Oithona davisae, the Most Predominant Copepod in Tokyo Bay, a Highly Eutrophic Embayment: Why Are They So Predominant?

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Abstract
Oithona davisae is a planktonic cyclopoid copepod species, known to be extremely abundant and often predominates in coastal marine embayment. To understand why this animal is so successful, we have been looking into its swimming ability to escape from predators. Here we show how *O. davisae* escapes from the moon-jelly *Aurelia aurita*, which devours zooplankton and occurs in a huge number in embayments including Tokyo Bay. Direct observations revealed that *O. davisae* is agile enough to escape from the moon-jelly's *ephyra* larvae, which appear much more numerously than adult moon-jelly. This agility reducing the predation mortality may be crucial for *O. davisae* to predominate in this bay and somewhere else that are full of predators. Direct observations by the use of video cameras suggested that *O. davisae* may be recognized as a genius in escaping from predators, comparing with some other planktonic animals such as *Acartia* (larger copepod), barnacle *cypris*, decapod zoeas, etc., being less agile than *O. davisae*.

1 Introduction

Among various factors, anthropogenic loading and global warming are considered to be causing significant changes in the coastal marine environment. We need to holistically understand mechanisms in such changes to predict how the environment would be in the future. Prerequisite is detailed knowledge on biological processes as well as physical and chemical ones in response to the environmental changes. Planktonic copepods are important in the aquatic ecosystems because of their abundance and diversity; they are considered to bridge the primary producers (phytoplankton) and higher consumers (such as larger zooplankton and fish). (Nishida 1985; Tsuda and Nemoto 1988; Itoh and Aoki 2010).

Among them, a cyclopoid copepod *Oithona davisae* (Fig. 1) is one of the most predominant species in the zooplankton community of coastal

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Fig. 1 Adult of *Oithona davisae*, of which prosome length is ca. 400 µm

waters including embayments such as Tokyo Bay (Ferrari and Orsi 1984; Anakubo and Murano 1991; Itoh et al. 2011), one of the most eutrophic embayment in the world.

This bay is also known to be inhabited by abundant moon-jelly *Aurelia aurita*, having planktonic stages being voracious to smaller zooplanktons such as copepods (Omori et al. 1995). It is intriguing that *O. davisae* remains so predominant in spite of the abundant existence of the "copepod eater" *A. aurita*. In this context, we may speculate that certain reasons should exist for the coexistence of such abundant *A. aurita* and *O. davisae* as its prey.

In the present paper, we will (a) show some direct observations on the feeding behavior of moon-jelly's *ephyra* in laboratory conditions; (b) discuss the special feature of the behavior of *O. davisae*, able to escape easily from the *ephyra*; and (c) speculate the reason why *O. davisae* is predominant in Tokyo Bay today.

2 Materials and Method

2.1 *Ephyra* as Predator

In order to perform direct observations of predator-prey interactions between moon-jelly's *ephyra* and zooplankton, after the method previously established (Ishii et al. 2004), from mature moon-jelly *Aurelia aurita* captured from the innermost part of Tokyo Bay, planula larvae were obtained first, and then through the polyps, after strobilation, the *ephyra* larvae were liberated (Fig. 2).

2.2 Zooplankton as Prey

As preys of the *ephyra*, zooplankton such as *Oithona davisae*, *Acartia omorii, cypris* larvae of barnacles, zoea larvae of decapods, and adults of a small species of hydromedusae *Rathkea*

