Dietary shift for juvenile freshwater redclaw crayfish (*Cherax quadricarinatus*): A review

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Abstract. The freshwater crayfish (*Cherax quadricarinatus* von Martens, 1868), also known as the redclaw, is a freshwater lobster (crustacean) that has the potential to be developed as a consumption commodity. The development of lobster cultivation can be carried out using an intensive system. The juvenile production is one of the important keys to produce lobster in consumption size. The productivity of the juvenile stage must be supported by growth and survival. Appropriate feed is one of the important keys that influences the growth and survival of juvenile. Information regarding the nutrients needed by juvenile has to be conveyed in a comprehensive manner to be useful for lobster cultivation development efforts. This review article aims to elaborate on nutrient requirements and the metabolic role of these nutrients for juvenile redclaw. The review was carried out by studying various Indonesian national and international articles, which discussed redclaw related subjects, such as natural food and the role of feed nutrients in the growth of juvenile. The review results show that one of the important problems in the aquaculture of redclaw was the growth and survival of juveniles. Juveniles showed non-selective feeding behavior. However, there was ontogenetic dietary shift. Redclaw feeding habits were characterized by exogenous feeding and, in general, detritivorous or omnivorous. Naturally, redclaw fed mostly on decayed plants and animals, macroinvertebrates, detritus, macrophytes, and fish. Juvenile redclaw showed filter-feeding and scraping behavior, being non-selective feeders. In cultivation environments, some studies have shown that juvenile redclaw fed on *Alona* sp., *Daphnia* sp., *Artemia* sp., blood worms, silkworm, and some combinations with other organic matter such as rice flour, carrot, golden snail, earthworms, and anchovies. There was a relationship between the composition of nutrients and feeding habit, ontogenetic dietary shift, and its metabolism of enzymes. Juvenile redclaws need proteins more than carbohydrates and lipids, although the overall nutrient intake of vitamins and minerals is important for growth and survival.
Key Words: feeding habit, productivity, protein, ontogenetic.

Introduction. Freshwater lobster is one of the species of crayfish (crustaceans) that has the potential to be cultivated and developed as a business. One of the crayfish species that is widely cultivated is the redclaw lobster (*Cherax quadricarinatus* von Martens, 1868), which is a native species from northern Australia and southeastern Papua New Guinea (Lawrence & Jones 2002; Snovsky & Galil 2011; Partini et al 2019; Akmal et al 2021; Faiz et al 2021).

The species *C. quadricarinatus* is commercially exploited and introduced to various tropical and subtropical countries. Redclaw, which originally lived in the wild, has now become an invasive organism in numerous waters. In Indonesia, redclaw only lives in the southern Papua Province (Patoka et al 2016). This species began to be developed as a commodity for the aquaculture industry in Indonesia since 2003 (Edgerton 2005; Patoka et al 2018).

Some of the advantages of redclaw cultivation are ease of maintainance and cultivation in aquariums and ponds, faster growth than other species, low stress and resistance to disease attacks, resistance to a wide range of temperatures, pH and dissolved oxygen concentration, flexible diets, their high protein nutritional content (21.6%) and low fat (<2%), and a high selling price including in the juvenile phase (Snovsky & Galil 2011;

Andriyeni et al 2022). These advantages are the factors that make redclaw widely cultivated, including in Indonesia.

Redclaw cultivation activities so far are not optimal and are hampered mainly by the availability of young lobster. Collecting young lobsters from nature is limited in terms of quantity and quality and hampered by technical and regulatory constraints (Yusnaini et al 2018).

One of the main problems currently faced by redclaw cultivators is the relatively low survival rate at the young stage (Karplus et al 1995; Fatihah et al 2020; Andriyeni et al 2022). A better understanding of nutrient requirements at the juvenile-young-mature transition in the life cycle is very important (Mutti et al 2024). Suitable feed, both in quality and quantity, plays an important role in producing optimal growth (Mamonto et al 2023).

Various studies have been carried out regarding the quality and quantity of feed that is suitable for redclaw juvenile to adults. This review aims to produce a synthesis of available information for providing a more complex and holistic explanation and understanding regarding the feed needed by juvenile redclaw.

