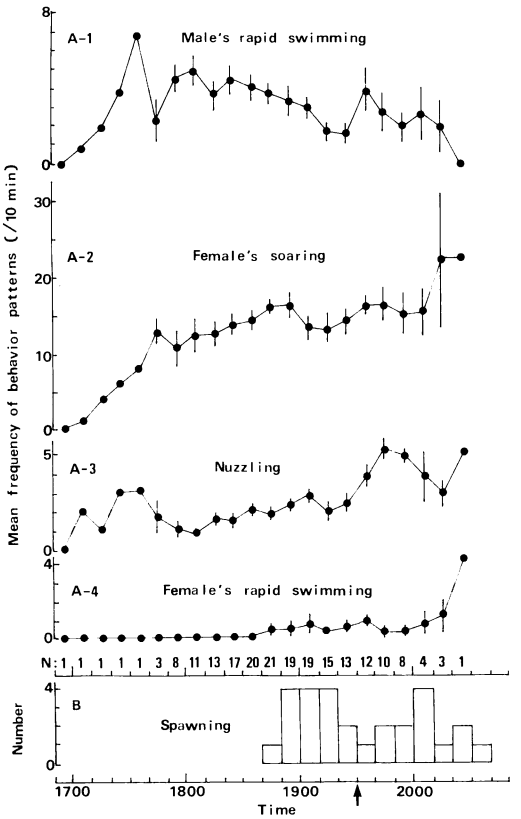

Fig. 2. Behavior of *Chaetodontoplus duboulayi* in an aquarium. A) Changes in frequency of courtship behaviors, based on mean frequencies (per 10 min) of courtship displays, except for those observed after the first spawning. Vertical bars = standard errors; n = number of 10-min observations; B) distribution of spawning time based on spawnings observed during 14 March and 19 May 1992. Arrow indicates mercury lamps switched off.

spawning time neared. The female frequently showed fluttering of the dorsal and anal fins during soaring in the later period of the courtship.

In response to her soaring the male moved beneath the female, positioning his snout near her vent. If the male did not respond to the female's courtship, the latter sometimes performed rapid swimming (Fig. 2), which was similar to the male display except that normal head color was maintained. As the male started to nuzzle the female's flank above the vent, the pair made a slow ascent toward the surface with the male taking a position behind the female (nuzzling, Figs. 2 and 3). The male angled upward at 20–

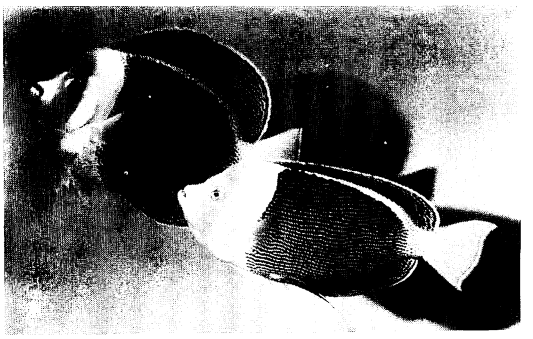

Fig. 3. Male *Chaetodontoplus duboulayi* (*right*) nuzzling abdomen of female (*left*). (The small fish near the abdomen of the male is *Labroides dimidiatus*.)

40° from the horizontal, with the female slightly upward at 5–20°. They moved obliquely forward while nuzzling, often curving to one side or the other. The pair reached the surface after several seconds and continued to swim slowly just below the surface.

Spawning occurred as the female moved slightly forward,suddenly shedding eggs in a conspicuous cloud. The male dashed forward and then quickly descended to the bottom, being followed by the female. Though sperm were not visible, the forward dash of the male might facilitate fertilization by mixing sperm and eggs. Once on the bottom, the male, with pale head coloration, chased the female in tight circles (after-chase). The female responded to the chase by extending the soft dorsal and anal fins, while the spinous parts remained folded.

After spawning, the male sometimes courted the female again by rapid swimming. The latter usually hid behind the artificial coral, although sporadically reappearing in response to the courtship. When a second spawning was observed, it occurred 23–82 min after the first. The spawning behavior was identical with the first.

