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STUDIES OF *NAUTILUS BELAUENSIS* IN PALAU

The Predatory Activity of Captured *Nautilus belauensis*

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Abstract

Nautilus has been described as a "living fossil" although its life cycle and behavior have not been fully studied in terms of its whole life history. The authors investigated the predatory activity of *Nautilus* in the laboratory and its ability to detect food when a stimulant is present. Four *Nautili* were used for this experiment. Their activity was recorded when live shrimp and artificial food in the form of meat extract were provided. Even when in hungry state they showed little activity, but when a stimulant in the form of live shrimp or artificial food was introduced into the water column, their activity increased. In the case of live prawns, they kept searching for prey until they obtained it. However, when meat extract was given, searching activity increased for nearly 5 minutes but later decreased.

Introduction

The emergence of *Nautilus*, a mollusk, took place on the earth about five hundred million years ago. Since then, its one genus and six species have been widely known as the "living fossil." These species are deep sea animals which live at depths of 100 to 600 meters, ranging from the South Seas to the coral reef of the Indian Ocean. For this reason, their living conditions and natural life cycle have not been fully clarified, except from the viewpoint of geology, paleontology, morphology, physiology, ethology, and ecology. However, the predatory activity of *Nautilus belauensis* had not been described. So we carried out experiment in Aquarium studies on the predatory activity of Nb using live prawns, slices of fish, squid, chicken meat, bivalve, and meat extract.

Materials and Methods

The *Nautilus* research group in Kagoshima University captured *Nautilus belauensis* (hereafter cited as Nb) offshore of the Palau Islands about 200 meters deep at 15℃ water temperature in September 1988 and January 1989. The Nbs were kept in a water tank made of vinyl, whose size reached 1.5m in diameter and 1m in height. The Nbs were not fed or made to excrete; each of them was kept in a separate vinyl bag, and sea water was poured into the bag until the shell was fully immersed. Adequate oxygen was supplied and the bags were shipped to Japan by air. Three days after their capture, the Nbs were transferred to water tanks at Kagoshima Marine Park where our observations were carried out.

The sea water used for keeping Nbs was supplied by a long water pipe from

the Marine Park to water tanks, filtered twice through sand. (Water tanks consisted of three types, namely A, B, and C.)

Type A: a sand filter tank, made of double glass; a square pillar shape 55.5cm in length, 47cm in width, and 64cm in height. Volume was 167 ℓ and its water supply was adjustable from 1.0 to 2.5 ℓ /min.

Type B: a filter tank, made of acrylic; a column 50cm in radius and 100cm in height; the volume was 785 ℓ ; water supply was adjustable from 1.0 to 2.5 ℓ /min.

Type C: made of F. R. P.; 100cm in length, 200cm in width, and 30cm in depth; 600 ℓ in volume.

In tanks A and B, water temperature was kept between 15℃ and 18℃ by a cooler, and also by adjusting the amount of water supplied. Since the water temperature of tank C could not be adjusted, a continuous supply of water was used during the experiment and during summer this tank was not used.

The quality of sea water was kept at the following levels: pH. 8.2 ~ 8.6 with specific gravity of 1.020 ~ 1.030. Nbs numbered 6, 5, 2, and 1 were used for our experiments, but No. 2 died on 30th December 1988.

Observations and Results

I. Activity without food for twenty-four hours

Water tank activity of four individuals numbered 6, 5, 2, and 1 was observed and recorded for twenty-four hours on November 2-3 and 23-24, and on December 1-2 and 7-8. Our record is shown in Fig. 1. A solid circle indicates the moment when a Nb adhered to the wall of the water tank with a tentacle while swimming. The solid line following the circle denotes the time duration of its sticking to the wall.

A lacuna between solid lines designates the time duration of rocking motions. We expected to observe specific time periods of food searching because predatory activity is higher in the evening, and at night and dawn (1985, Y. Kakinuma and J. Tsukahara). However, Fig. 1 shows the activities of adherence and swimming are not consistent, and their movement is independent of one another.

