ARTIFICIAL FEEDING OF *BIRGUS LATRO* (L., 1767) (ANOMURA: COENOBITIDAE) AS AN ALTERNATIVE TO NATURAL DIET: PERSPECTIVE FOR CONSERVATION BREEDING*

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The coconut crab *Birgus latro* (L., 1767), also known as the robber crab, is an endangered terrestrial anomuran facing extinction due to accelerating overexploitation and habitat destruction. It is therefore crucial to develop methods of its culture in captivity. Generally, an artificial diet is beneficial and important to formulate a specific content of decapod crustaceans feed. Thus, we decided to test different food treatments including pellets and coconut to feed adults of *B. latro* in captivity from December 2018 to May 2019. The survival rate of coconut crabs was high in all tested groups (80–100 %). The potential use of artificial feeding in stocked *B. latro* feeding was confirmed. Thus we recommend future experiments to ascertain which food formula will be the best one for the species' culture in conservation programs.

coconut crab, robber crab, hermit crab, survival, food, Indonesia

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INTRODUCTION

The coconut or robber crab, *Birgus latro* (L., 1767), is a terrestrial hermit crab (Anomura: Coenobitidae) native throughout the islands in the western Pacific and Indian Oceans (Kessler, 2006; Drew et al., 2010) with the northernmost population in Okinawa Island (Oka et al., 2021). With body weight up to 4 kg, 20 cm in carapace width and 78 cm in walking leg span, this is the largest living terrestrial arthropod in the world (Lavery et al., 1996). This species has the highest carapace abrasion resistance among all arthropods (Inoue et al., 2021a) and robust claws (Inoue et al., 2021b). It is an endangered marine

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decapod crustacean facing extinction due to accelerating overexploitation (Amesbury, 1980; Sato, Yoseda, 2008; Drew et al., 2010; Sulistiono et al., 2019; Loganimoce et al., 2020) with negative impact on genetic diversity and genetic population structure (Yorisue et al., 2020).

Indonesia is the Southeast Asian island country covering three biodiversity hotspots (Sahul, Sundaland, and Wallacea) where numerous endemic crustaceans occur (Patoka et al., 2017; Ng, Wowor, 2019; Yonvitner et al., 2020). *Birgus latro* can generally be found there in the eastern part of the country, namely, Sulawesi, East Kalimantan, Nusa Tenggara, Maluku, North Maluku, and Papua, including smaller islands, islets, and atolls in the surroundings. Regarding its enormous size and robust body, *B. latro* is popular for human consumption and has been intensively harvested in several regions in Indonesia, e.g. in North Maluku, North Sulawesi, Central Sulawesi, Southeast Sulawesi, and even in remote islands such as Derawan Archipelago (East Kalimantan Province). This species is highly valuated on the market: USD 14.0–24.5 per individual of 1–2 kg body weight in the field; USD 52.5 per 1 kg in restaurants (Sulistiono et al., 2014, 2016). Even though human poisoning is also possible when *B. latro* eats the sea mango *Cerbera manghas* L. (Maillaud et al., 2010), it is consumed as a luxury food also in other regions across its native range (Kessler, 2006; Buden, 2012). Moreover, some locals believe that its meat is efficacious as an aphrodisiac (Sulistiono et al., 2009).

Even if huge amount of up to 138 000 eggs is produced as a single batch each year by adult female, just less than 0.1 % reach the adult stage (Helagi et al., 2015). Thus, due to the aforementioned harvesting and slow reproductive rate, this hermit crab populations have declined. Currently, it is extinct in the wild in mainland Australia, Madagascar, and Mauritius (Drew et al., 2010; Caro et al., 2020)the largest terrestrial decapod, is under threat in most parts of its geographical range. Its life cycle involves two biomes (restricted terrestrial habitats near the coast, and salt water currents of the tropical Indian and Pacific Oceans. For this reason, and since its decline in many of the remaining island populations, it was listed in the IUCN Red List of Threatened Species in 1981 and currently is classified as vulnerable (Cumberlidge, 2020).