Material and Method. The analysis was carried out through a review process of a number of published research articles, both at national (Indonesian) and international level. This article review was carried out based on articles related to freshwater lobster *Cherax quadricarinatus*, freshwater lobster juveniles, feed and nutrients. This review article was structured descriptively to provide comprehensive information regarding the evaluation of feed nutrients for juvenile freshwater craysfish.

Cherax quadricarinatus. According to Haubrock et al (2021), redclaw are known by the global names red claw, red-claw, redclaw yabby, tropical crayfish, tropical blue crayfish, and the blue lobster, with or without the prefix Australian or Queensland. It was first described as *Astacus quadricarinatus* by the German zoologist Karl Eduard von Martens in 1868. The holotype sample was collected in Cape York, Queensland, Australia, and later stored at the Natural History Museum, Berlin, Germany, with No. 2972 (von Martens 1868). Haubrock et al (2021) explained further that the species discovered by von Martens (1868) was later reclassified as *Cherax quadricarinatus* by Clark (1936). *Cherax* was first designated as a subgenera of the genus *Astacus* by Erichson (1846) with the name of the subgenus *Cheraps* or *Chaeraps* (e.g Huxley 1878). Therefore, the first subgenus name given was *Cherax*. The use of the name *Cherax* takes priority over the name of the next subgenus. *Cherax quadricarinatus* is included in the subgenus *Astaconephrops*, which was later proven to be invalid, being no longer recognized within the genus *Cherax*. This is also reinforced by the opinions of Bláha et al (2016) and Crandall & De Grave (2017).

Freshwater lobsters are crayfish (Coelho et al 2007) which can be grouped into yabbies (*Cherax destructor* Clark, *Cherax albidus* Clark), marron (*Cherax cainii* Austin, *Cherax tenuimanus* Smith), and redclaw (*Cherax quadricarinatus* von Martens). The redclaw species is the only tropical species that has been widely expressed as the candidate with the most potential for cultivation (Rigg et al 2020).

Dina et al (2013) explained that based on the identification key, *Cherax quadricarinatus* belongs to phylum Arthropoda, subphylum Crustacea, class Malacostraca, order Decapoda, suborder Pleocyemata, infraorder Astacidea, superfamily Parastacoidea, family Parastacidae, genus *Cherax*. The morphological visualization of male and female of *C. quadricarinatus* is presented in Figure 1. The visualization showed that males have a red color of the claw, which was absent for the females.

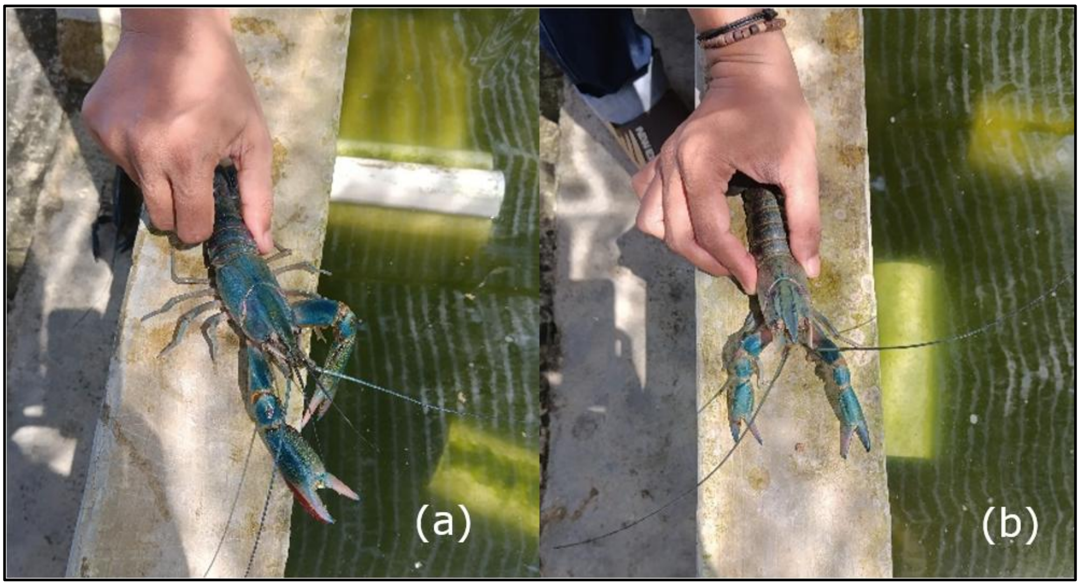

Figure 1. *Cherax quadricarinatus*, male (a) and female (b) (personal documentation).

