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Nautilus Behavior in Aquaria

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Abstract

Observations on behavior were conducted, using *Nautilus pompilius* from the Philippines and Fiji, and *Nautilus belauensis* from Palau, kept at Kamoike Marine Park Aquarium. These studies on *Nautilus* include observations or experiments on locomotion, predation, respiratory, rhythm, image recognition and coupling behaviour and show its considerable ability to adapt to changes in the natural environment.

Introduction

Cephalopods such as squid and octopus have the biggest brains among invertebrate animals. Their interesting behavior is in some cases well known: for example, sexual display in sepia, learning and territorial activities in octopus. But it is less easy to study the behavior of *Nautilus*, a surviving tetranchiate cephalopod, its investigation here has just begun, but specimens are rare.

Some attention has been paid to the vertical movement involved in *Nautilus* behavior mechanism of ups and downs. The research group of paleontologists in Japan reported long-term observations of *Nautilus* in an aquarium (JECOLN, 1980).

The present report is based on three experimental records: i) Observation of *Nautilus pompilius*, captured near the Philippine Islands (Aug.–Sep., 1981) and kept there in an experimental water tank (HAYASAKA et al., 1982); ii) On *Nautilus pompilius* captured in the Fiji area, in Fiji during Aug.–Sep., 1984 (KAKINUMA and TSUKAHARA, 1985, 1986); iii) *Nautilus belauensis* brought from Palau and kept for a long period at Kamoike Marine Park in Kagoshima. Aquarium specimens ate frozen fish in small pieces from 8 to 12 grams in average, and a maximum of 20 grams and some times small shrimps. Observations of *Nautilus* activities were carried out using one tank. The predatory activity and breeding behavior of captured *Nautilus belauensis* were already reported. (KAKINUMA et al., 1995a, 1995b)

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Observations

1) Resting behavior in Aquaria

Four patterns of resting behavior were observed in aquaria:

(1) Their adherence flotation of the tentacles to the wall or bottom of the tank.

(2) Their flotation on the water surface with shrinking tentacles and drift along in the stream flow.

(3) They float with swinging of the shell back and forth.

(4) They rest the shell on a stone or the glass wall at the bottom of the tank, with contraction of the tentacles.

These observations suggest that aquarium specimens show behavior similar to that of *Nautilus* living in the sea. The variety of behavior patterns suggests that *Nautilus* adapts quite well to short-term changes in the natural habitat.

2) Locomotion in Aquaria

Nautilus usually moves horizontally (forward–backward) or vertically (ascend–descend). In *Nautilus* captured in the Philippines and Fiji the following behaviors were observed:

(1) Forward movement

Nautilus moves forward by extending its tentacles in front and directing its funnel backward. This type of movement is often observed in searching for prey before settling on a substrate and before breeding activity.

(2) Backward movement

This is most often seen either in flight or in ordinary locomotion. The tentacles are sometimes extended a little, the shell swings back and forth, and meanwhile the sea water is jetted from the funnel and the *Nautilus* moves backward, also the tentacles usually contract. In aquaria *Nautilus* usually moves about one meter in five to eight seconds. A *Nautilus* just after capture moved about two meters in three to five seconds (24–40 m/min.) in a water tank aboard the research vessel ship of the University of the South Pacific.

(3) Ascending movement

Nautilus adhering to the bottom of the tank detaches its tentacles swinging the shell. Then it slowly ascends by jetting sea water downward.

(4) Descending movement

The *Nautilus* descends slowly by jetting the water upward from the funnel. Rapid downward (or upward) movements were not observed.

(5) Beside these movements, *Nautilus* crawls with the tentacles, attaching to the tank wall. This was observed only when the animal was searching.

(6) The specimens on board the ship immediately after capture had rapid, direct motion and exhibited a variety of movements. It was astonishing to those accustomed to their slow motions when living in an aquarium.

Fast forward and backward rotations were performed in response to horizontal rotation of

360 degrees. There was a jumping reaction when the tentacles were touched by a foreign substance. Movements included extending the tentacles and jetting strongly backward while resting against coral, a crawl-like sliding movement using tentacles alternately, and searching movements at night, extending the tentacles twice as far as usual.

