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Study on Predation of Moon Jellyfish *Aurelia aurita* on Edible Jellyfish *Rhopilema esculenta*

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Abstract: In recent years, jellyfish blooms have attracted considerable scientific interest for the potential impacts on marine organism and ecosystem functioning, with much attention paid to jellyfish as predators. Other than qualitative data and observations, few studies have quantified direct predation on jellyfish. This study is designed to test the predation between edible jellyfish *Rhopilema esculenta* and moon jellyfish *Aurelia aurita* with the average time and captured rate. And comparisons are done using the least significant difference (LSD) test at $P < 0.05$ and $P < 0.01$. The young edible jellyfish and moon jellyfish are bred and observed on the predatory behavior in Qingdao aquarium. A total of 520 jellyfish are sampled to quantify predation between moon and edible jellyfish in four tests. The results show that moon jellyfish of 10-11 mm in umbrella diameter prey on edible jellyfish of 4-5 mm in 16 min, and the predation rate is 100%. Moon jellyfish of 18-20 mm spend a longer time to feed all edible jellyfish of 9-12 mm. Edible jellyfish can not be caught, if its umbrella diameter is more than 20 mm. Though edible jellyfish is bigger than moon jellyfish, the former can not prey on the later in a tank. The differences between the four groups are very significant ($P < 0.01$). The observation indicates that moon jellyfish is one of the natural enemies of the young edible jellyfish. Early prediction and reduction of moon jellyfish can not only effectively defense adult jellyfish outbreaks, but also improve the yield of edible jellyfish. With the edible jellyfish growing, its defense is enhancing. Edible jellyfish can not prey directly on moon jellyfish, but they still interact in the food, water quality and the survival space.

Key words: Predation, moon jellyfish, edible jellyfish.

1. Introduction

In recent years, jellyfish have achieved a prominent position in studies of marine organism and ecology. However, their roles in marine food webs may vary according to species, life stages, potential predators and available resources. Many studies have shown that jellyfish act as predators on both invertebrate (e.g., cnidarians, crustaceans, tunicates) and vertebrate (fish eggs and larvae) zooplankton [1]. In addition, the predators may impact relative webs by impairing the phytoplankton-crustacean-fish pathway [2]. Because of the rapid digestion, poor preservation and difficult recognition of gelatinous organisms inside digestive systems, fish predation on them has been poorly investigated and probably underestimated [3].

Moon jellyfish (*Aurelia aurita* Linnaeus, 1758) is a kind of the cosmopolitan zooplankton, which belongs to Cnidaria, Scyphozoa, Semaeostomeae, Ulmaridae, Aurelia. It distributes mainly along the sea coast reef and shallow sea area from 70° N to 40° S, such as Dalian, Yantai, Weihai and Qingdao in China. Moon jellyfish captures mainly planktonic animals, such as copepods, mollusks, cladocerans, fish eggs and the young fish. And sometimes, it also eats small ctenophore and hydrozoan jellyfish. Moon jellyfish floats on the surface of the water by the rhythmic contraction from the exumbrella. In order to prey on food, its umbrella and tentacles are always expansive. Nearly half a century, many areas in the world have happened frequently jellyfish outbreak. Just as the large gelatinous zooplankton, moon jellyfish outbreak has caused great harm to marine ecosystems and marine fishery economy [4].

Edible jellyfish (*Rhopilema esculenta* Kishinouye, 1891) is the most important economic jellyfish in the

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Asia, which belongs to Cnidaria, Scyphozoa, Rhizostomeae, Rhizostomatidae, Rhopilema. It distributes mainly in China, Japan and the Korean Peninsula. People have caught it to eat for thousands of years. Its production accounts for more than 90% of all edible jellyfish. In recent years, the commercial aquaculture has expanded greatly in China. Many biological studies have focused on the culture techniques and environmental impact of aquaculture activities [5, 6].