II. Nb's Predatory Activity

We investigated how Nbs locate food. Experiments were performed twelve times in Tank C at 18℃. Food was placed both on the upper side ((a) in Fig. 2) and on the lower side ((b) in Fig. 2) of the water stream. Fig. 2 shows two examples of (a) and (b). When a live prawn was used as food, mark X indicated its location. The time when food was released into the water tank was set at 0:00, and the time indicated beside a sketch of Nb denotes the time of its leaving the wall.

The location of Nb at ten second intervals is illustrated in Fig. 3 In cases (a) and (b), Nb left the tank wall two and seven minutes after food stimulation, respectively. It first swam backward for about twenty seconds and then turned around, went forward, and started searching for food by protruding its tentacles.

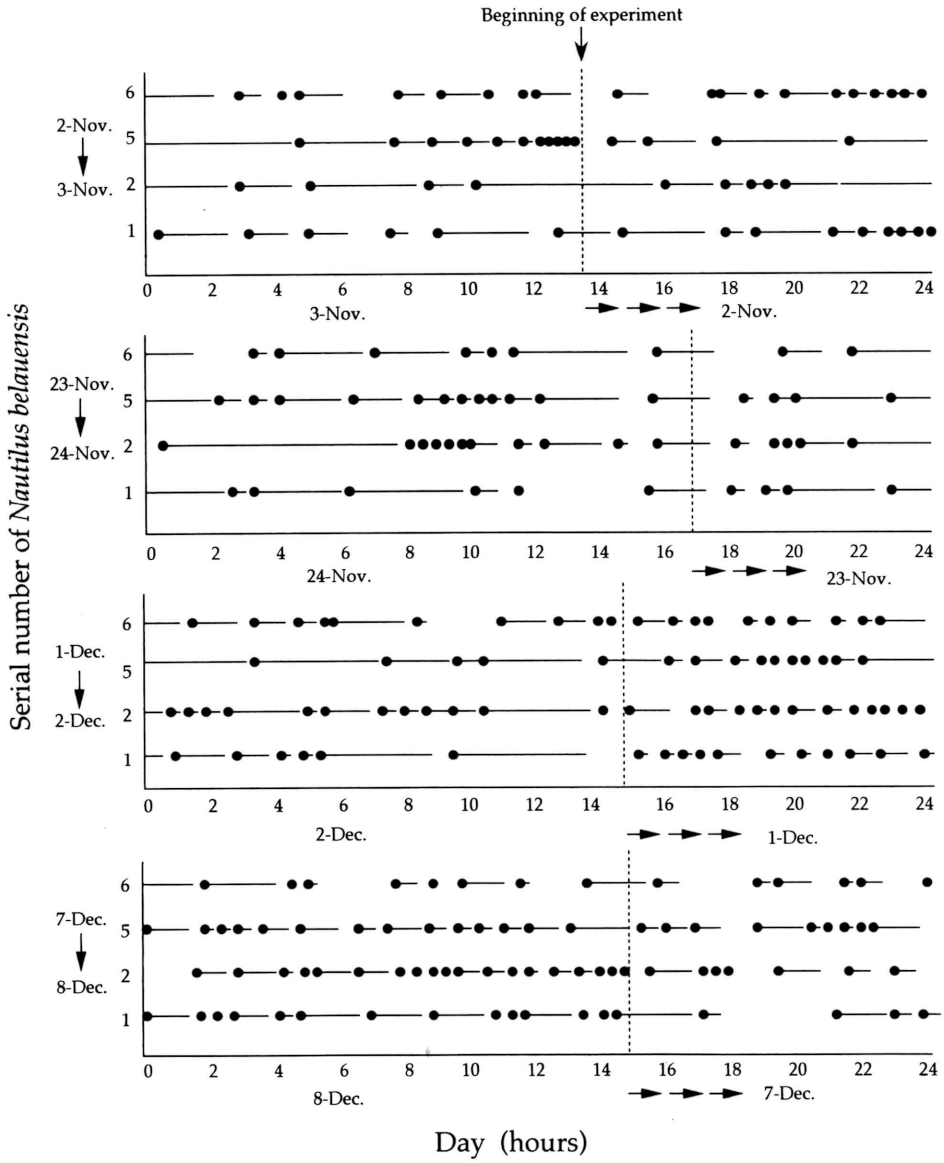

Fig. 1. Activity of four Nautili for a 24 hour period.