3) Diurnal Rhythm of Movements

For a *Nautilus* kept in natural lighting, captured two to five days before, there is no difference in the level of activity in the night or daytime. But with time its periods of activity gradually become longer in the night than in the day and eventually there are peaks

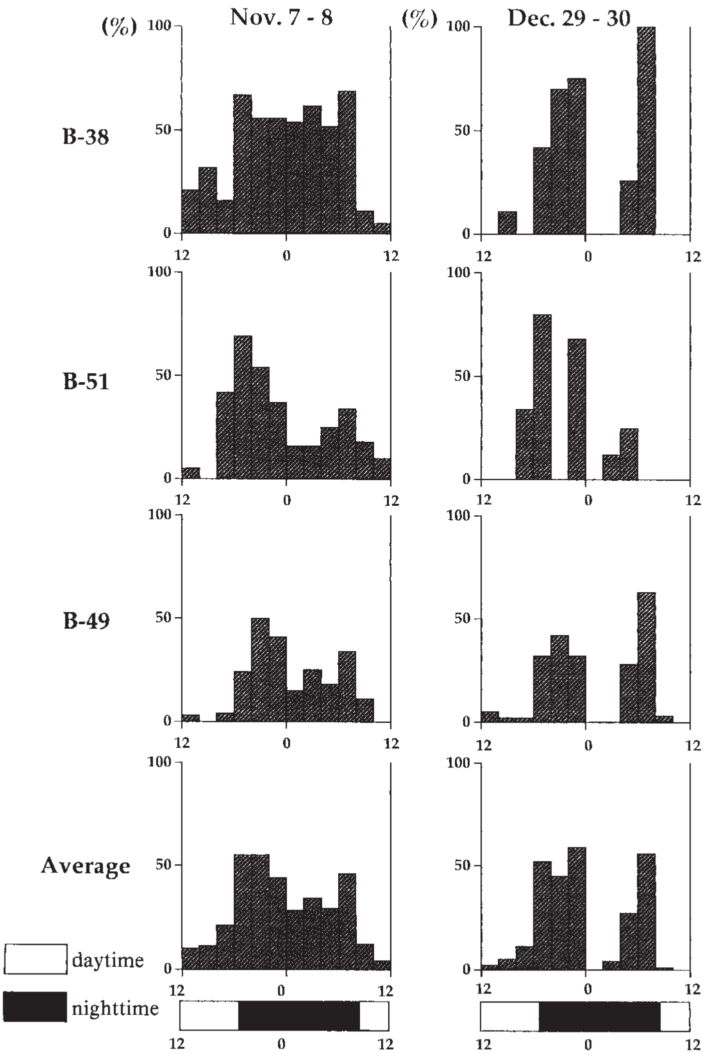

Fig. 1. *Nautilus*'s diurnal changes of swimming activity (Philippines Nov. 7–8 and Dec. 29–30, 1981).

of activity at dawn and in the evening (Fig. 1). At these peaks, swimming (for 4 to 15 minutes) and rest (for 10 to 20 minutes) are repeated alternately. This suggests some diurnal rhythm.

The level of activity was measured by the number of the shell swings during one swimming period (30 min.). For Philippine female *Nautilus*, this reached 780 or 880 swings and for males from 890 to 1010. The swimming period is also longest for males. The months of August and September, when the observation were made, were the breeding season for *Nautilus* captured in the Philippines. But *Nautilus* captured in Fiji, whose genital glands were still immature, showed low activity. From these observations, it seems that the number of swings (or the length of swimming periods) is seasonal behavior which depends on maturity.

In the environment, *Nautilus* was active and moved by swimming a long distances quickly, or by flowing with a current. This suggests that *Nautilus* has potentially wide distribution.

4) Predator Behavior

We monitored the reactions of a *Nautilus* adhering to the wall of the tank. A coral stone (about 20 cm diameter) was put in the center of the tank and a live shrimp (wet weight 8−12 g) was placed on it with a pair of tweezers. The *Nautilus* immediately left the glass, turned the axis of the body toward the shrimp, and rushed to the food. While swimming, it picked up the shrimp with a tentacle, rolled it up to the mouth and ate it. The time taken was from 2 seconds to 2 minutes. Another *Nautilus* took 15 minutes to eat a shrimp after it was left on the stone. It is unknown whether the food is located by sight or smell.

Next, we put a small trap (40×30×30 cm) in the tank and observed the *Nautilus* behavior. This trap was made of black vinyl net with a entrance hole (10×12 cm) at each of its four sides. These holes are designed so that *Nautilus* can get in or out. After the trap was left in the tank, and six *Nautilus* were kept inside the tank, outside the trap. One of the *Nautilus* jumped up when it touched the net to about 10 cm distance. Rest of them were swimming around and avoided the trap. Some adhered to the net for a couple of minutes (several times), but the others adhered only to the glass wall of the tank. None of them entered the trap.