Eggs and larvae

The eggs were free, pelagic and spherical, and 0.92–0.97 mm in diameter, each having a colorless transparent chorion, narrow perivitelline space and yellowish transparent oil globule, 0.22–0.24 mm in diameter. The yolk was segmented on the animal pole side.

The following developmental sequence was de-

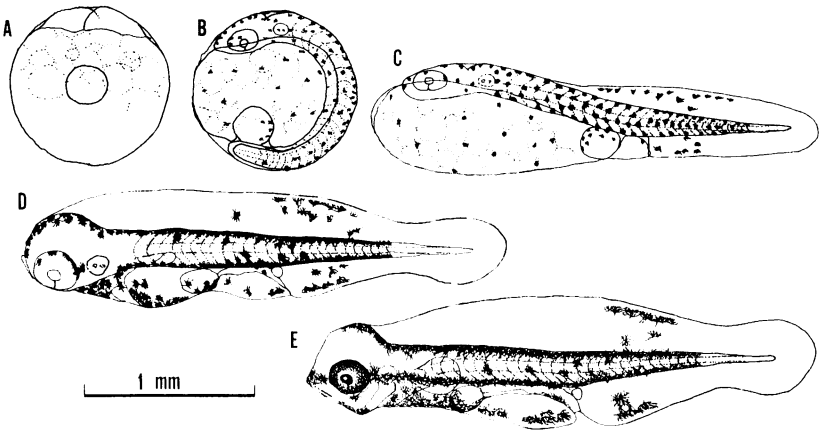

Fig. 4. Early ontogeny of *Chaetodontoplus duboulayi* in an aquarium. A) 2-cell stage, 49 min after fertilization; B) 23-myomere stage, 18 hrs; C) newly-hatched larva, 2.62 mm TL; D) larva 24 hrs after hatching, 2.84 mm TL; E) larva 48 hrs, 3.02 mm TL.

scribed from eggs spawned at 18 : 46 on 26 March. The water temperature during early development was 25.0–25.4°C. The eggs reached the 2-cell stage 49 min after fertilization (Fig. 4A), the 4-cell stage in 60 min, the 8-cell stage in 81 min, the 16-cell stage in 102 min, and the blastula stage in 4.5 hrs. By 13 hrs, an embryonic body had appeared and the blastopore closed. The embryonic body, with 12 myomeres, covered half of the yolk circumference. Eye vesicles and Kupffer's vesicle had also appeared, and the whole yolk was segmented. At 16 hrs, 18 myomeres were recognized, pigments appearing on the head, body, yolk and oil globule. Kupffer's vesicle had disappeared, and the oil globule was located near the tail tip. At 18 hrs, the body, with 23 myomeres, covered 3/5 of the yolk. The ear vesicles and eye balls had formed, with pigments increasing in number and appearing on the eye (Fig. 4B). At 20 hrs, the embryo, with 25–26 myomeres, began to move and the heart commenced pulsation. Pectoral fin buds had appeared. At 23 hrs, the tail bud was separated from the yolk. Hatching occurred at 24–25 hrs.

The newly-hatched larvae, 2.40–2.63 mm TL, had 12 + 16 = 28 myomeres with an elliptic yolk sac, which extended beyond the snout (Fig. 4C). The oil globule was located at the rear end of the yolk sac and measured 0.22–0.24 mm in diameter. The whole yolk was segmented. The mouth was not open, and the anus located at 2/3 of TL. The body was uniformly pigmented, except for the tip of the notochord. Single series of 5–15 dendritic pigments were present, near the margins of the dorsal and ventral finfolds. Several pigments had appeared on the eyes.

Twenty-four hrs after hatching, the larvae, measuring 2.80–2.93 mm TL, had 11–12 + 14–15 = 26 myomeres (Fig. 4D). The yolk sac had decreased in size to 1/3 of that at hatching. The oil globule had also decreased, to 4/5 of its initial size. The mouth was open, but not functional. The dorsal finfold above the trunk had developed, having a depth nearly equal to the body depth. Pigments were denser on the dorsal and ventral parts of the body than on the sides, and had also increased in number on the eyes. Pigments on the dorsal and ventral finfolds had accumulated on the anterior portion of the tail (13–23rd myomeres) with 5–15 pigments on each finfold; 1–4 pigments were present on the finfold anterior to the anus.