Nb swam towards the food and protruded its tentacles as if perceiving the prawn. However, Nb did not directly approach the food; rather, it swam around the prawn and spouted water towards it once or twice. Then Nb caught it. It took one or two minutes after food was placed in the upper supply near the entrance of the water stream before predatory activity (case (a)). It took five or seven minutes in the case of (b) when the prawn was placed in the lower part of the stream (near the water exit). However, once Nb recognized the food, the time taken to capture it became shorter, about one minute, in both cases (a) and (b). Since water tank C was not very deep (25cm in depth) only Nb's horizontal motion was recorded.

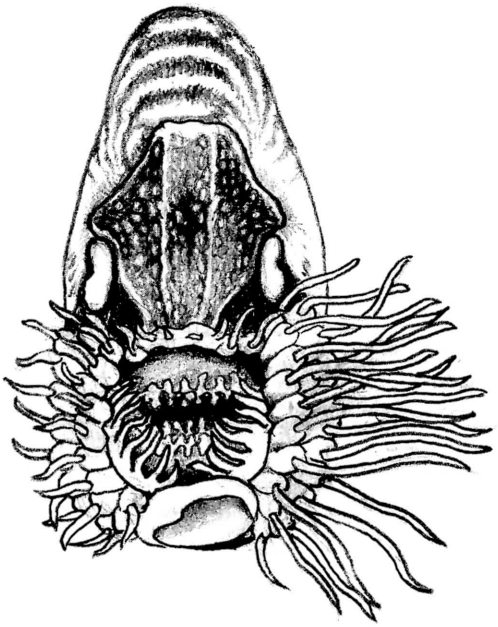

Fig. 2-A.

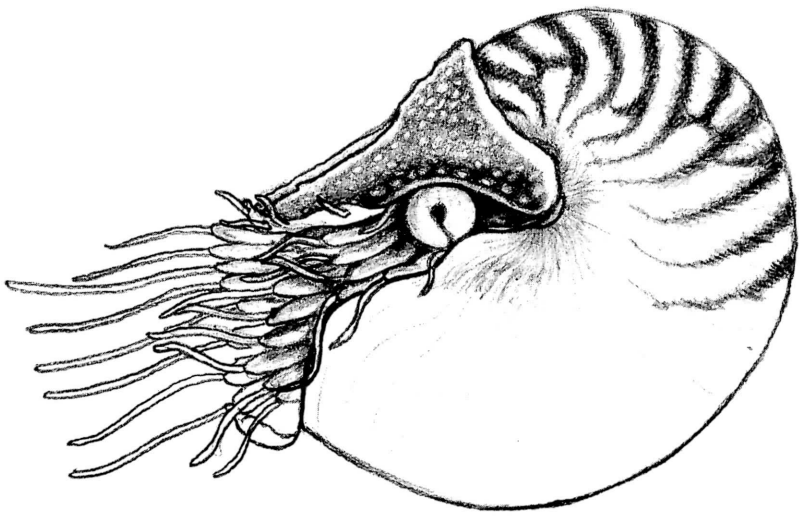

Fig. 2-B.

Fig. 2-A. When there is a strong stimulant from the right side, it is seen that the tentacles on the right side only are protruded.

2-B. If the stimulant comes from the front, it is seen that the tentacles in front only are protruded.

Later, Nb was transferred to the deeper tank, type B, whose depth was 100cm. Nb adhered to the wall at a height of about 50cm in the new experiment. Madagascar shrimps were used for food. The shrimps were placed on the water surface in trial (a) and at the bottom in trial (b). In case (a), Nb swam almost horizontally and then toward the water surface, searching for and catching food. In case (b), Nb swam almost horizontally, making a circular trip; then it extended one tentacle, searched for, and caught the food. This behavior suggests that Nb recognized the vertical position of the food. The behavior of *Nautilus* towards external stimuli indicates that it only protrudes its tentacles in the direction from which the stimuli are coming. This behavior is further illustrated in Fig. 2-A and Fig. 2-B.