However, in recent years, the production of edible jellyfish has been declining in China sea. Now, it is difficult to appear in large numbers in the traditional edible jellyfish grounds, such as Zhejiang, Jiangsu provinces. In Liaodong Bay, edible jellyfish are also found at a low level. But other disastrous jellyfish have increased year by year [4]. This controversial phenomenon is the result of competition between different species, or the change caused by the environment. If there are some rules to the rise and fall of the species, it is necessary to study further. In this regard, it has been investigated in many areas. Dong et al. [7] thought that there was direct relation between the reductive production of the edible jellyfish and the outbreak of a large jellyfish *Cyanea nozakii*. Other experts believed that there was a periodicity of the large jellyfish outbreak [8]. But the predation between moon jellyfish and edible jellyfish was not studied. Thus, the present study has evaluated the predator-prey relationships between larval moon and edible jellyfish by feeding observation, and provided theoretical and practical application to prevent the early outbreaks of moon jellyfish and improve the yield of edible jellyfish.

2. Materials and Methods

2.1 Materials

A total of 520 jellyfish, including of 330 moon and 190 edible jellyfish, are sampled to quantify predation in four tests. All jellyfish were bred artificially in Qingdao aquarium. In a group, animal's umbrella size and birth are close. They were fed *Artemia nauplii* hatched for 24 h with two times a day. Test 1 was finished in the 13 L circular cylinder with inflation driving. Tests 2 and 4 were finished in the 19 L circular cylinder with inflation driving. Test 3 was finished in the 100 L circular tank with pump driving. All tests were repeated three times.

2.2 Tested Methods

All animals have been reared *Artemia nauplii* before tests begin (Table 1). Then they can not be reared anything for 17 h. Predation is successful when edible jellyfish is bound by oral arms of moon jellyfish. *Artemia nauplii* which has been incubated for 24 h is fed jellyfish after the observation.

To observe carefully, everyday 10 edible jellyfish are put into the cylinder with 100 moon jellyfish in tests 1, 2 and 3, and continue three days in a group. While, 10 moon jellyfish are put into the cylinder with 100 edible jellyfish in test 4. Tests 1 and 2 finish when all edible jellyfish have been captured. Tests 3 and 4 finish after 24 h.

Table 1 Morphometric information and quantity of jellyfish used.

No.	Tested animal	Umbrella diameter (mm)	Umbrella thickness (mm)	Oral arms length (mm)	Tested number
Test 1	Moon jellyfish	10-11	0.8-1.0	4.2-4.5	100
	Edible jellyfish	4-5	2.3-2.4	4.1-4.5	30
Test 2	Moon jellyfish	18-20	1.3-1.5	6.1-7.6	100
	Edible jellyfish	9-12	4.2-5.7	5.5-7.2	30
Test 3	Moon jellyfish	55-60	5.3-6.0	25.0-33.0	100
	Edible jellyfish	20-23	5.2-6.5	18.0-21.0	30
Test 4	Moon jellyfish	10-11	0.8-1.0	4.2-4.5	30
	Edible jellyfish	20-23	5.2-6.5	18.0-21.0	100

Table 2 The captured time and captured rate between two kinds of tested animals.

No.	Time of the first captured (min)	Time of the end captured (min)	Average time ± standard deviation (min)	Captured rate
Test 1[A]	2	16	6.3 ± 3.5	100%
Test 2[B]	7	112	38.5 ± 29.1	100%
Test 3[C]	-	-	-	0
Test 4[D]	-	-	-	0

[A-D]Mean the significant difference in four tests ($P < 0.01$).

2.3 Statistical Analysis

Umbrella diameter, oral arms length and umbrella thickness are measured before experiment (Table 1). The experimental analysis of variance (ANOVA) is performed with the analysis Toolpak-VBA Excel 2010 for Windows, and comparisons are done using the least significant difference (LSD) test at $P < 0.05$ and $P < 0.01$(Table 2).