Birgus latro plays an essential and partly irreplaceable ecological role, e.g. by opportunistic omnivorous behaviour including the consumption of fruit and pith of fallen tree, predation, scavenging various carrions (Drew et al., 2010; Krieger et al., 2016), and by a wider distribution of coconuts which are dragged to burrows for later consumption but some of them are not consumed and subsequently germinate (Alexander, 1979). Since this terrestrial anomuran can serve as an indicator organism of the quality of seashore waters, coastal forests and scrubland, it is a perfect candidate as an umbrella and flagship species for increasing awareness on conservation of endangered tropical islands (Wang et al., 2007; Caro et al., 2020) the largest terrestrial decapod, is under threat in most parts of its geographical range. Its life cycle involves two biomes (restricted terrestrial habitats near the coast, and salt water currents of the tropical Indian and Pacific Oceans. In Indonesia, trade with *B. latro* is regulated by the Government Regulation (PP) No. 9 (1999) on the administration of commodity futures trading (Penyelenggaraan Perdagangan Berjangka Komoditi). Despite the protection of *B. latro* in certain regions (Read et al., 2010; Hamasaki et al., 2011; Sulistiono et al., 2019) locals frequently do not respect the restrictions and still hunt this crustacean for consumption (Patankar, D'Souza, 2012). Due to their attractive colouration (Caro, Morgan, 2018; Nokelainen et al., 2018), some individuals are also harvested for preservation and exported and traded as a curious product of nature (see e.g. https://www.pontusnaturalart.com/product-page/extra-large-filled-birgus-latro-coconut-crab-taxidermy or https://www.terraquagroup.it/en/home/986-birgus-latro-blue-sulawesi-rarita--800884.html).

In light of the above information, it is important to protect this species by effective management, including establishing conservation areas and replenishing and strengthening wild populations by artificial breeding (Wang et al., 2007; Sugizaki et al., 2010). The methodology of larval cultivation of marine zoeae and megalopae has already been published (Hamasaki et al., 2009, 2015; Sugizaki et al., 2010; Ohashi et al., 2019), and also the methodology for rearing after the megalopal stage in the terrestrial environment is known (Hamasaki et al., 2013, 2014).

Stocking and keeping of selected adults to start the reproduction in captivity is one of the possible

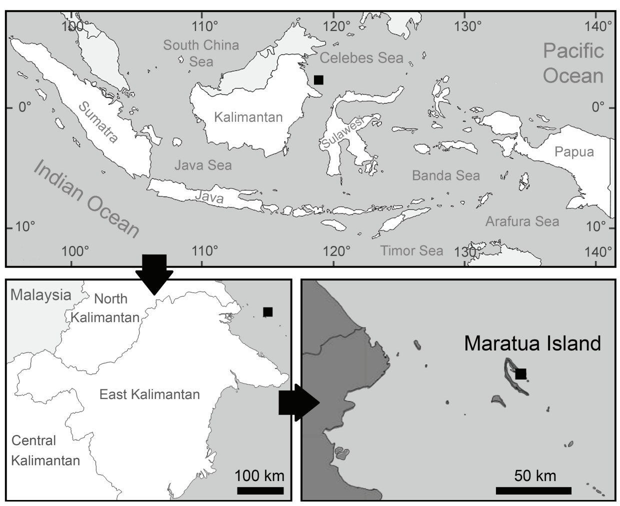

Fig. 1. Map of Indonesia with the experimental site on Maratua Island (indicated by black square)

approaches to improve the culture and our knowledge about this species. In experiments, natural food is usually used, but artificial food brings new possibilities and numerous advantages on managing the diet content of kept animals. After the preliminary study (Sulistiono et al., 2019), we decided to continue with modified food treatments and feeding frequency to establish a feasible method supporting the keeping and culture of this endangered hermit crab in captivity.

