

Feeding behaviors of three tropical scleractinian corals in captivity

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(Received 19 March 2015; accepted 06 November 2015; first published online 10 May 2016)

This study examined the capture rates and prey digestion of three corals species in two genera (*Acropora* and *Pocillopora*) found dominantly in Thailand and the Federated States of Micronesia using *Artemia salina* nauplii as a food source. In addition, feeding during day and night times of corals was investigated. Results showed that all three coral species, namely, *Acropora millepora*, *Acropora nobilis*, and *Pocillopora damicornis* captured and consumed *A. salina* nauplii under both light and dark conditions. The capture rates of the three species ranged between 0.44 and 2.39 individuals/polyp/12 h. The results also showed complete digestions of *A. salina* nauplii by *A. millepora* and *A. nobilis* after 2 h, whereas *P. damicornis* took 2.5 h to complete the prey digestion. Even though feeding corals with *Artemia* is not a novel implication since this is widely used, the results of optimum daily feeding frequency of corals by *Artemia* may be applied for optimum corals growth and survival in captivity or aquarium.

Keywords: sexual reproduction; feeding; *Artemia salina*; prey; captivity; Thailand; Federated States of Micronesia

Introduction

Coral reefs worldwide have been declining due to several natural and anthropogenic threats (Chavanich et al. 2005, 2009; Wilkinson 2008; Burke et al. 2011). Several restoration techniques have been developed to restore reefs and increase coral coverage (Edwards and Gomez 2007; Edwards 2010). Restoration techniques include both active and passive restoration methods such as fragment transplantation, seeding production, and larval rearing by sexual reproduction, as well as artificial reefs (Edwards and Gomez 2007; Edwards 2010). However, some techniques remain at an experimental stage and can be success at scales of up to few hectares only (Edwards 2010). Recently, efforts to raise coral eggs to juvenile stage in a hatchery before being released to natural reefs have increased popularity because this technique can maintain genetic diversity of a coral species (Omori and Fujiwara 2004). However, nutritional requirement to maintain corals in a hatchery or in captivity remains a major constraint (Houlbrèque and Ferrier-Pagès 2009; Leal et al. 2014; Toh et al. 2014). In addition to restoration, a strong demand exists on culturing corals in captivity because live corals are among the most popular marine organisms in marine ornamental industry (Green 2003; Wabnitz et al. 2003). However, the culture method is not completely successful because of the limitation in maintaining live organisms and the

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nutritional requirement in captivity (Arvedlund et al. 2003; Wabnitz et al. 2003, Houlbrèque and Ferrier-Pagès 2009; Leal et al. 2014; Toh et al. 2014).

To fulfill the nutritional need, scleractinian corals use both autotrophic through symbiotic zooxanthellae and heterotrophic mechanisms (Muscatine 1990; Fabricius and Klumpp 1995; Houlbrèque and Ferrier-Pagès 2009). The majority of energy in corals is gained through zooxanthellae photosynthesis (Muscatine 1990; Fabricius and Klumpp 1995). However, several studies have shown that corals ingest various food ranging from bacteria to zooplanktons as well as dissolved organic and particle matter (Sebens et al. 1996; Anthony 1999; Houlbrèque and Ferrier-Pagès 2009), and the amount can account for up to 66% of fixed carbon into coral skeletons (Houlbrèque and Ferrier-Pagès 2009). Given the different amounts of energy needed, different corals show different feeding rates (Sebens et al. 1996; Ferrier-Pagès et al. 2003). Ferrier-Pagès et al. (2003) found that *Stylophora pistillata* Esper, 1797 captured less zooplankton than *Galaxea fascicularis* (Linnaeus, 1767). Corals use their tentacles to catch planktons (Ferrier-Pagès et al. 2003; Palardy et al. 2006), and digestion takes place in the gastrovascular cavity after the planktons pass the polyps. Thus, the prey digestion time is also related to the number of prey initially captured and ingested (Leal et al. 2013). In addition, the prey size and size of coral polyps, water flow rate, and ability of prey to avoid being captured are all related to the corals' potential to capture prey (Sebens et al. 1996; Piniak 2002; Palardy et al. 2006). *Artemia* spp. can be used to feed corals, and are easier to culture than other marine zooplankton species, yielding high nutrient value, and exhibiting a small size of about 0.5 mm in length (Leversee 1976; Heland et al. 2003; Reynaud et al. 2004). Petersen et al. (2008) and Toh et al. (2014) found that corals feeding on *Artemia* spp. showed higher growth rates than those not feeding on this species. Thus, to increase the coral growth in a hatchery, feeding corals with supplementary food may be an alternative as compared to non-feeding method. However, few studies have measured the feeding rates and digestible capacity of corals in captivity and no research has been conducted on *Acropora millepora* (Ehrenberg, 1834) and *Acropora nobilis* (Dana, 1846) (Petersen et al. 2008; Hii et al. 2009; Wijgerde et al. 2011).