Apart from live prawns (*Penaeus japonicus*), fish (*Trachurus japonicus, Sardinops melanostica, Spratelloides gracilis*), Squid, chicken meat, and bivalves (*Rudditapes philippinarum*), were used as stimuli in our experiment. It consumed all the different kinds of food given, except the bivalve meat. Also, it spouted the remains of shrimp heads and tails.

Moreover, when Nb seeks food with a tentacle, it uses its right or left tentacle properly. After catching the food, Nb brings this towards its mouth with both tentacles. This confirms that Nb distinguishes right and left, as well as directional axiality around a median line.

III. Behavior patterns during the period between food stimulation and the capture of food

Experiments were carried out in water tanks B and C. It is difficult to observe consistent behavior patterns since there are differences between foods, between individuals, and between physiological states. Therefore, in order to study Nb's basic predatory activities, we used Ehrlich meat extract (1% water solution of 0.5cc) as a food stimulant instead of live food. The solution was dropped into the water outlet at 10cm deep and we observed how Nb behaved after receiving this food stimulation. The sea water was kept running as usual by adjusting its flow at a rate of 1.5 - 2.0 ℓ per minute to ensure a consistent level of water quality. The behavior pattern of Nb during this process is shown in Fig. 3. Before adding the meat extract, Nb was stuck to the wall with its tentacles or was in a rocking state in the water (stage 1). At about 10 seconds after dropping the meat extract, Nb protruded the lower part of its tentacle sheaths downward and all tentacles were seen protruding from sheaths including the uppers part (stage II). Nb swam forward with tentacles stretched in front to search for the food, opening the tentacles and touching the bottom of the water tank. It appeared that each tentacle functioned independently (stage III). Nb then stopped its searching activity, perhaps because it had found no food or because the concentration of the meat extract had weakened. It withdrew half to two-thirds of its tentacles and returned to a rocking state (stage IV). After this, Nb continued to rock or returned from stage I (stage V). The time durations of stage I-IV were more than ten seconds, one minute, 4-5