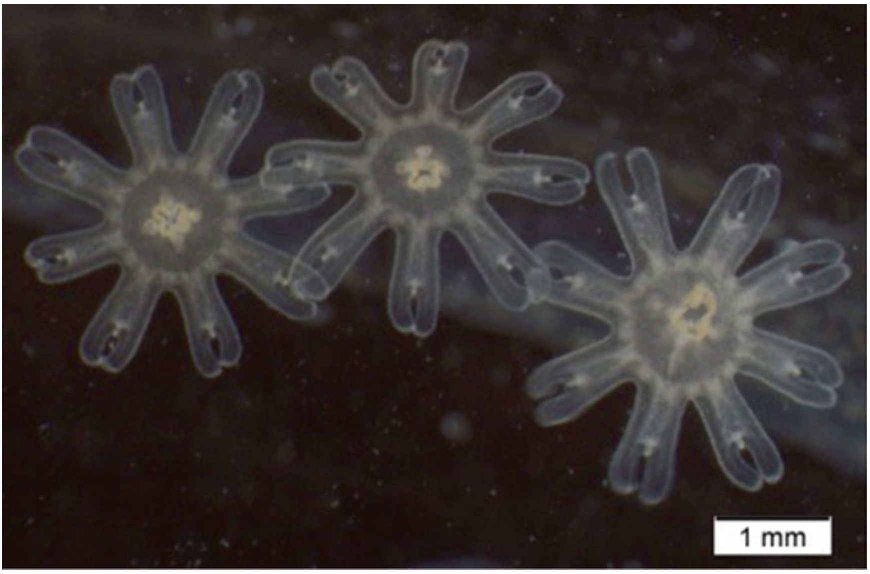

Fig. 2 *Ephyras* of moon-jelly *Aurelia aurita*. These were newly liberated from strobila being cultured in the laboratory. The whole diameter is ca. 3 mm

octopunctata were captured from the innermost part of Tokyo Bay and kept in a healthy condition. In addition, nauplii of *Artemia* were obtained from canned cysts.

2.3 Video Recording

A flat-drum chamber (100 mm diameter, 25 mm thick) made of Plexiglas filled with filtered seawater was used to perform direct observations on the feeding of *ephyra* on each kind of zooplankton. Holding the flat surface upright, while slowly rotating the chamber (1 revolution per minute) containing the *ephyra* and a limited number of one kind of zooplankton, recordings were done with a Sony Handycam video (30 frames per second).

Transparent cells of 40 mm cube and also cells for absorbance meter (10 mm × 10 mm and 50 mm tall) filled with filtered seawater and standing still were also used to make closer view of the prey and predators' behavior. Video images were analyzed frame by frame afterwards.

3 Results

3.1 *Oithona*

Live adult of *Oithona davisae* did not show any special behavior while the *ephyras* were not in the vicinity. However, once the *ephyras* were came near, they easily escaped. As a consequence of such behavior, almost no *Oithona* was captured by *ephyra* (Fig. 3).

3.2 *Acartia*

Acartia which is larger in size than *Oithona* is expected to swim faster and thus thought to be able to escape better than *Oithona*. However, unlike the case of *Oithona*, *Acartia* did not always succeed to escape, but sometimes were in contact with *ephyra* and eventually eaten (Fig. 4).

3.3 *Cypris*

Cypris larvae of barnacles were very often into contact with *ephyra*, but never eaten.