MATERIAL AND METHODS

Locality

Adult individuals of *B. latro* were collected using trap nets baited by pieces of coconut in Bulingisan, Derawan, and Maratua Islands (Derawan Archipelago, East Kalimantan Province, Indonesia). The experiment was conducted in Alulu bay, Maratua Island (2°15′11.6″N, 118°37′25.2″E) (Figs. 1, 2a) from December 2018 to May 2019. This location is known for the occurrence of a well established *B. latro* population with numerous adults and crablets (Fig. 2b, c). Selected adults were kept separately in opaque plastic boxes (0.7 × 0.4 × 0.4 m) equipped with a lid, wooden shelter, food dish, and containers with both freshwater and seawater (Figs. 2c, 3).

Food treatment

Four types of food treatment of different formulas were used in the experiment: (A) pellets (composition: wheat flour 60 %, coconut powder 30 %, fish powder 5 %, vitamin mixture 2 %, and minerals 3 %) and coconut pieces; (B) pellets (composition: wheat flour 40 %, coconut powder 50 %, fish powder 5 %, vitamin mixture 2 %, and minerals 3%) and coconut pieces; (C) pellets (composition: wheat flour at 20 %, coconut powder 70 %, fish powder 5 %, vitamin mixture 2 %, and minerals 3 %) and coconut pieces; and (D) coconut pieces only. Pellets were produced in a laboratory at the IPB University, Bogor, Indonesia. Raw materials were crushed, mixed, and extruded, produced pellets were dried, and packed. Feeding frequency in treatments A–C was twice per week (Monday and Wednesday) in case of pellets and once per week (Friday) in case of coconut pieces, while three times per week in case of the treatment D. All doses were 40–70 g depending on animals' body weight (ca. 9 % of their total body weight). Water was changed once per month. Food was always consumed for the most part and waste was removed daily.

Experimental groups characteristics

By the onset of the experiment, the treatment groups (A–D) of *B. latro* adults showed the following characteristics: (A) total number of individuals (n) = 8, weight mean 196.5 ± 121.2 g (118.0 + 121.5 + 123.5 + 139.5 + 144.3 + 224.0 + 225.0 + 476.2 g), weight range 118.0–476.2 g; (B) n = 10, weight mean 172.96 ± 79.08 g (68.5 + 91.2 + 103.9 + 115.1 + 163.4 + 198.0 + 206.5 + 210.5 + 257.5 + 315.0), weight range 68.5–315.0 g; (C) n = 9, weight mean 282.94 ± 223.0 g (49.8 + 115.0 + 122.5 + 175.5 + 257.6 + 268.3 + 285.9 + 517.9 + 754.0), weight range 49.8–754.0 g; (D) n = 10, weight mean 170.44 ± 186.16 g (60.6 + 60.9 + 80.2 + 80.9 + 94.9 + 97.8 + 100.4 + 113.5 + 395.4 + 619.8), weight range = 60.6–619.8 g. Details given in Table 1.