The aim of this study was to investigate the capture rates and prey digestion of three corals species in two genera, *Acropora* Oken, 1815 and *Pocillopora* Lamark, 1816, found dominantly in Thailand and the Federated States of Micronesia using *Artemia salina* (Linnaeus, 1758) nauplii as a food source. In addition, the feeding during day and night times was examined.

Materials and methods

Coral specimens and Artemia salina nauplii

The experiments were run in Thailand and in the Federated States of Micronesia to compare different sources of coral samples and to investigate whether the same genus or species of corals would consume differently or not if they were from different locations. In Thailand, specimens of common reef-building coral species, *A. millepora*, and *Pocillopora damicornis* (Linnaeus, 1758), were used in the experiments. All experimented corals were obtained from aquaculture by sexual reproduction in a coral hatchery. *A. millepora* is a spawning coral, whereas *P. damicornis* is a brooding coral. The experimented colonies of *A. millepora* were derived from cross fertilization of gametes from at least three colonies. Larvae were then allowed to settle on cotta tiles and grow in the coral hatchery located at Samae San Island until they reached one year of age before the experiment. In the case of *P. damicornis*, larvae were collected directly from parental colonies. Then, cotta tiles

were provided for larval settlement and metamorphosis into the juvenile stage. Similar to *A. millepora*, juvenile *P. damicornis* were raised until they reached one year of age. The one-year-old cultured juvenile corals were approximately 2 cm in diameter and exhibited about 130 polyps. During the first year in the coral hatchery, no supplement food was given to juvenile corals.

In Chuuk, the Federated States of Micronesia, *A. nobilis* was selected instead of *A. millepora* because of the former's greater abundance in the area (Taihun et al. 2013). Both *A. nobilis* and *P. damicornis* were collected at 2–4 m depths at a reef in front of the Korea South Pacific Ocean Research Center. The collected corals were then broken into small fragments. The fragments were glued to small rocks using nontoxic super glue, and then placed in a tank for acclimation at least four days prior to the trials. The sizes of the fragments were approximately 2–3 cm in diameter, similar to those of the experimented corals in Thailand.

Before starting the trials, all corals were acclimated to experimental conditions at an indoor temperature of approximately 28 °C (controlled by a chiller) with a 12-h light and 12-h dark cycle (controlled by metal halide lamp 400 W (21 $\mu\text{mol m}^{-2} \text{s}^{-1}$)) for at least four days, and were not allowed to feed. During the experimental trials, the water was also filtered by 20 μm plankton net and changed every 12 h. In addition, newly cultured *A. salina* nauplii were hatched from commercial eggs, and prepared 24 h prior to the experiments.

Feeding behavior

Feeding experiments were performed to investigate the feeding activities of juvenile corals both *Acropora* spp. and *P. damicornis*. Newly hatched *A. salina* (at the umbrella stage of the *Artemia*) was used as coral food. Each coral colony was assigned to feed in one of the following treatments: (1) during the day (0600–1800), (2) during the night (1800–0600), (3) both in the day and night times (0600–1800 and 1800–0600). Five replicates in each treatment were employed for each coral species in each study site. In each replicate, a juvenile colony was placed in a 1-L glass aquarium, and 300 individuals of *A. salina* were given to corals each time based on the experimental times. During the experiment, the air pump was used to provide gentle water flow in the aquarium. Corals were allowed to feed for 12 h. The remaining densities of *A. salina* in the aquarium were counted 12 h after food was given each time. Control corals of each species were placed at identical aquariums and environment, but without *A. salina*. The experiments were run for seven days. In addition, the numbers of coral polyps were counted at the beginning and at the end of the experiment. The capture rate was measured by the number of *A. salina* eaten per polyp per 12 h as shown in the equation (Hii et al. 2009).

$$\text{Capture rate (per 12 hour)} = \frac{\text{Density}_i - \text{Density}_r}{\text{Number of polyps}}$$

density_i = initial number of *A. salina* nauplii, density_r = remaining *A. salina* nauplii after 12 h

Digestion rates

To determine the digestion rates of both *Acropora* spp. and *P. damicornis*, a laboratory experiment was conducted. A total of 108 coral fragments from 3 species (27 fragments of each coral species in each location) were experimented. Each coral fragment (with approximately 220 polyps) was fed with *A. salina* at 500 individuals per 1-L aquarium.