Captured rate in tests 1, 2 and 3 was calculated by Eq. (1):

$$\text{Captured rate} = \frac{\text{edible jellyfish}}{\text{moon jellyfish}} \times 100\% \quad (1)$$

However, the captured rate in test 4 was calculated as Eq. (2):

$$\text{Captured rate} = \frac{\text{moon jellyfish}}{\text{edible jellyfish}} \times 100\% \quad (2)$$

3. Results

The density of moon jellyfish larvae is 10 times to edible jellyfish in test 1, and the former umbrella diameter is two times to the latter. The results show that edible jellyfish larvae are preyed quickly by moon jellyfish through the oral arm and umbrella. Almost edible jellyfish are preyed after being captured firstly, because they can not get rid of moon jellyfish. A few were captured quickly after they had escaped. Only one was preyed after it had escaped successfully for four times. Moon jellyfish have preyed on four edible jellyfish in 2 min. And six edible jellyfish had survived in the test for 10-16 min. All edible jellyfish were preyed in 16 min, and the predation rate was 100%. The average time is 6.3 min to capture each edible jellyfish (Table 2).

The umbrella diameter of moon and edible jellyfish is about two times larger in test 2 than that in test 1. Moon jellyfish have captured all edible jellyfish in 2 h, though edible jellyfish escape easier in test 2 than in test 1. Only two edible jellyfish are successful preyed in 10 min in test 2. Moreover, edible jellyfish, which survival time is long, have broken away moon jellyfish for many times. Survival time of two edible jellyfish is more than 100 min, and 26 edible jellyfish are captured successfully in 10-100 min. The average time is 38.5 min to capture each edible jellyfish.

Edible jellyfish and moon jellyfish can coexist in a cylinder tank in test 3. Their appearance and viability are good until the end of experiment. In this process, moon jellyfish show predatory behavior, but all edible jellyfish have escaped.

In test 4, edible jellyfish do not show predatory behavior on moon jellyfish, though the umbrella diameter of the former is larger than the latter. At the same time, moon jellyfish have tried to prey on edible jellyfish when they are swimming. But edible jellyfish is free in a few seconds.

The difference between every two groups is very significant ($P < 0.01$) by LSD test.

4. Discussion

Moon jellyfish outbreak was frequently in recent years [9, 10]. At the same time, the number of edible jellyfish has been declining year by year due to many factors. However, the bigger the density of moon jellyfish, the higher is the opportunity to capture edible jellyfish. The breakout of moon jellyfish in the pond culture has seriously influenced the growth of edible jellyfish [8], which is consistent with this

experiment.

4.1 Human Fishing Limits the Number of Edible Jellyfish

Moon jellyfish is not useful to human, and is rarely fished. However, edible Jellyfish can be used in human feeding and traditional medicine [11], because edible jellyfish is extreme rich in nutrients. According to the determination, it contains 12.3 g of protein, 4 g of carbohydrates, 182 mg of calcium, 132 μg of iodine and a variety of vitamins in hectogram [12]. Additionally, traditional Chinese medicine thinks that the jellyfish can clear fever, phlegm and toxic materials. People have the tradition to eat edible jellyfish in Asia. Although more cultivated edible jellyfish is released each year, the number of jellyfish captured has decreased. There were 3.75 billion edible jellyfish released artificially in Shandong province in 2009, and 15,383.97 ton was recaptured; while 4.82 billion edible jellyfish was released artificially in 2010, and 13,966 ton was recaptured [13]. Nowadays, sand jellyfish, *Nemopilema nomurai*, is replacing edible jellyfish to be utilized in China because of the recession of edible jellyfish and the outbreak of sand jellyfish. In the future, the sustainable utilization of edible jellyfish can realize in nature through increasing artificial stocking, fishing control and increasing the alternative sand jellyfish [14].

4.2 The Number of Moon Jellyfish Is Dominant Because of the Reproduction and Strobilation

Both moon jellyfish and edible jellyfish life history include the attached scyphistoma stage and the planktonic ephyra and adult stage. Moon jellyfish is dominant in the scyphistoma propagation, strobilation and survival. The scyphistoma of moon jellyfish can reproduce through budding, stolon and podocyst [15], while edible jellyfish can only reproduce through podocyst proliferation [16]. The strobilation of moon jellyfish can produce 10-24 ephyra, while edible jellyfish is 4-10 ephyra. The survival rate after strobilation is 100% in moon jellyfish, while 20% in edible jellyfish [17]. Survey by Wan and Zhang [18] shows that the number of moon jellyfish ephyra is more in Jiaozhou Bay every year. Therefore, the young of moon jellyfish is more than that of edible jellyfish in early spring.