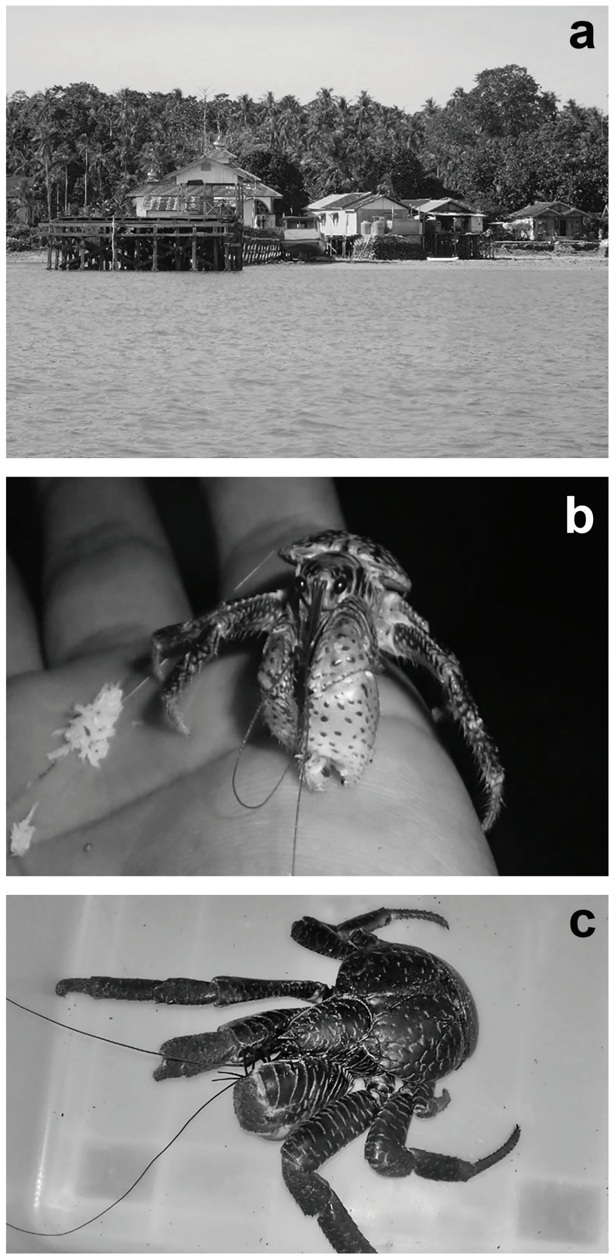

Fig. 2. (a) Experimental site in Alulu bay, Maratua Island, Indonesia; (b) *Birgus latro* crablet (cephalothorax length 20 mm); (c) *B. latro* adult in a plastic box (cephalothorax length 150 mm)

Table 1. Body weight (g) of *Birgus latro* individuals on different diet formulations (A–D) by the onset of experiment

	Treatments			
	A (*n* = 8)	B (*n* = 10)	C (*n* = 9)	D (*n* = 10)
Body weight (g)	476.2	315.0	175.5	395.4
	123.5	257.5	49.8	619.8
	139.5	115.1	115.0	113.5
	118.0	103.9	285.9	94.9
	121.5	210.5	268.3	80.9
	144.3	163.4	754.0	60.6
	225.0	91.2	517.9	60.9
	224.0	198.0	122.5	97.8
		206.5	257.6	80.2
		68.5		100.4

(A) pellets (composition: wheat flour 60 %, coconut powder 30 %, fish powder 5 %, vitamin mixture 2 %, and minerals 3 %) and coconut pieces; (B) pellets (composition: wheat flour 40 %, coconut powder 50 %, fish powder 5 %, vitamin mixture 2 %, and minerals 3%) and coconut pieces; (C) pellets (composition: wheat flour 20 %, coconut powder 70 %, fish powder 5 %, vitamin mixture 2 %, and minerals 3 %) and coconut pieces; (D) coconut pieces only

Throughout the experimental period, the kept individuals of *B. latro* were daily checked for survival.

RESULTS AND DISCUSSION

The final survival rate of *B. latro* within the experiment was 90 % in treatment A, 80 % in treatment B, and 100 % in treatments C and D (Fig. 4). Because during our experiment no individuals had moulted (normal situation in these size classes of coconut crabs), the potential effect of different food treatments on *B. latro* ecdysis and growth rates could not be evaluated. In compare with a previous study (S u l i s t i o n o et al., 2019), our formulas contained a lower proportion of coconut, the hermit crabs' natural diet, but the survival rate was high in all treatment groups. Therefore, we may conclude that feeding artificial diets is feasible in further experimentation when culturing *B. latro* in captivity.