The density of *A. salina* in the digestion rates was higher than that of in feeding behavior experiment in order to increase the capture rate in a short time. A preliminary experiment showed that the capture rates did not influence the rates of the coral digestions. After the corals were fed, every 9 fragments were withdrawn at 1.5, 2.0, and 2.5 h after the initial food was given. Then, samples were preserved with 5% formalin, and decalcified by using 50% formic acid for 1 h to analyze the gastrovascular content of each coral polyp. The remaining tissues were dissected and investigated under a stereo light microscope. The percentage of *A. salina* digestion by each coral species was calculated on the basis of the contents left in the gastrovascular cavity of each coral polyp. To calculate the prey percentage, *A. salina* remained in the gastrovascular cavity was photographed and compared with an undigested one using CPCe program (Kohler and Gill 2006). The gastrovascular cavity contents of corals starved for two days were used as controls.

Statistical analysis

One-way ANOVA followed by Tukey's pairwise mean comparison was performed to examine the differences in capture and digestion rates of different corals in Thailand and the Federated States of Micronesia between day and night times.

Results

The experiments showed that all three coral species, *A. millepora*, *A. nobilis*, and *P. damicornis* captured and consumed *A. salina* nauplii (Figure 1). The capture rates of these three species ranged between 0.44 and 2.39 individuals/polyp/12 h (Figures 2–3). Overall, the capture rates were not significantly different between *Acropora* species in Thailand and in Chuuk, the Federated States of Micronesia ($F_{(1,194)} = 0.02$); however, *P. damicornis* in Thailand captured more significantly than the species in Chuuk ($F_{(1,202)} = 296.582$). *Acropora* spp. and *P. damicornis* in Thailand and the Federated States of Micronesia tended to have lower capture rates than other coral species (Table 1). Additionally, from the experiments, there were significant differences on the capture rates of both corals in Thailand be-

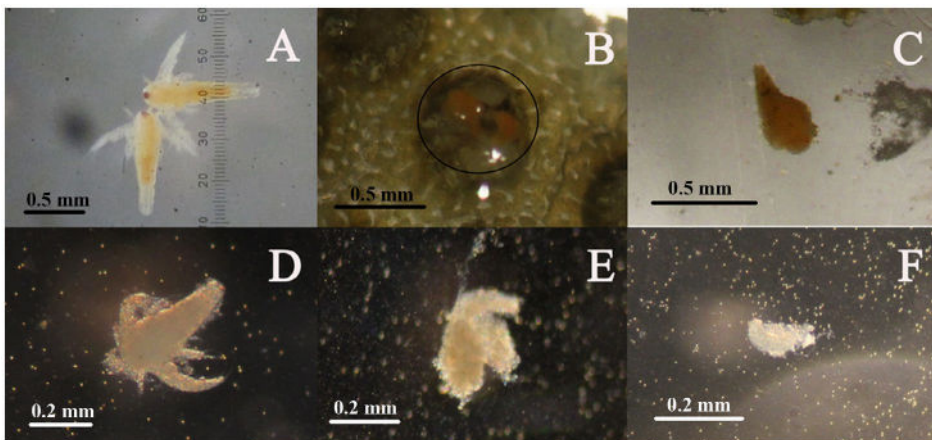


Figure 1. *Artemia salina* nauplii from the gastrovascular cavity of coral *Pocillopora damicornis* at different time series (A) newly hatched *A. salina*, (B) *A. salina* in gastrovascular cavity 1.5 h after feeding, (C and D) 1.5 h after feeding, (E) 2 h after feeding, (F) 2.5 h after feeding

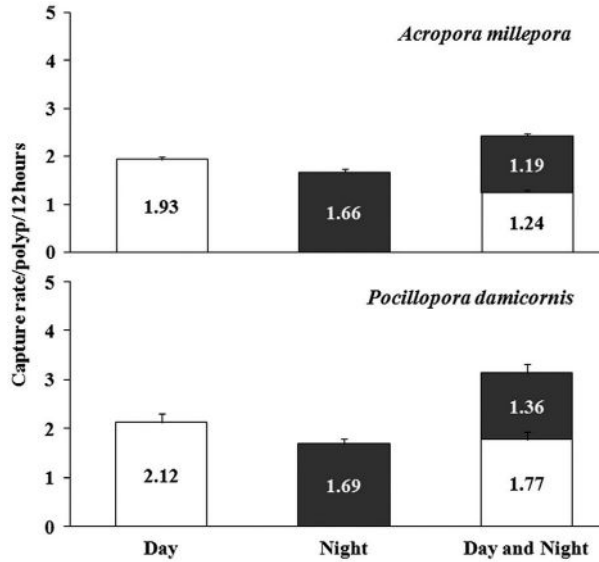


Figure 2. Capture rates of experimented *Acropora millepora* and *P. damicornis* fed on *A. salina* nauplii in Samae San Island, Thailand.