In the second test, eight *Nautilus* kept without food from the previous day were put in the tank. All *Nautilus* adhered to the tank wall. A shrimp was then hung on a wire in the center of the trap. As soon as the shrimp was given, all *Nautilus* turned to face the trap and approached to it within one to three minutes (Fig. 2). One of the *Nautilus* touched the trap carefully. After searching outside the trap, it tried to catch the shrimp by extending and inserting its tentacles into the trap. When it failed to catch the food, it entered the trap after searching the interior of the trap with its tentacles. It was still crawling quietly around inside the trap even when it was close enough to the food to catch it. Then the *Nautilus* extended one tentacle and rolled it up with the shrimp. After catching the food, it turned to the opposite hole by rotating body in a horizontal direction. Then it swam backward, shaking several

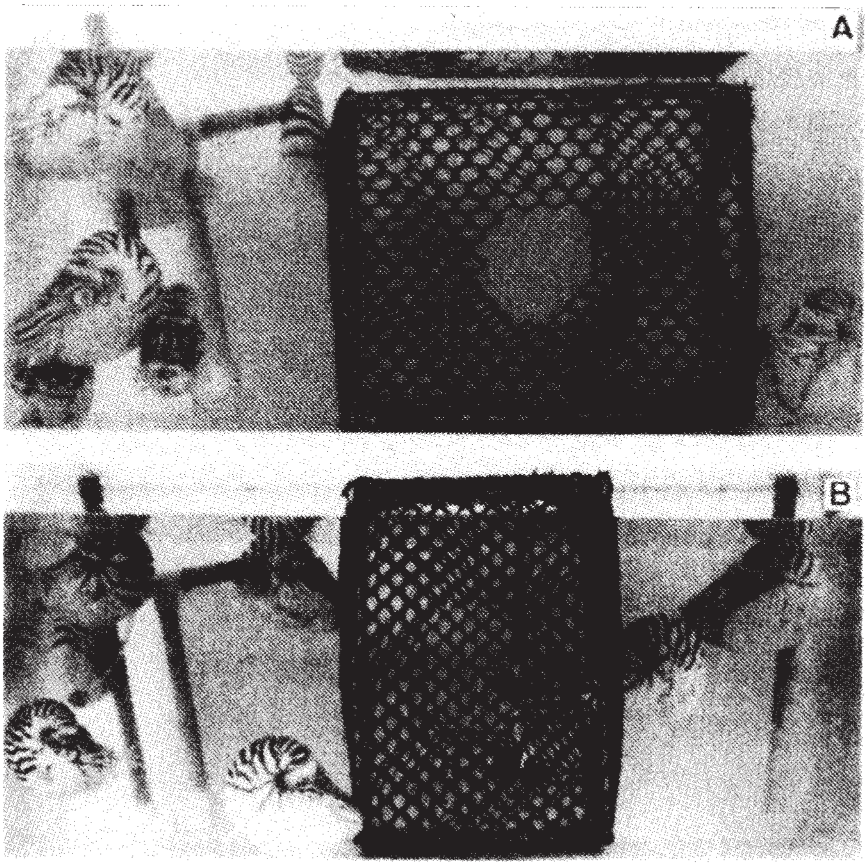

Fig. 2. A Before food was put in the trap.
B The *Nautilus* then faced the food and swam to it.

times, and left the trap. Then further shrimps were given, and each time another *Nautilus* showed the same searching and catching behavior. There was only one *Nautilus* which did no searching but merely caught the food. The time taken to catch the food and finding their way out of the trap ranged from 5 to 27 minutes. There was no difference between males and females.

When a *Nautilus* enters the trap voluntarily it swims around calmly, and on leaving the trap, it behaves as though it measures its size and the location of the exit. It moves smoothly inside the trap and hardly touches the net. But if a *Nautilus* was forced to enter the trap in which the shrimp was hung, it became excited and swam backward and did not feed. If it touched the net, it immediately moved away from it. Even when touching the shrimp, the *Nautilus* never took it. It tried instead to leave the trap by swimming backward. After getting out of the trap, it was excited and kept swimming for several minutes. Then it finally adhered to the tank wall. During this state, the *Nautilus* contracted and lifted up its hood.

Like squid and octopus, *Nautilus* perform quite complicated searching behavior before predation. How do they recognize their surroundings? What is the role sight and smell in predation? What part is played by memory?

We investigated the amount of the food consumed by the Philippine *Nautilus* kept in Kamoike Marine Park From 28 September 1981 to 30 January 1982. Frozen small fish and Crustacea such as shrimps were eaten in amounts of 8 to 12 g per day or, at most 20 g. Food was given once a day, but some did not eat. One of the four *Nautilus* died within three months. The amount of food consumed by the rest gradually decreased, and all had died by March 1982.