Habitats. The redclaw is one of 30 species of lobster found in world waters (Putra et al 2018; Eprilurahman et al 2021). Redclaw is an invasive species that has the ability to adapt to most waters in Indonesia. In its natural habitat, this species inhabits stagnant and flowing waters such as swamps, lakes, rivers, and lagoons (Jones 1990). Redclaw tend to be found in waters with slow currents and static waters with hard and complex substrates that provide food and shelter (Haubrock et al 2021).

In the aquaculture environment, the ecosystem can be modified by adding aquatic macrophyte vegetation such as *Pistia stratiodes* and *Eichhornia crassipes* as shelter and natural filtration for cultivation water. The PVC pipes can also be added as artificial shelters for juvenile and adult lobsters (Jones 1995a, b). The addition of dry coconut leaves, hydrilla and bamboo can also provide shelter for lobster protection so that it can influence its growth and survival (Mamuaya et al 2019).

Redclaw is a species that has the ability to live in a wide range of values of water quality parameters. Redclaw is physiologically hardy and can tolerate a variety of water conditions, including low dissolved oxygen (DO) concentrations (>1 ppm; up to 7-10 ppm), hardness and alkalinity levels (20-300 ppm), pH (6.5-9) (Ghanawi & Saoud 2012; Widigdo et al 2020). The optimum temperature for growth is 23±1 to 31±1°C (Tropea et al 2010). Meade et al (2002) describe redclaw as a mesohaline eurythermal species because it has the ability to adapt to a wide range of salinities and temperatures.

Life Cycle. Information on redclaw reproduction can provide an overview of its life phases, which is especially useful in studies of the reproduction, feeding and metabolic systems. Jones (1990) described the life cycle of the redclaw (Figure 2a). We also offer the redclaw life cycle (Figure 2b).

Freshwater lobsters that have surpassed 6 months can be used as prospective broodstock and are ready to be mated. Mating can take place in one set of lobsters consisting of 1 male and 4 females (Jones 1995a). Mass mating can be carried out in a number of 6 sets of lobsters per m^2. The female produces eggs that are visible on her abdomen 10-15 days after mating. The eggs are incubated by the female for 1.5-2 months.

The development of lobster eggs goes through a number of phases, namely: Stage 1 (1-4 days), with cream colored eggs; Stage 2 (5-7 days), with light brown eggs; Stage 3 (8-14 days), with dark brown blackish eggs; Stage 4 (15-17 days), when eggs are grayish purple; Stadia nauplius (18-21 days) - eggs turn red without eye spots; Stadia protozoea (22-27 days) - eggs are red with eye spots; Stadia mysis (28-35 days) - the eggs almost hatch; then the eggs turn gray and separate from the pleopods on day 35-40. The color change of lobster eggs is presented in Figure 3.