In this study, 10 edible jellyfish and 100 moon jellyfish are cultivated in a group in tests 1, 2 and 3. The density is consistent with that in nature. The density of tested animals impacts the predation. Sting cell is more in water, higher effect on edible jellyfish and more opportunities to capture.

4.3 Moon Jellyfish Is Bigger than Edible Jellyfish in Natural Waters

Ephyra of moon jellyfish began to appear in the Jiaozhou Bay in April, 2009. The abundance increased in May. For edible jellyfish, the umbrella size is 8 mm in the early June, while the artificial releasing begins [18]. In the laboratory, scyphistoma of moon jellyfish can strobilate at the temperature of 10-15 °C after low temperature, while that of edible jellyfish is 16-27 °C. Therefore, the birth of moon jellyfish is earlier, and the diameter of umbrella is larger than edible jellyfish. It is similar to this test. The umbrella diameter of moon jellyfish is two times than that of edible jellyfish in tests 1, 2 and 3. Moon jellyfish have always showed the predatory behavior, though all edible jellyfish have escaped in test 3.

4.4 The Structure of Moon Jellyfish Is Easier to Predation

Moon jellyfish has four oral arms and more than 100 tentacles for predatory. The prey is put into stomach and transported to the body through the radial canal after digestion. The outer umbrella and oral arms of edible jellyfish are smooth with a few sting cells. Food is inlet into the gastric cavity. And the diameter of suction is only 0.3-0.5 mm [19]. Compared with the moon jellyfish, special suction structure limits its prey.

Moon jellyfish can prey a variety of food in the artificial environment, including of *Artemia nauplii*, frozen shrimp and artificial feed. But edible jellyfish can only feed *Artemia nauplii* in the life history, and feed ability is very weak. Therefore, the disadvantage in the structure affects the number of edible jellyfish in the nature.

4.5 Moon Jellyfish Is Dominant in the Food Competition

Moon jellyfish affects other plankton through predation and competition. Greve's test [20] indicated that when a large number of moon jellyfish appeared, plankton had decreased sharply, even to zero, in a short period. In addition to edible jellyfish, moon jellyfish can prey on Atlantic herring larvae and copepod [21, 22]. In addition, polyps of moon jellyfish can prey on the polyps of some hydrozoan. Therefore, density of moon jellyfish is bigger, and the opportunity is higher to capture edible jellyfish year by year.

4.6 Moon Jellyfish and Edible Jellyfish Have the Ability to Escape Predators

This study shows that moon jellyfish can capture small edible jellyfish. The bigger edible jellyfish, the times is more to escape. Maybe there is more defensive with the bigger diameter, more powerful muscle contraction and thicker skin.

However, edible jellyfish have no predatory behavior on moon jellyfish, though the umbrella diameter of the former is two times larger than the latter in test 4. Maybe in the nature water, edible jellyfish can not capture moon jellyfish of any sizes. However, small moon jellyfish can affect edible jellyfish, because the former have tried to prey on the latter in test 4.

5. Conclusions

In this study, moon jellyfish show the predatory behavior on edible jellyfish, however, the latter can not capture the former. It is important to explain moon jellyfish outbreaks recently.

Moon jellyfish is not economic animals, but it is the basic feed for many animals. It is necessary to *Chrysaora* spp., *Sanderia malayensis* and sea turtle at the Qingdao aquarium. Edible jellyfish has the high economic value, but the yield is decreasing significantly since the middle 1980s. Therefore, proliferation and artificial breeding have been carried out in China. But the fishing yield is not increasing in the nature waters. And it has been found that production of edible jellyfish is very small even crop failure, if moon jellyfish has appeared in its breeding pool. Therefore, it should prevent scyphistoma and larvae of moon jellyfish into the farming pool.

How to use moon jellyfish and reduce harm for other biology in the nature? How to increase the yield of edible jellyfish? We can eliminate completely scyphistoma and larvae of moon jellyfish in the breeding pool. And it is necessary to establish the ecological balance in natural waters. In order to rapidly increase the density of edible jellyfish, we can artificially release more larvae of edible jellyfish in short term.

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