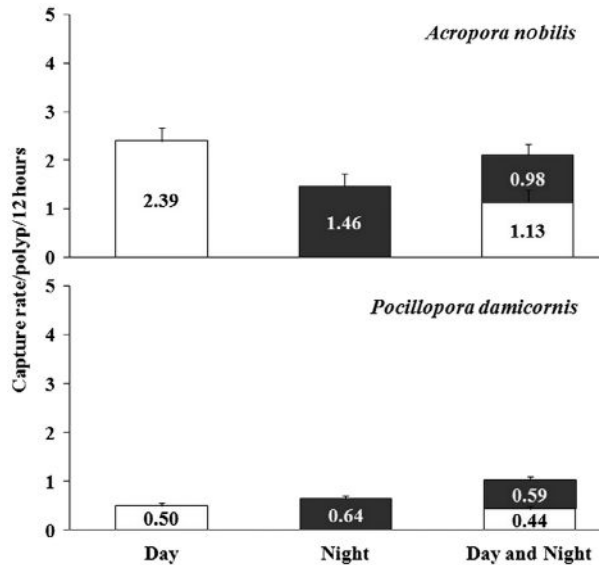


Figure 3. Capture rates of experimented *Acropora nobilis* and *P. damicornis* fed on *A. salina* nauplii in Chuuk, Federated States of Micronesia.

tween treatments (*A. millepora* ($F_{(2,87)} = 27.361$), *P. damicornis* ($F_{(2,87)} = 52.487$), $p < 0.05$). When food was given once a day, *P. damicornis* and *A. millepora* consumed *A. salina* actively during the day (average 2.12 ± 0.08 and 1.93 ± 0.08 individuals/polyp/12 h) than during the night (average 1.69 ± 0.04 and 1.66 ± 0.07 individuals/polyp/12 h), respectively

Table 1. Comparison of capture rates of planktons by scleractinian corals from various locations.

| Places where samples were collected or raised for experiments | Species | Concentration of food (ind./l) | Capture rate (ind. polyp/h) | Sources |
|---|-------------------------------|--------------------------------|-----------------------------|-----------------------------|
| Aquarium in Netherland | <i>Galaxea fascicularis</i> | 2000 | 50.68 | Osinga et al. (2008) |
| | <i>G. fascicularis</i> | 4100 | 93 ± 0.12 | Wijgerde et al. (2011) |
| Mediterranean Sea | <i>G. fascicularis</i> | 2000 | 9 | Ferrier-Pagès et al. (2010) |
| | <i>Turbinaria reniformis</i> | 2000 | 20 | Ferrier-Pagès et al. (2010) |
| | <i>Stylophora pistillata</i> | 2000 | 27 | Ferrier-Pagès et al. (2010) |
| Pulau Bidong in Malaysia | <i>G. fascicularis</i> | 10,000 | 50 | Hii et al. (2009) |
| Samae San Island in Thailand | <i>Pocillopora damicornis</i> | 300 | 0.14 ± 0.01 | In this study |
| | <i>Acropora millepora</i> | 300 | 0.13 ± 0.01 | In this study |
| Chuuk Island in the Federated States of Micronesia | <i>P. damicornis</i> | 300 | 0.05 ± 0.004 | In this study |
| | <i>Acropora nobilis</i> | 300 | 0.12 ± 0.03 | In this study |

Table 2. Percentage of prey remaining during the *Artemia salina* nauplii digestion by different corals at different sampling times.

| Country | Coral species | % of prey remaining | | |
|--------------------------------|----------------------|---------------------|--------------|-------|
| | | 1.5 h | 2.0 h | 2.5 h |
| Thailand | <i>A. millepora</i> | 62.14 ± 6.95 | 0 ± 0 | 0 ± 0 |
| | <i>P. damicornis</i> | 43.64 ± 7.84 | 62.50 ± 22.5 | 0 ± 0 |
| Federated States of Micronesia | <i>A. nobilis</i> | 58.44 ± 6.03 | 0 ± 0 | 0 ± 0 |
| | <i>P. damicornis</i> | 39.72 ± 5.19 | 18.32 ± 4.55 | 0 ± 0 |

(Figure 2). However, when *P. damicornis* and *A. millepora* were fed twice a day, *P. damicornis* consumed 3.13 ± 0.01 individuals of *A. salina*/polyp/day, and preferred to feed during the day while *A. millepora* consumed only 2.43 ± 0.09 individuals/polyp/day, and showed no significant difference in its capture rates between day and night times (Figure 2).