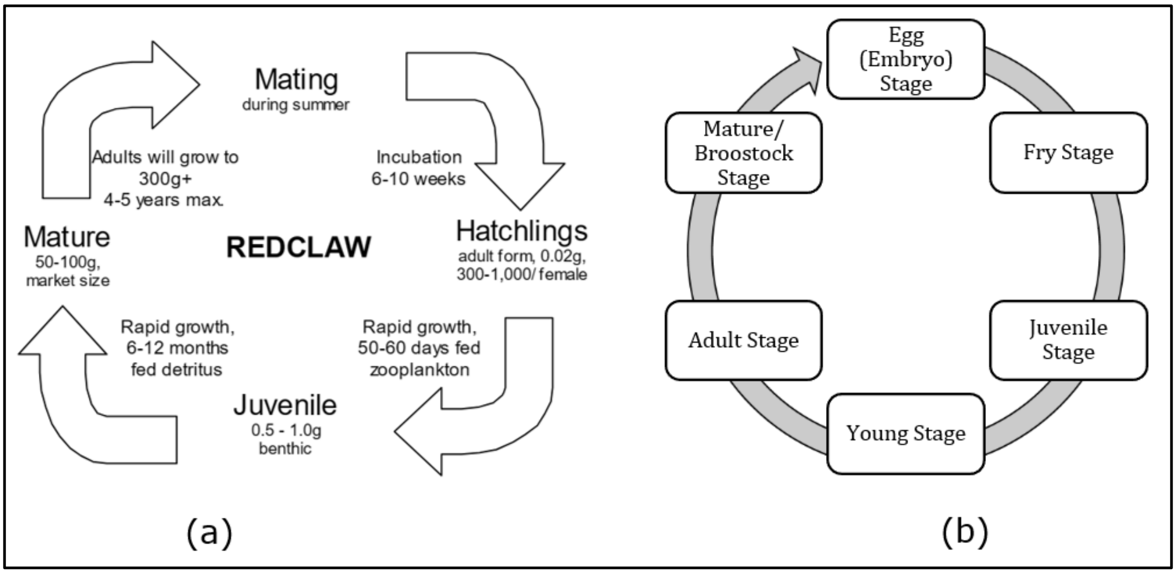

Figure 2.Redclaw (*Cherax quadricarinatus*) life cycle (Jones 1990) (a); and our initiation (b).

Figure 3. Changes in pigmentation of redclaw (*Cherax quadricarinatus*) eggs in the first 1 week (a); 1-2 weeks (b); 2-3 weeks (c, d, e); 3-4 weeks (f, g); more than 4 weeks (h) (personal documentation).

The development and color change of lobster eggs was confirmed by Levi et al (1999), who explained that the duration of the egg phase is 30±2.4 days. The eggs are elliptical and attached to the pleopods with filaments, which then change color from green-brown to orange-red.

The eggs that have hatched are kept by the female under her abdomen for 10-12 days (Paputungan et al 2021). The eggs that have hatched will be separated from the mother or pleopods entering the fry (larvae) phase. The fries are 4-7 mm in length and 3-5 days old. The next phase is the change of fry (larvae) into juveniles measuring <1 cm, with an age of 8-15 days, to 1-3 cm (1 inch) with an age of 20-30 days. Rigg et al (2021) documented the early developmental phases (instars) of redclaw (Figure 4).

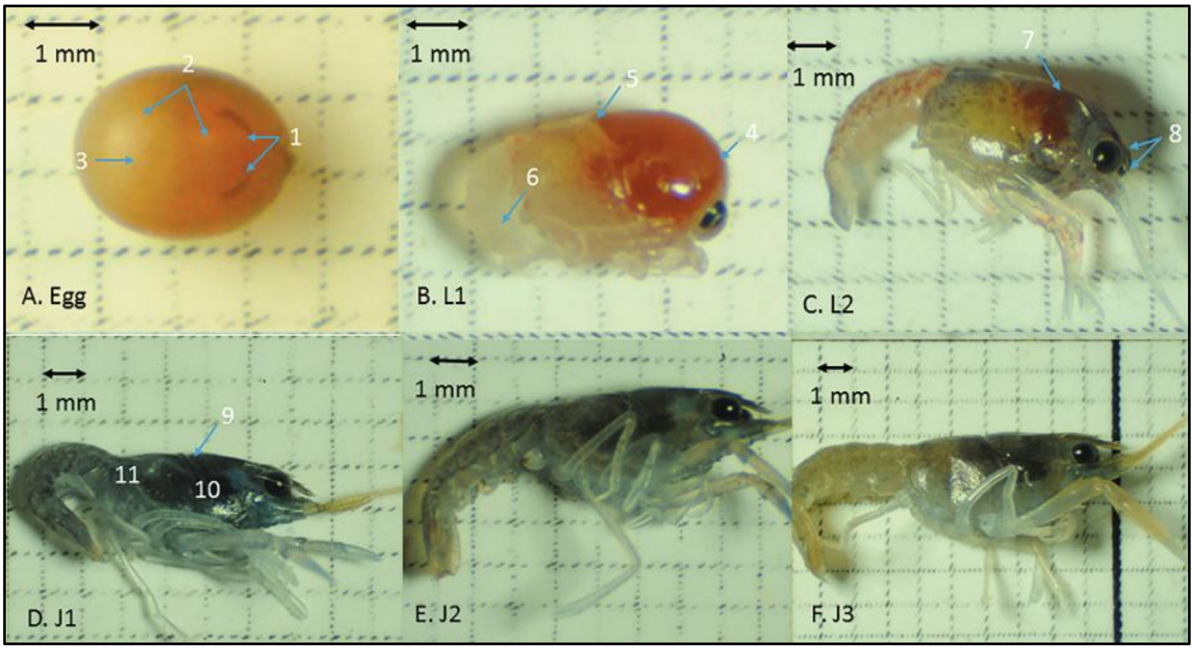

Figure 4. Early developmental phase (instar) of *Cherax quadricarinatus* (Rigg et al 2021) (photo quoted with permission from Jones); L - larval stage; J - juvenile stage.