Since the kept *B. latro* fed by fresh coconuts, fruits, vegetables and fish meat can moult in captivity (H e l d , 1963; F l e t c h e r et al., 1990), future experiments on the ability to moult when fed by artificial food are recommended. If these suggested experiments would show the successful ecdysis process and low mortality in *B. latro*, the method of artificial diet could be fully introduced into practice. Also, the food preference and choice should be of attention to researchers similarly as in the congeners of *B. latro*, terrestrial hermit crabs of the genus *Coneobita* (T h a c k e r , 1996).

Once when *B. latro* is confirmed to be able to consume an artificial diet and survive the repeating moulting process, it should be possible to enrich the content of feed with various substances such as carotenoids. Carotenoids have bioactive metabolic and physiological roles and influence pigmentation, antioxidant balance and effectiveness. As a source of provitamin A, they

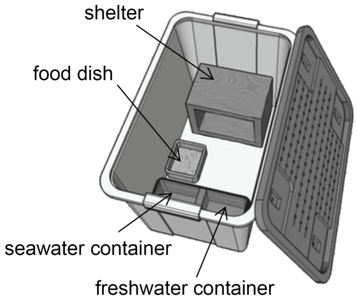

Fig. 3. Scheme of the experimental plastic box for keeping a single adult *Birgus latro* individual. The box is equipped with a cover, wooden shelter, food dish, and freshwater and seawater containers

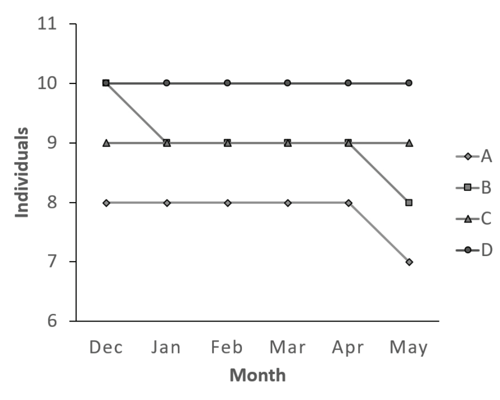

Fig. 4. Survival rate of *Birgus latro* individuals in each food treatment (A, B, C, D) within the experimental period (December 2018–May 2019)

provide cellular protection from photodynamic damage, enhance growth, reproductive potential and ovarian development in crustaceans (Linan-Cabello et al., 2002). Moreover, many terrestrial decapods, such as *B. latro*, retreat to their burrows where they safely consume exuviae for reingestion and calcium balance (Greenaway, 1993; Zanotto, Wheatly, 2002). Thus, the artificial diet with an enriched content of calcium and other essential supplements can be significantly beneficial to saturate these requirements of individuals kept in captivity.

High-performance formulated feeds with several natural and synthetic supplements have been developed for the culture of many crustacean species (Bordner et al., 1986; Wade et al., 2017); thus, the present study should serve as preliminary in this regard for *B. latro*. Our findings showed that it is feasible to feed *B. latro* by an artificial diet and hence, the content of feed can be possibly easily managed as needed. This output is promising for further investigations and culture of *B. latro* with possible overlap to repatriation programmes.

CONCLUSION

Management of endangered *B. latro* can be supported by its breeding in captivity. Our findings showed that this anomuran crustacean is able to survive on the artificial diet, which can be perceived as the first step in its further culture. Further research activities are required to reveal how formulated content of vitamins and nutrients in the artificial diet can prevent nutritional imbalances, deficiencies and diseases in *B. latro* in culture. The results can form a basis for the policy on management improving with a focus on a higher survival rate of *B. latro* individuals kept in conservation breeding and restocking programs. Further detailed experiments focused on the keeping and breeding of *B. latro* are strongly recommended and required. We believe that the presented findings will be interesting for conservationists, wildlife managers, and other stakeholders dealing with this so charismatic decapod crustacean and will help improve the establishment of the species culture in captivity.

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