

## 学 位 論 文 の 要 旨

論文題目      A Physio-ecological Study of Ephyrae of the Common Jellyfish *Aurelia aurita* s.l. (Cnidaria: Scyphozoa), with Special Reference to their Survival Capability under Starvation

(ミズクラゲ (*Aurelia aurita* s.l.) エフィラの生理生態学的研究、特に飢餓条件下における生残能力について)

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The moon jellyfish *Aurelia aurita* s.l. is the most common scyphozoan jellyfish in the coastal waters around the world, and the mass occurrences of this species have been reported from various regions. In recent decades, *A. aurita* blooms have become increasingly prominent in East Asian seas, causing serious problems to human sectors such as fisheries and coastal power plant operations. Therefore, it is important to identify causes for the enhancement of *A. aurita* populations to forecast likely outbreaks prior to the season of medusa blooms. In the population dynamics of scyphozoan jellyfish, the following two factors are important to determine the size of adult (medusa) population: (1) the abundance of benthic polyps, which reproduce asexually and undergo seasonal strobilation to release planktonic ephyrae, and (2) the mortality of ephyrae before recruitment to the medusa stage. Although much knowledge has been accumulated about physio-ecology of the polyp stage by previous studies, only few studies have been conducted for the ephyra stage.

The success for survival through larval stage is basically affected by two factors, viz. food availability and predation. For development to the medusa stage, ephyrae must start feeding before their nutritional reserves run out. However, they are functionally inefficient feeders compared to the medusa stage and the liberation of *A. aurita* ephyrae usually takes place during winter and early spring, when the biomass and production of prey zooplankton are the annual lowest. Therefore, starvation is considered to be a primary factor accounting for the mortality of ephyrae. The goal of this study is to understand physio-ecological characteristics of *A. aurita* ephyrae in order to enable forecast of medusa population outbreaks prior to regular medusa bloom season. For this, I conducted laboratory experiments mainly to examine the effect of starvation on various physio-ecological aspects of *A. aurita* ephyrae.

This thesis consists of 5 chapters. In Chapter 1, I extensively reviewed past and current scyphozoan jellyfish blooms in East Asian seas, in particular Chinese waters. Since I am a student from China, I also reviewed jellyfish studies in China, most of which were published in Chinese and hence are not easily accessible for non-Chinese researchers. These reviews can be useful to obtain specific jellyfish research and people's thoughts of jellyfish in China. Anyhow, the East Asian seas are a representative sea area in the world where massive jellyfish blooms recurrently take place. As *A. aurita* is the most prominent bloom forming species in this area, it is of importance not only to identify causes for the blooms but also forecast the blooms.

In Chapter 2, in order to evaluate starvation resistance and recovery capability in

first-feeding *A. aurita* ephyrae, I determined the median longevity ( $ML_{50}$ ), i.e. duration of starvation at which 50% of ephyrae die, and the point-of-no-return ( $PNR_{50}$ ), i.e. duration of starvation after which 50% of ephyrae die even if they subsequently feed, at 15, 12 and 9°C. The  $ML_{50}$  were 50, 70 and 100 d, and the  $PNR_{50}$  were 33.8, 38.4 and 58.6 d at 15, 12 and 9°C, respectively. These  $PNR_{50}$  are nearly one order of magnitude longer than those of larval marine molluscs, crustaceans and fishes, demonstrating that *A. aurita* ephyrae have strong starvation resistance and recovery capability. By the time of the  $PNR_{50}$ , ephyrae showed significant body size reduction: ca. 30 and 50% decrease in disc diameter and carbon content, respectively.

In Chapter 3, I investigated the effect of starvation on respiration rate of *A. aurita* ephyrae, because their extremely long  $PNR_{50}$  was thought to be attributed to their low metabolic rates. The respiration rate of a newly released ephyra was actually very low, i.e. 0.24, 0.24 and 0.19  $\mu\text{l O}_2 \text{ ephyra}^{-1} \text{ d}^{-1}$  at 15, 12 and 9°C, respectively. The respiration rate tended to decrease with the increase of starvation period, but statistical analysis did not detect the effect of starvation because of wide variation of respiration rate data. The carbon weight-specific respiration rates were constant for up to the period nearly  $PNR_{50}$ , indicating that the kinetics for basic metabolism is stable so far as metabolic substrate is available. The minimum food requirement based on the respiration rate was equivalent to 2.0, 2.0 and 1.6% of ephyra carbon weight at 15, 12 and 9°C, respectively. I also examined the effect of starvation on pulsation rate, since swimming ability is closely associated with feeding and escaping capabilities. The pulsation rate was accelerated by starvation for up to 20 d, indicating that moderately starved ephyrae actively swim so that they can capture more prey than newly released ephyrae. The maximum swimming speed achieved by *A. aurita* ephyrae was 8.9  $\text{cm min}^{-1}$ , suggesting that their main prey are confined to slow moving zooplankton such as barnacle nauplii, veliger larvae and hydromedusae. The pulsation rate decreased for ephyrae after 30 d of starvation, and hence the heavily starved ephyrae may be exposed to higher predation loss.

In Chapter 4, I examined whether a scyphozoan jellyfish *Chrysaora pacifica* acts as predators of *A. aurita* ephyrae, since extraordinarily long starvation resistance and strong recovery capability of *A. aurita* ephyrae implied that predation loss may probably be more important to determine their mortality in the field. I confirmed that *C. pacifica* young medusae could feed on *A. aurita* ephyrae. Based on the clearance rate determined for a *C. pacifica* young medusa (i.e. ca. 1.2  $\text{l predator}^{-1} \text{ d}^{-1}$ ), the clearance of a medusa of 5 cm disc diameter was estimated to be ca. 150  $\text{l predator}^{-1} \text{ d}^{-1}$ , which may be significant to influence the mortality of *A. aurita* ephyrae.

In the last chapter (Chapter 5), I fully discussed the physio-ecological specificity of *A. aurita* ephyrae, in particular emphasis to adaptation mechanisms for starvation. In the Inland Sea of Japan, for example, the release of ephyrae is programmed to occur during winter and early spring (i.e. January-March), when the zooplankton biomass and production rates are at its annual lowest. Thus, it is very likely that newly released ephyrae are exposed to severe nutritional stress in this cold season of minimal food abundance. Extremely long  $PNR_{50}$  of *A. aurita* ephyrae may be a physiological as well as ecological adaptation allowing them to survive the first few months after release. In the Inland Sea of Japan, the mortality of ephyrae seems to be very high like in Tokyo Bay, where 99% of ephyrae die before young medusa stage, but actual causes for the mortality could not be identified in this study. Meanwhile, a sympatric scyphozoan *C. pacifica* can be one of prominent predators of *A. aurita* ephyrae. In order to make the forecast of *A. aurita* medusa population outbreaks in a reliable manner, detailed population dynamics studies particularly during the ephyra stage as well as more studies on predators are needed in the future.