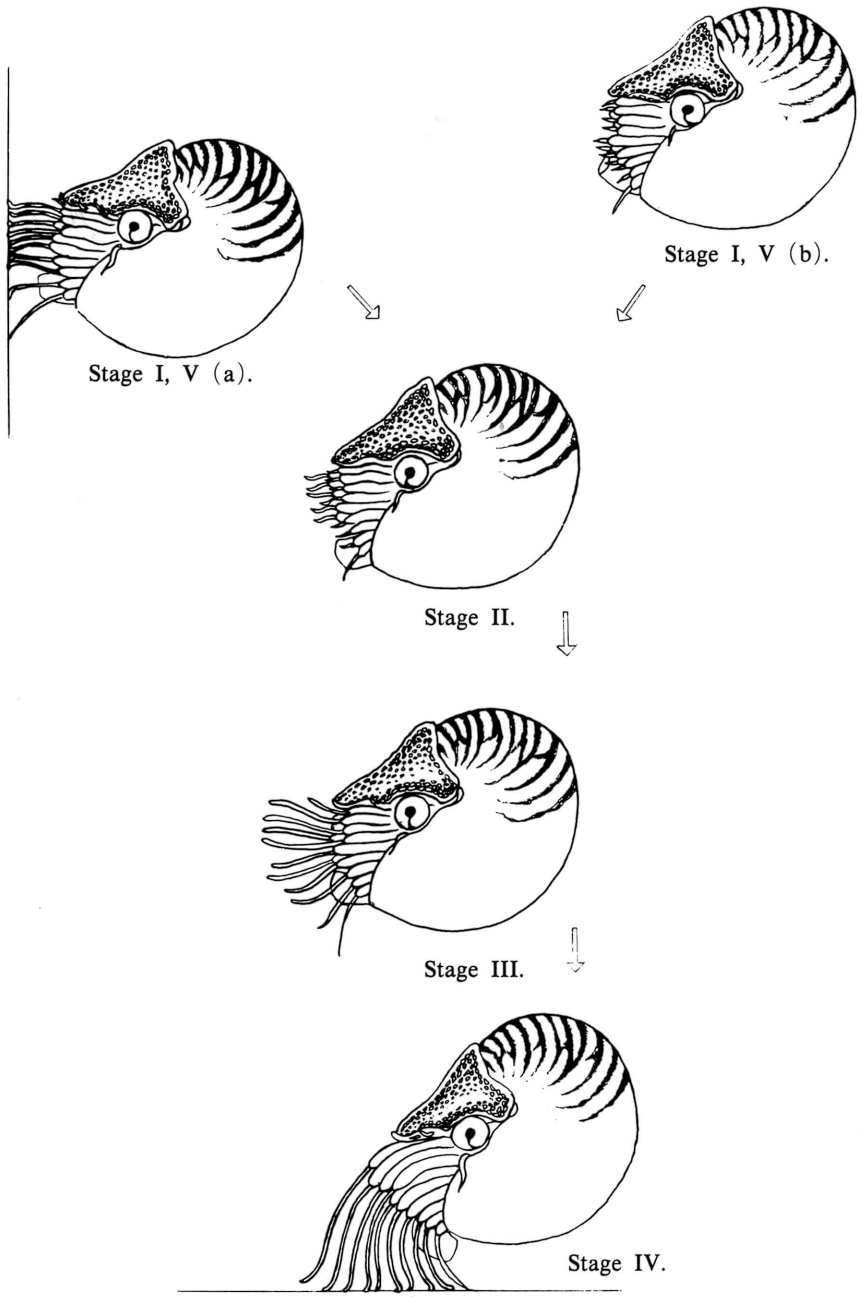

Fig. 3. A typical behavior when Nb responded to the food stimulation.

Stage I, V (a).	Attached to the wall.
Stage I, V (b).	Free swimming stage.
Stage II.	Detected smell and started searching for the food.
Stage III.	Protruded its tentacles.
Stage IV.	When the stimulant is not detected, it goes to the bottom of the aquarium and protrudes its tentacles.

minutes, and even 10-20 minutes; behavior patterns do not coincide with time. When more concentrated solutions of meat extract of 1cc, 1.5cc, and 2cc were used, there was no effect on elapsed time. The repeated pattern of stages I - V was observed again. What may be more important are different degrees of hunger and different physiological states of Nb individuals. Furthermore, it was impossible to describe predatory behavior in terms of distance, so instead we investigated Nb's activity by counting the number of breaths. The breathing rate of smaller individuals was more rapid than those of bigger ones. However, breathing rates of all individuals rapidly increased by food or food stimulation, and these rates remained constant during searching activity. In the case of food stimulation and food recognition, breathing rate was 70-80, more than double the normal value. In some cases, certain individuals were less active, and breathing rates increased only up to 10-15. At any rate, breathing returned to normal a few minutes after search activity had stopped, perhaps because Nb recognized the absence of living food. When actual food was supplied, the number of breaths decreased remarkably. After capture the number gradually returned to the normal value obtained (Fig. IV). Moreover, when the food was placed at the water surface of tank B (100cm deep), Nb immediately swam towards the surface to catch the food, after a horizontal circular trip. This indicates that Nb is capable of recognizing the direction and position of food.

Conclusion

Nbs from the Palau Islands were observed to have two usual behavioral activities in water tanks; that is, sticking to the wall of the tank or rocking swimming. No search activity was observed, even in a hungry state, until food is given. Nb immediately starts hunting food, swimming directly to it by moving vertically and horizontally, extending its tentacles forward, seeking the food with opened tentacles, catching it, and finally consuming it. When meat extract as an artificial food stimulation was given, it increased predatory activity, but returned to a normal state in a short time after one to 4.5 minutes regardless of the concentration of the meat extract. Nb does not seek food for a long time, and any activity requiring unnecessary energy consumption was not observed. But Nb searching behavior shows a consistent pattern of activity, although time duration varies. These observations suggest the following: in nature Nb does not actively hunt to catch food when it is hungry, but waits, rocking in a water stream or adhering to a rock, until it senses food by olfactory stimulation (as demonstrated with the meat extract). It can be concluded that Nb has efficient perception capacities allowing it to locate and catch the food.

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