Rigg et al (2021) gave the following explanation for Figure 4: (A) - *C. quadricarinatus* late-stage egg showing crescent-shaped eyes, differentiation within the egg, a translucent area posterior to the eyes, and a general granular appearance of egg contents; (B) - *C. quadricarinatus* L1 instar, a non-mobile lecithotrophic stage, showing the large, rounded cephalothorax, largely undifferentiated abdomen to carapace region with a hunchback containing yolk, and a transparent almost abdomen; (C) - *C. quadricarinatus* L2 instar, the final lecithotrophic stage, showing differentiation from the L1 stage via reduction in the shape and size of the hunchback due to partial depletion of the yolk sac, and commencement of the development of the eye-stalks and rostrum; (D) - *C. quadricarinatus* J1 instar is the first instar with independent locomotion and exogenous feeding, has a depletion of the yolk sac resulting in the disappearance of the hunchback form, and the appearance of the cephalothorax in the proportions and shape which will continue the life of the crayfish, the J1 instar also has the beginnings of darker pigmentation; (E) - *C. quadricarinatus* J2 instar, indiscernible from J1 instar except for increase in size and mass; (F) - *C. quadricarinatus* J3 instar, also indiscernible from J1 or J2 instar except for an increase in size and mass.

Juveniles aged 1 month or more must be sorted by size with the aim of growing evenly and avoiding cannibalism. Juveniles develop into young lobsters, which start to look like adult lobsters, have a head shell and a body shell and experience moulting repeatedly, until they are 3 months old.

The size of the young lobster at 60-90 days is 5-7 cm (2-3 inches) with a weight of approximately 50 g. The culturing for 6-8 months produces adult lobsters that are ready to become prospective broodstock with a size of 10-15 cm (4-6 inches) and a weight of 70-100 g. Lobsters that can be used as broodstock have a size of 15-17 cm (>6 inches) with a weight of 100-350 g and are older than 10 months old. Optimum water conditions can support faster lobster growth, so they reach commercial size (40-200 g) within 6-9 months. Redclaw is a gonochoristic species with a faster male growth pattern and larger size than females (Ghanawi & Saoud 2012).

Food and Ontogenetic Diet Change. Redclaw feeding habits, which are polytrophic and require external food intake (exogenous feeding), have given the impression that redclaw can be grouped as predators (carnivores), omnivores, and/or detritivores. In general, the genus *Cherax* is grouped as a detritivorous or omnivorous group that consumes algae, detritus, plants and animals (Beatty 2006).

The diverse feeding habits of redclaw in the wild are supported by the structure of their mouth parts and the ability of their walking legs to hold or grasp food (Pavasovic 2008). Its digestive enzymes also have the ability to hydrolyze various types of food that it encounters in nature, being able to adapt to various types of food (Linton et al 2009).

Redclaw in the wild feed mostly on decayed plants and animals, macroinvertebrates, detritus, macrophytes, and fish. Freshwater crustaceans generally consume feed that contains high levels of carbohydrates, while seawater crustaceans are more carnivorous and consume feed that contains higher protein levels (Pavasovic 2008; Haubrock et al 2021).

Various studies have shown that redclaw experience ontogenetic dietary shifts. This condition allows redclaw to adapt their digestive physiology to food availability and nutritional needs.

Juvenile redclaw show filter-feeding and scraping behavior and are non-selective when starting to eat (Figueiredo & Anderson 2003). The juvenile stage of redclaw in nature eats zooplankton, as indicated by the dominance of zooplankton in their digestive system (Jones 1995a,b). Marufu et al (2018) added that juvenile and young redclaw can predominantly consume macrophytes and detritus (Table 1).