Forty-eight hrs after hatching, the larvae had attained 2.97–3.17 mm TL (Fig. 4E), with the yolk being almost absorbed. The oil globule had decreased in size to 0.11–0.13 mm in diameter, the mouth had begun to move and the anus had opened. The pectoral finfolds had increased to a length equal to the eye diameter. The eyes were fully pigmented, but pigments on the frontal region of the head had disappeared. Several pigments were present on the ventral parts of the upper and lower jaws. Pigments on the finfold anterior to the anus had increased in number, whereas those on the finfolds on the dorsal and ventral parts of the tail had decreased.

Only black pigments were recognized during the observations. Larvae were not fed, and most died

within 48 hrs after hatching.

Discussion

Spawning behavior

Several differences were recognized in the spawning behavior of *Chaetodontoplus duboulayi*, compared with the seven motor patterns reported in *Centropyge interruptus* (Moyer and Nakazono, 1978), which are regarded as similar or essentially the same as those of other pomacanthids, except for *Genicanthus*. Moyer (1990) also reported that motor patterns in the spawning behavior of *Chaetodontoplus mesoleucus* were nearly identical to those of *Centropyge interruptus* (Table 1).

The first two patterns, rushing and circling (Table 1), were not observed in *Chaetodontoplus duboulayi*. These motor patterns were rarely observed also in *C. septentrionalis* in an aquarium (Hioki, 1992). Such patterns are regarded as agressive behavior, by which the male maintains its dominance and synchronizes gamete release (Moyer, 1987). Instead, *C. duboulayi* performed a rapid swimming display which resembled the rushing of *Centropyge interruptus*, but seemed not to be aggressive, because it was not directed toward the female. Rapid swimming was not observed throughout the day, as was rushing in *C. interruptus*. The rapid swimming of *Chaetodontoplus duboulayi*, which was the only courtship behavior of the male, has not been reported for other species. Lateral display, which was regarded as a male courtship pattern in pomacanthids by Hioki (1992), resembles rapid swimming, but includes sporadic "lying-down" in front of the female, which was not observed in the present study.

Soaring by the male and mutual soaring were also absent, although active soaring by the female was seen in *C. duboulayi* (Table 1). It is noteworthy that the male *C. duboulayi* did not perform any courtship display with extended fins, whereas males of other pomacanthid species seem to court females intensively by soaring with their fins extended (Lobel, 1978; Neudecker and Lobel,1982; Thresher, 1982; Moyer et al.,1983; Moyer, 1984; Thresher, 1984; Gronell and Colin, 1985; Moyer, 1990; Hioki, 1992).

Nuzzling and spawning in *C. duboulayi* were almost identical to those of *Centropyge interruptus* (Table 1).

The last pattern observed in *Chaetodontoplus duboulayi*, after-chase, differed from that of *Centropyge interruptus*, but resembled that of *Pomacanthus imperator* (Thresher, 1982), except for the absence of sound (grunting). Following after-chase by the male, the female responded with a display in which her soft dorsal and anal fins were extended, at the same time keeping the spinous parts folded. Because this display was also performed by the female on the approach of the male in the daytime, it appears to have an appeasement function.

In nature, pomacanthid spawning generally occurs during a limited time span, mostly 10–20 min (occasionally 40 min) around sunset (Lobel, 1978; Neudecker and Lobel, 1982; Thresher, 1982; Moyer et al., 1983; Moyer, 1984; Gronell and Colin, 1985; Moyer, 1990). In this study, the female *Chaetodontoplus duboulayi* spawned only once each evening in most cases, but a second spawning was observed 23–82 min after the first on three evenings. Hioki (1992)

Table 1. Comparisons of motor patterns associated with spawning among *Chaetodontoplus duboulayi*, *Chaetodontoplus mesoleucus*, and *Centropyge interruptus*

Motor patterns	*C. duboulayi* (present study)	*C. mesoleucus* (Moyer, 1990)	*C. interruptus* (Moyer and Nakazono, 1978)
Rushing	−	+	+
Circling	−	+	+
Male rapid swimming	+		
Male soaring	−	+	+
Mutual soaring	−	+	+
Female soaring	+		
Female rapid swimming	+		
Nuzzling	+	+	+
Spawning	+	+	+
After-chase	+	+	+

+, observed; −, not observed; blank, not mentioned.

also reported an example of subsequent spawning in *C. septentrionalis* in an aquarium, suggesting that both species have the potential to spawn twice in an evening in nature.