In Chuuk, the results showed a significant difference in the capture rates of *A. nobilis* between day and night times ($p < 0.05$), whereas *P. damicornis* showed no significant difference in the capture rates ($p > 0.05$). When *A. nobilis* was fed once a day, it consumed more *A. salina* during the day (average 2.39 ± 0.28 individuals/polyp/12 h) (Figure 3).

Table 2 summarized the digestive rates of the three coral species in Thailand and the Federated States of Micronesia. Complete digestions of *A. salina* nauplii by *A. millepora*

and *A. nobilis* were observed after 2 h, while *P. damicornis* took up to 2.5 h to complete the prey digestion.

Discussion

Our results revealed that all three corals species, *A. millepora*, *A. nobilis*, and *P. damicornis*, in Thailand and the Federated States of Micronesia were able to feed on and digest *A. salina* nauplii. The feeding capability of coral species depends on the feeding mechanism, polyp size, number of tentacles, prey size, prey density, water flow, temperature, and light (Lasker 1981; Fabricius and Klumpp 1995; Sebens et al. 1998; Anthony 1999; Piniak 2002; Houlbrèque and Ferrier-Pagès 2009; Toh et al. 2014). Light and dark conditions affect the feeding behavior of corals (Ferrier-Pagès et al. 1998; Hii et al. 2009). For example, under light condition, *S. pistillata*'s polyps were closed and had low ingestion rates compared with those under dark condition (Ferrier-Pagès et al. 1998). The coral feeding capacity also depends on the coral's feeding effort in which corals can control their feeding rate under changing environmental conditions such as light intensity (Anthony and Fabricius 2000; Ferrier-Pagès et al. 2010). In the current study, corals fed both during the day and at night; thus, light condition demonstrated no effect on the feeding of *Acropora* and *Pocillopora* species.

The results from the experiments both in Thailand and in Chuuk demonstrated that when experimented corals were fed twice a day, most experimented coral species, except *A. nobilis*, tended to consume more number of *A. salina* nauplii than those fed only once a day. The results also showed that when the frequency of food given increases, chance of corals to capture preys also increases. So far, no previous study was done on the frequency of food given. Only studies related to prey densities were performed. The study of Hii et al. (2009) revealed that the feeding behavior of coral species varied and depended on prey density. When a coral, *G. fascicularis*, was fed with high *A. salina* nauplii density, its feeding rate was 50 times higher than those fed with low density (Hii et al. 2009).

From our observation under the stereo light microscope, all ingested food in experimented corals was cleared from their gastrovascular gut within 2.5 h (Table 2). Depending on coral and soft corals species, the time to complete zooplankton digestion ranged from 2.5 to 6 days (in this study; Coffroth 1984; Lewis 1992; Sebens et al. 1996; Hii et al. 2009; Leal et al. 2013). Recently, molecular techniques were also used to detect and analyze prey digestion times in corals (Leal et al. 2013). Several factors such as prey size and polyp size can play an important role (Houlbrèque and Ferrier-Pagès 2009). However, Wijgerde et al. (2011) pointed that in *G. fascicularis*, 98.6% of captured preys was not digested in the gastrovascular cavity, but externally digested by mesenterial filaments. Thus, extracoelenteric feeding is also an important mechanism for nutrient acquisition of corals (Wijgerde et al. 2011).

In conclusion, this study showed that *A. millepora*, *A. nobilis*, and *P. damicornis* can be fed with *A. salina* nauplii under light and dark conditions, even though, the feeding rates were different under various conditions depending on coral species.

Acknowledgments

We would like to thank the Dusadeepipat Endowment Fund of Chulalongkorn University, the 90th Anniversary of Chulalongkorn University Fund, NRCT-JSPS Asian CORE COMSEA Program, TRF (RSA5480028), Korea Institute of Ocean Science and Technology, Naval Special Warfare Command, and RSPG project for field assistance.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This research was also financially supported by Ratchadaphiseksomphot Endowment Fund [CU-56-921-CC], Chulalongkorn University.

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