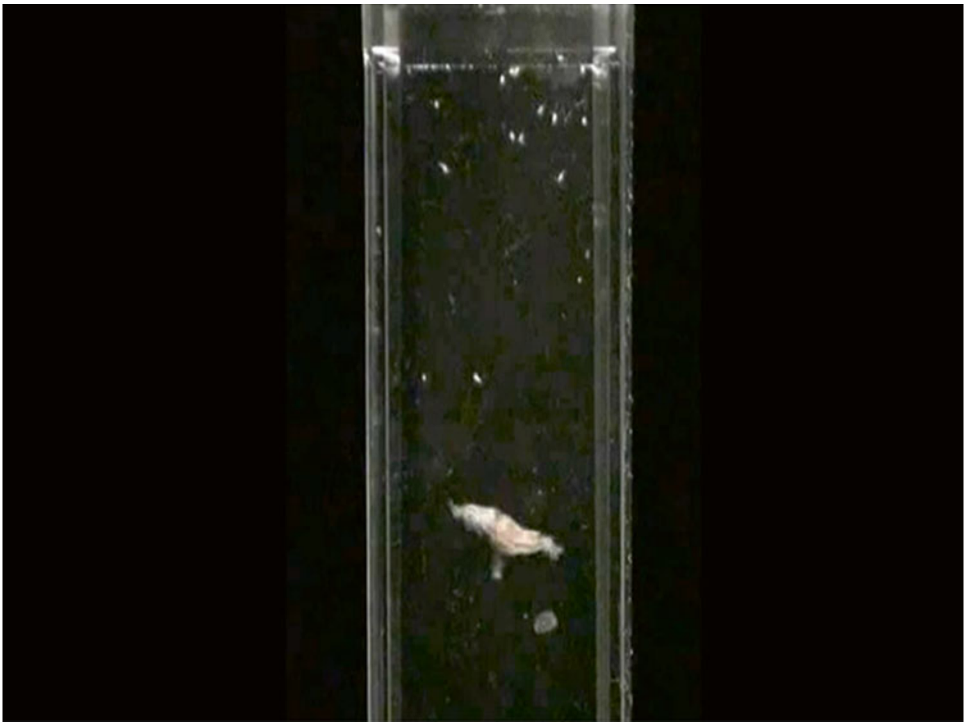

Fig. 3 Side view of the 10 mm absorbance cell containing an *ephyra* and ten *Oithona*. After this clip, the *ephyra* swam upward near the surface where *Oithona* is swimming. Nevertheless, not a single *Oithona* was in contact with *ephyra*. All the individuals of *Oithona* easily escaped from the *ephyra*

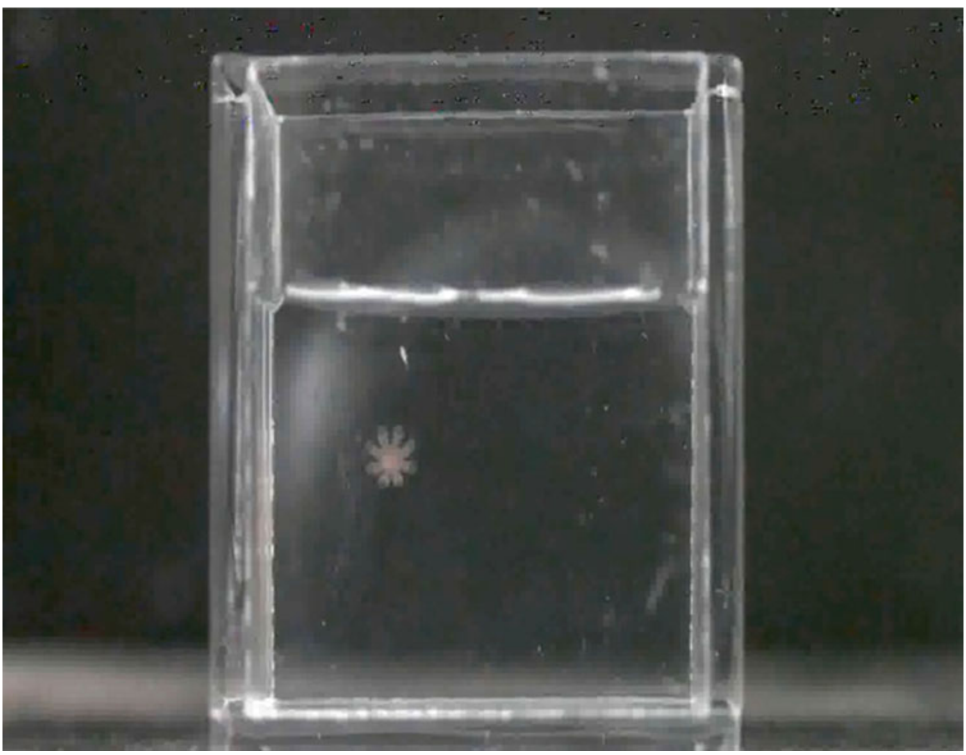

Fig. 4 Side view of the 40 mm cubic chamber containing an *ephyra* and a few *Acartia*. After this clip, the *ephyra* swam upward near the surface where *Acartia* were located. Unlike the case of *Oithona*, *Acartia* did not always succeed to escape, but sometimes were in contact with *ephyra* and eventually eaten