Table 1

Occurrence of the six categories of food items recorded in the stomachs of *Cherax quadricarinatus*

Size class (mm)	*Percentage (%)*				
	Macrophytes	*Detritus*	*Fish*	*Macroinvert*	*Crayfish*
<28.9	87.5	12.1	0.0	0.4	0.0
29.0-37.9	69.0	29.7	0.8	0.4	0.0
38.0-46.9	61.1	35.9	2.2	0.2	0.0
47.0-55.9	62.0	36.4	1.4	0.1	0.0
>56	57.2	42.8	0.0	0.0	0.0

Source: Marufu et al (2018).

In cultivation environments, various studies have shown that redclaw can consume various types of feed. Juvenile aged 23 days are given natural food, namely *Alona* sp., *Daphnia* sp. and *Artemia* sp. (Paputungan et al 2021). 30-day old juveniles are fed blood worms (Taufiq et al 2016), or 32-day old juveniles are fed with a combination of silkworm and rice flour (Kurniawan et al 2024), 39-day old juveniles eat zooplankton and need high protein levels (Jones 1995b). Juveniles weighing 2.51±0.98 g can be fed carrots, golden snails, earthworms and anchovies (Safir et al 2023).

Juveniles that enter the young phase measuring 3.5-4.5 cm can be given additional feed in the form of artificial feed (Duffy et al 2011; Rosmawati et al 2019), golden snails and silk worms (Yusuf et al 2022). Partini et al (2019) explained that juveniles measuring 3.15±0.02 cm can be given pellet feed measuring 0.4-0.7 mm. Gutiérrez & Rodriguez (2010) also modified the addition of protein sources to redclaw juvenile food (Table 2).

A number of studies have also been carried out to increase nutrient adequacy in juvenile feed such as soybean lecithin, vitamins and wheat flour as a source of nutrients

(Thompson et al 2003), honey to increase growth and survival (Mukti et al 2010), calcium hydroxyde ($CaOH_2$) to accelerate growth (Hadie et al 2016), L-carnitine to increase growth rate and feed efficiency (Wahono et al 2019), tryptophan to increase growth and reduce cannibalism rates (Trisnasari et al 2020), nanocalcium from shells to accelerate moulting (Handayani & Syahputra 2018).

Table 2

Proximate content of diets used in food of *Cherax quadricarinatus*

Diet	*Fish*	*Soy*	*Squids*	*Krill*
Moisture (%)	12.5	11.45	12.42	11.55
Protein (%)	35.28	35.55	35.10	35.80
Lipids (%)	10.63	9.75	9.68	10.38
Carbohydrates (NFE) (%)	20.02	19.55	20.30	20.61
Ash (%)	21.57	23.7	22.5	21.66

Source: Gutiérrez & Rodriguez (2010).

A number of feeds have been studied to accelerate reproductive maturity and the spawning process in adult lobsters, including *Acetes indicus*, *Pomacea canaliculata*, *Tubifex* sp. (Mudlofar et al 2023), bean sprouts, silk worms and white sweet potatoes, which can increase fecundity and hatching rate (Sidharta et al 2018).

Changing feeding habits can be supported by changes in the ontogeny of the digestive tract as indicated by the secretion of redclaw digestive enzymes (Pavasovic et al 2007). Redclaw is able to digest plant-based food more efficiently than animal-based food (Campaña-Torres et al 2005, 2006). In general, the genus *Cherax* has carbohydrase enzymes such as amylase, cellulase, endo-β1,4-glucanase, β-glucosidase, laminarinases, lichenase, xylanase, endochitinase, and N-acetyl-β-D- glucosaminidase. The genus *Cherax* also has serine protease and cysteine protease enzymes, as well as lipase enzymes (Figueiredo et al 2001; López-López et al 2003; Crawford et al 2005; Linton et al 2009; Coccia et al 2011). Digestive enzymes (protease, carbohydrase and lipase) in redclaw are found in the midgut gland and the gastric fluid. The presence of these enzymes is an indication that redclaws are able to digest food with varied components (Figueiredo et al 2001).

Redclaw juveniles show non-selective feeding habits when they start feeding, but experience changes in food preference as they grow, tending to eat plant matter more. Enzymes in the digestive tract initially show high concentrations of proteases and low carbohydrases. However, as redclaws grow, protease concentrations decrease and carbohydrase levels increase, which is consistent with an increased preference for plant foods. Meanwhile, cellulase is found in all stages of the redclaw life cycle (Figueiredo & Anderson 2003).