5) Respiratory movements

The respiratory movement of *Nautilus* are indicated by opening and closure of the fronto-lateral mantle openings. As shown in Table 1, for 16 *Nautilus* the frequency of these movements fluctuated between 15 and 98 per minute. The frequency was lowest when they were floating on the surface with contracted tentacles or resting on a stone at the bottom. When they adhered to the tank wall or crawled with tentacles, it increased. Respiratory movement was the greatest during swimming. There was variation between individuals but not between males and females. Smaller individuals respire at higher frequency than large ones.

Table 1. Frequency of respiratory movements in relation to behavior.

Nautilus			Number of breaths per minute				
No. of individual	Weight (g)	Shell diameter (mm)	Swimming	Crawling and Searching	Adhering	At bottom	Floating
Mele							
SV 5-1	310	118.2	80	-	60	60	-
SV 5-2	175	100.1	88	-	60	60	-
SV 6-1	545	150.0	60	52	46	40	36
SV 7-1	485	134.8	64	60	32	-	30
SV 9-1	545	150.0	75	68	60	48	40
SV 13-2	490	138.6	66	-	60	-	40
SV 5-2	475	100.1	88	-	66	60	-
SV 6-12	585	154.4	68	-	38	36	32
Female							
SV 8-1	540	147.1	50	-	40	32	15
SV 8-2	480	143.6	60	50	40	40	35
SV 12-7	260	114.0	84	-	66	60	-
SV 12-11	650	154.3	52	-	40	40	32
SV 13-3	250	112.4	80	70	62	54	40
SV 13-15	580	150.8	84	66	60	38	15
SV 14-1	460	135.4	50	-	45	40	30
Unidentified							
SV 10-6	170	96.8	96	88	66	60	-

6) Control of pupil diameter

The eye of *Nautilus* resembles a pin hole camera. Since there is no lens in the eye, it has been said that *Nautilus* cannot recognize images of objects but can perceive the amplitude of light. But we infer from the complicated searching and eating behaviors observed that, *Nautilus* can recognize the shape of objects, perhaps visually. We investigated the reaction of the pupil to light. Using a *Nautilus* whose shell was 15 cm in length, measured the diameter of the pupil including the black pigment band around it by means of photographs. We compared the changes of diameter with the intensity (Lux units) of light incident on the pupil. The results were as follows: there is a decrease in diameter of 0.5−1 mm on lighting a 300 W lamp, this was in daytime and in addition to a fluorescent lamp in the laboratory. A young Fijian *Nautilus*, whose shell length was 7 cm and whose pupil diameter was photographed at a depth of 180 meters had a pupil width of about 3−5 mm. *Nautilus* thus appears to open and close its pupil according to stimulation by light. We do not know, however, how light controls pupil diameter.

There was no effect with normal lighting, but when there was some shadow, due to people moving around, some movement of the pupil was observed.

The eye of a *Nautilus* was removed and was cut open. There was greenish fluorescent material inside the sack-like eyeball. This may suggest that *Nautilus* has the eye of nocturnal animal's behavior.

7) Excretion after breeding

Nautilus captured and transferred to the aquarium ejected excreta a little later. A *Nautilus* captured with fish as bait ejected a lump of blackish excreta after being transferred to the tank. This was seen in Philippine and Fijian *Nautilus*. The first lump of excreta of Fijian *Nautilus* was a cylinder 5 mm in diameter and 5 cm in length. After examination it showed that red small particles were mingled in the excreta. These corpuscles looked like a shrimp's under a microscope. The excreta consisted of a spiral bundle of thin threads of 1 mm diameter. There were various chitin shells like crustacea, mixed with plant fibers. There were also 136 light brown unicellular algal cells in the excreta, resembling coral zooxanthellae.

When a shrimp was given to a *Nautilus* in the tank, it excreted three days later. In another *Nautilus* fish from bait were packed into the gullet but the first excreta discharged in the tank contained shrimps. Those shrimps were therefore taken in the open sea before trapping (as it is unlikely that the *Nautilus* ate shrimps incidentally got into the trap.) The excreta also contained zooxanthellae, but it is not known if *Nautilus* eats corals or only animals which feed on coral and do not digest the symbiotic algae. There seems to exist some connection between the coral and *Nautilus* living in the reef.

When *Nautilus* behavior at night was observed, matter discharged appeared fluorescent. Is this fluorescence due to bacteria or is it simply due to a food chain? Or are *Nautilus* luminous animals like coral?