Fig. 5 Side view of the rotating flat drum chamber containing the *ephyra* and *Artemia* larvae. The *ephyra* in the top-middle of the image just captured two *Artemia*

After the contact with *ephyra, cypris* stopped swimming and made the body curled to sink. They restarted swimming after a delay ranging from several seconds and 2 min after the contact.

3.4 Zoea

Zoea larvae of decapods were often in contact with *ephyra*, but never eaten. It seems they were not seriously influenced by the *ephyral* venomous stings, probably having harder shell to avoid stings of the jellyfish tentacles.

3.5 *Rathkea*

In the vicinity of *ephyra*, the small hydromedusa *Rathkea octopunctata* seemed to try escaping. A single hit of *ephyra* seemed to be was enough to paralyze and capture *Rathkea*.

3.6 *Artemia*

Nauplius larvae of *Artemia* did not seem to avoid *ephyra* and were easily captured (Fig. 5). Once in contact with *ephyra*, the nauplii quickly got paralyzed probably by the *ephyra* venom. Additional observations using *Artemia* eggs as prey showed that the eggs were not captured by the *ephyra* (Fig. 5).

4 Discussion

We observed that *O. davisae*, being different from other zooplanktons, are not easily eaten by the *ephyra* of moon-jelly. In other words, they are capable of avoiding *ephyral* predation very well, suggesting that not all kinds of zooplankton are passively eaten by every stage of the moon-jelly. This observation may give a clue to understand why *O. davisae* are predominant in Tokyo Bay today. Our speculation is as follows:

- The recent predominance of *O. davisae* in Tokyo Bay may partly be explained by the increase in the abundance of moon-jelly due to the heavy increase of artificial constructions on the coast offering the substrata of the asexually growing polyps of the moon-jelly (Ishii and Katsukoshi 2010), directly followed by the *ephyra* and medusae.
- In addition, the increase in the occurrence of oxygen depletion in the lower layer of inner Tokyo Bay (Ando et al. 2005) may cause the general decrease of species diversity of planktons except for the moon-jelly that is less vulnerable in such oxygen-depleted environment (Ishii et al. 2004).
- Increase in *ephyras* of moon-jelly due possibly to the above reasons, which voraciously eat zooplanktons except for *O. davisae*, may eventually lead to enhance the predominance of *O. davisae*.
- Moreover, not spawning but carrying the eggs, being different from many other copepods, reproduction of *O. davisae* may not seriously be affected by the development of oxygen depletion in the bottom layer (Uye 1994).

It has been pointed out that the predominance of *O. davisae*, with a very small size (even adults >0.5 mm) and thus grazing smaller phytoplankton such as dinoflagellates but not diatoms, leads to leftovers and excess growth of diatoms that sink to the aphotic bottom (7). The increase of organic materials in the aphotic bottom deteriorates the oxygen depletion due to excess decomposition. This possible process of enhancement of oxygen depletion may also cause the increase of moon-jelly and predominance of *O. davisae* again. These processes may lead to some loss of species diversity in Tokyo Bay. To avoid this spiral, reduction of nutrient input and mitigation of artificial construction of the coastline are possible measures. Resilience of the Tokyo Bay ecosystem may not well function without reviving the natural coastline or without reducing the nutrient loading. To examine if the above speculation is valid, we are working on more quantitative studies on the prey-predator relationship between zooplanktons including *O. davisae* and the moon-jelly *A. aurita* (not only the *ephyra* stage but also the polyp and medusa stages).

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