Redclaw feeding habits change from consuming detritus to decayed plant material. Animal food is more commonly found in the digestive tract of young redclaw compared to adult redclaw, which strengthens the argument that ontogenetic dietary shift occurs as redclaw age (Momot et al 1978; Figueiredo & Anderson 2003; Pavasovic 2008).

Another argument for the ontogenetic dietary shift is that redclaw has sharp pointed teeth on the small, third maxilliped and mandible, combined with reasonably long setae around the margins of the mouth parts, useful in handling and capturing small animals as their prey and food. However, as they grow to young redclaw adults, the teeth become less pointed, but larger. This indicates a decline in small animal consumption, while the ability to cut plant material is increasing (Barker & Gibson 1977; Lavalli & Factor 1992; Loya-Javellana & Fielder 1997; Rigg et al 2020).

Nutrient Requirements. Nutrients are required by all organisms, including redclaw, for their various metabolic activities. A number of nutrients needed include protein, lipids, carbohydrates, vitamins and minerals.

Protein plays an important role in the female gonad maturation, gonad development (Rodríguez-González et al 2009a), composition of ovaries, the nutritional status of eggs, egg quality, and larval survival (Ghanawi & Saoud 2012), growth, weight, length, and survival of juveniles (Gutiérrez & Rodriguez 2010; Borisov et al 2022). Lysine and threonine, two of the most important limiting essential amino acids (EAAs), are particularly important for the healthy growth of redclaw. The supplementation of lysine and threonine in the diet can increase significantly hepatopancreas trypsin activity of redclaw. In general, amino acids are important for growth, digestive capacity, antioxidant activity, and intestinal health of redclaw (Jiang et al 2024).

Lipids can support the survival of the redclaw (Hernández-Vergara et al 2003; Cortés-Jacinto et al 2005). Lipids are important for redclaw, especially for growth performance, antioxidant state, lipid metabolism, and gut microbiota (Chen et al 2022). Lipids are also essential as structural components of cell membranes, as an energy source and the major energy reserve, and also provide essential fatty acids during embryonic development (Coutteau et al 1997; Monge-Quevedo et al 2014). Fatty acids are essential for maintenance and function of biomembranes (Rodríguez-González et al 2009b). Furthermore, lipids are required for gonadal development and maturation in adult female (Xu et al 2023), tissue synthesis and other metabolic tasks (García-Guerrero et al 2003).

Carbohydrates are components of biomineral organic matrices (Luquet et al 2012). However, carbohydrates have little to no importance when it comes to gonadal maturation (Rodríguez-González et al 2006). In fact, carbohydrates are found in eggs and embryos in low concentration, which indicates carbohydrates are not used for energy production and they are not the main energy source in eggs. However, carbohydrates are essential and important during embryogenesis, especially for the synthesis of chitin for the exoskeleton (García-Guerrero et al 2003).

Vitamins and minerals are essential micronutrients. Vitamins and minerals in sufficient quantities allow optimal growth (Kobayashi et al 2015). Some minerals such as calcium and magnesium improve immunity, health, and the enzyme systems (Shahroom et al 2023). Phosphorus and calcium improve the hardening and calcifying parts of the exoskeleton (Luquet et al 2016; Casaretto et al 2023). Vitamins and minerals are reported to impact gonadal maturation and reproduction, nervous system development, and also improve the function of amino acids and fatty acids in fertilized eggs (Liñán-Cabello et al 2004; Ghanawi & Saoud 2012; Xu et al 2023).

Conclusions. One of the important problems in the aquaculture of redclaw is the growth and survival in culturing the juvenile stage. The understanding of nutrient requirements from the juvenile to the mature stage plays an important role to improve redclaw production. Juveniles show non-selective feeding behavior. However, there is an ontogenetic dietary shift among the juvenile, young, adult and mature stages. The nutrient composition may be related with feeding habit, ontogenetic dietary shift, and metabolism of enzymes. Redclaw juveniles need proteins more than carbohydrates and lipids, although the overall nutrient intake of vitamins and minerals is important for growth and survival.

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Conflict of Interest. The authors declare that there is no conflict of interest.

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