Eggs and larvae

Pomacanthid eggs and larvae have been well described for the genera *Centropyge* (Bauer and Bauer, 1981; Hioki and Suzuki, 1987; Hioki et al., 1990; Hioki, 1992), *Apolemichthys* (Hioki, 1992), *Genicanthus* (Suzuki et al., 1979; Hioki et al., 1982; Hioki, 1992) and *Chaetodontoplus* (Fujita and Mito, 1960; Hioki, 1992), and briefly so in *Pomacanthus* and *Holacanthus* (Moe, 1976, cited by Thresher, 1984; Moe, 1977). General features of the early ontogeny of *Chaetodontoplus duboulayi* were similar to those of other pomacanthids. Segmentation of the yolk in the egg and larval stages, as observed in *C. duboulayi*, was first described for *C. septentrionalis* by Fujita and Mito (1960), and has not been found in other pomacanthid genera (Hioki and Suzuki, 1987). The larvae of *C. duboulayi* up to 48 hrs after hatching resembled those of *C. mesoleucus* and *C. septentrionalis* (Hioki, 1992) in pigmentation patterns, black pigments being uniformly distributed on the head, trunk and tail, except for the posterior most part. These three species can be distinguished from other pomacanthids based on these patterns. Pigments were present on the dorsal and anal finfolds in *C. duboulayi* and *C. mesoleucus*, but these were absent in *C. septentrionalis*. The larvae of *C. duboulayi* and *C. mesoleucus* at 48 hrs after hatching are distinguishable from each other by the pigmentation patters on the frontal region of the head and the posterior part of the tail.

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キンチャクダイ科の1種 *Chaetodontoplus duboulayi* の水槽内での産卵行動と初期発生

荒井 寛

オーストラリア北部周辺に分布するキンチャクダイ属 *Chaetodontoplus* の1種, *C. duboulayi* の産卵を初めて水槽内で観察した. 雄は, 尾鰭の上下両葉が尖っており, 体側には多数の細い淡色縦線があった. 雌の尾鰭後縁は丸く, 体側には多数の淡色点および短い淡色線が散在していた.

1992年3月14日から5月19日まで産卵が観察された. 3月14日から4月27日までほぼ毎日, 水槽の水銀灯が消える約50分前から消灯後70分の間に産卵が行われた (18:40–20:40). 一晩に同じ雌が2回産卵したのを3回確認した. 1回の産卵数は5,000–33,000粒であった. 産卵行動を既知のキンチャクダイ科と比較すると, いくつかの相違点が認められた. 雄の唯一の求愛行動である, 頭部を白く変化させ, からだを傾け尾鰭で急速に泳ぎ回ること, そして雌が雄の前ですべての鰭を拡げてさかんに求愛するとともに, 雄と同様な求愛行動を示すことが, 他のキンチャクダイ科魚類にはみられない本種の特徴であった.

卵は無色透明な球形で, 卵径0.92–0.97 mm, 分離浮遊性であった. やや黄色い直径0.22–0.24 mmの油球が1個認められた. 水温25.0–25.4°Cで, 24–25時間で孵化した. 孵化仔魚は全長2.40–2.63 mm, 12+16=28の筋節があり, 楕円形の卵黄の先端が吻より前方へ突出していた. 卵黄には亀裂が認められた. 油球は卵黄の後端に位置していた. 孵化後2日で, ほぼ卵黄を吸収し, 全長2.97–3.17 mmでは開口していた. 黒色色素が頭部および躯幹部, 先端を除く尾部に一様に分布し, 背側および腹側の膜鰭にも認められた. 本種の孵化後48時間の仔魚は, 色素の分布パターンによって既知のキンチャクダイ科魚類と識別できた.

(〒134 江戸川区臨海町6-2-3　東京都葛西臨海水族園)