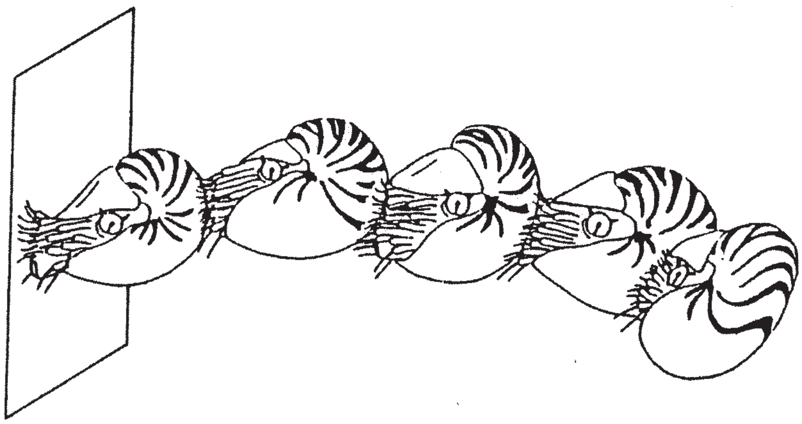

Fig. 3. Chain formation in which five Philippine *Nautilus* are in the sequence male—female—male—female—male.

8) Chain formation and reproductive behavior

We observed the behavior of 12 Philippine *Nautilus* (six females and six males). Two to three days after capture, all the *Nautilus* were kept in the same tank. Chain formation was observed often. The chain started with a *Nautilus* adhering to the glass wall. Another *Nautilus* then adhered to the shell of the first and so on. The chain sometimes consisted of five individuals (Fig. 3). The chain formed between the middle of the tank wall and under the water surface. For a longer chain it took 3 hours but a short chain took only from 2 to 6 minutes. Chain formation persisted for up to 8 hours. Couplings between a male and a female mutually connected with each other were 80% of the total. In the Philippine specimens copulation occurred often. But Fijian *Nautilus*, which were not in the breeding season, showed no chain formation. We suggest that chain formation in reproductive behavior which occurs in the breeding season.

Concluding Remarks

Freshly-collected *Nautilus* are capable of adapting themselves to new aquarium circumstances. Their fast, positive activity when captured implies that they possess quite complex behavioral potential. This rapid behavior is not found in *Nautilus* in aquaria, which behave slowly and appear passive. Their behavior depends on the interrelation between an advanced neural system, the muscular system and circulatory system, integrated according to the animal's physiology and structure. Behavior of *Nautilus* should be considered in the broad context of a long history of evolution. Judging from its adaptive behavior including communication between individuals, *Nautilus* are able to respond effectively to changes in the environment.

Summary

Behavior has been studied in *Nautilus pompilius* from the Philippines and Fiji, and *Nautilus belauensis* from Palau, kept at Kamoike Marine Park aquarium.

Behavioral observations suggest that captured *Nautilus* shows the same behavior as animals in the ocean. Some of the patterns observed were adhering to the wall or bottom of the tank, floating to the top of the tank, floating with swinging of the shell back and forth, clinging to a stone or the glass wall at the bottom of the tank with shrinking tentacles.

Since there is no lens in the eye, it has been said that *Nautilus* can not recognize images but can perceive different light. Fresh *Nautilus* are capable of adaptive pupil changes, and sudden movements of the *Nautilus* may be caused by a shadow reaction.

In case of predatory behavior, *Nautilus* like squid and octopus, performs quite complicated searching behavior before predation.

There is variation in respiratory behavior between individuals but not between male and female. Smaller individuals respire at higher frequency than large ones.

A young Fijian *Nautilus*, whose shell length was 7 cm and whose pupil diameter was photographed at a depth of 180 m, had a pupil width of about 3−5 mm. *Nautilus* appears to open and close its pupil according to the intensity of light but we do not know, however, how light controls pupil diameter.

As for their excretory behavior, when a shrimp was given to a *Nautilus* in the tank, it excreted three days later. The excreta also contained zooxanthellae, but it is not known if *Nautilus* eats corals or only animals which feed on coral and do not digest the symbiotic algae. There seems to exist some connection between the coral and *Nautilus* which live in the reef.

There is chain formation during breeding season. Couplings between a male and a female mutually connected with each other were 80% of the total. In the Philippine specimens copulation occurred often. But Fijian *Nautilus*, which were not in the breeding season, showed no chain formation. We suggest that chain formation is reproductive behavior which occurs in the breeding season.

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