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Original article

Temporal variations and pond age effect on plankton communities in semi-intensive freshwater marron (*Cherax cainii,* Austin and Ryan, 2002) earthen aquaculture ponds in Western Australia

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ABSTRACT

The abundance and diversity of the plankton community represents the health of the aquatic ecosystem, and plays an important role in the growth of cultured animals under aquaculture conditions. The temporal variations of plankton abundance, taxonomic composition, diversity, evenness and species richness were studied in three old and three new semi-intensive marron (*Cherax cainii,* Austin and Ryan, 2002) ponds. Water parameters such as temperature, dissolved oxygen, pH, turbidity, TAN, nitrite, nitrate and reactive phosphate were recorded, and plankton samples were collected every two months, for one year of juvenile production cycle. A total of twenty-six phytoplankton and seven zooplankton genera were recorded. Chlorophyceae was the dominant class of phytoplankton throughout the year, followed by Trebouxiophyceae. Rotifera comprised 49.8% of the total zooplankton community (individuals L^{-1}), the largest proportion of any group. Temporal variations impacted the plankton abundance and community structure, and plankton abundance were more abundant during summer. The pond age did not influence the phytoplankton abundance, whereas zooplankton abundance was higher in older ponds.

1. Introduction

Natural lentic water bodies and earthen aquaculture ponds are unique examples of freshwater ecosystems supporting communities of various aquatic organisms, including plankton and top predators such as fish and decapod crustaceans. Both environments are subject to an excess of nutrient loadings, entering from natural and anthropogenic sources (Nõges et al., 2016). However, while natural lentic water ecosystems receive considerably high amounts of nutrients through runoffs, nutrient loading in aquaculture ponds is largely sourced from fertilizers, feed input and cultured animal excreta (Boyd et al., 2010) as part of aquaculture management practice. Fertilization is applied to increase the pond production by promoting the natural productivity (Boyd, 2018), consisting of phytoplankton as primary producers, and zooplankton, the primary consumers and secondary producers. Phytoplankton being an integral component of freshwater ecosystems, including aquaculture ponds, contribute to the succession and dynamics of zooplankton (Li et al., 2019), that in turn provides a food source for cultured aquatic animals (Shao et al., 2019), including marron.

Western Australia's (WA) marron (*Cherax cainii*, Austin, 2002) industry produces approximately 50 tonne per year, in year 2016–17 marron production from WA was 51 tonne valued at AUD $ 1.6 million (ABARES, 2018). Numerically, its producers comprise the state's largest aquaculture sector (Department of Fisheries, 2015). In the south-west of WA marron farming is conducted in semi-intensive ponds. As the marron breed during the spring, farmers harvest the ponds in winter (June/July) and segregate the marron into different weight groups and restock them as juveniles, grow-out (+1) or brooders. Due to the wet weather in winter and chance of raining the drained-out ponds are left empty for only a short duration, and then refilled for restocking without liming and fertilization (Fotedar et al., 2015). The amount of formulated feed broadcasted into these semi-intensive ponds varies with the season and stocked life stages, for example during the winter the feed quantity is reduced to half than summer and ponds with adult marron are fed higher quantity than juveniles

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(anecdotal evidence from growers). Marron also attain nutrition from natural productivity, however the ponds plankton communities structures and their variations are poorly studied. Marron pond age is also shown to impact plankton abundance (Cole et al., 2019; Tulsankar et al., 2020); as the pond ages the natural productivity increases (Correia et al., 2002).

Marron are polytrophic and can attain additional nutrition from ponds natural productivity and thus marron farmers in southwest of WA apply fermented barley straw to post-stocked marron ponds (Fotedar et al., 2015). This practice is believed to balance the nutrient and bacterial loadings over a period of time in marron ponds, it also aids in managing natural productivity and improving the water quality for marron farming. Bacteria helps to reduce excessive nitrogenous wastes, provide feed for bacterivorous protozoans that in turn are consumed by macroscopic zooplankton, and contribute to the diet of freshwater crayfish (Brown et al., 1992; Rautio and Vincent, 2006; Martinez-Porchas et al., 2014).

The plankton growth is dependent on various environmental parameters such as temperature, light intensity, and nutrient concentrations (Ndebele-Murisa et al., 2010). These can also affect the pattern of phytoplankton succession, as different species have different thresholds towards nutrients and temperature ranges (Affan et al., 2005). For example, increased temperature and eutrophication promotes Cyanophyceae abundance (Kratina et al., 2012). The temporal variations of plankton communities are good indicators of water quality and trophic status in freshwater ecosystems, and for sustainable aquaculture (Reynolds, 1996; Affan et al., 2005). A better understanding of the temporal variations of plankton communities in freshwater ecosystems may help to improve the productivity of marron farms.

Researchers have studied Australian natural lentic freshwater ecosystems to determine water quality and plankton productivity (Casanova et al., 1997; Markwell and Fellows, 2008). However, there is a lack of information on plankton communities in Australian aquaculture facilities (Pearson and Duggan, 2018). This is an exploratory study to investigate the temporal variations in plankton communities in marron ponds of different ages. Moreover, a potential relationship between the plankton abundance, community diversity and the marron yield in each pond is investigated over a time period of one year.

2. Materials and methods

The study was conducted at a commercial marron farm with the capacity of 60 purpose-built earthen ponds each with a maximum depth of 1.5 m and water area of 1000 m^2, situated in the south west of Western Australia (WA) near Manjimup (34°18′75″ S, 116°06′61″ E). Out of 60, six ponds were randomly selected to study temporal variations in plankton abundance, diversity, composition and their community structure. Based on construction and number of years in use, the ponds were classified as older and newer (around 15 and 11 years respectively) ponds. Six ponds, with the ratio of three old and three new were selected for the study. The farmers have treated this ponds on the basis of their personal experiences with the addition of gypsum or barley hay straws. Gypsum were added only to the new ponds at the end of construction. Hay straw additions were conducted in the new ponds after five to six months of marron stocking. The paddle wheel aerators were not used in any ponds, the feeding were conducted manually in the evening. Both the ponds were supplied same amount of feed, water level and stocked marron weights.

Before collecting first water samples in July 2016 (winter), the ponds were stocked with grow-out male and female marron with the approximate weight of 150 kg/pond from the same farm with the same weight group on different days but same month before starting the sampling. The harvested ponds were left emptied for very short duration of 1 or 2 days and filled from the nearby dam owned by the farmer and was only topped up the loss due to evaporation. Stocking was conducted immediately after filling without grading, liming or fertilization. The number of culture days differed for each pond, ranging from 300 to 397. Water samples were collected every two months, once per each Noongar season. Dissolved oxygen (DO), pH and temperature were measured at approximate depth of 15–20 cm of pond water at the same location of each pond over every sampling. An Oxyguard® digital dissolved oxygen meter (Handy Polaris 2, Norway) was used to measure dissolved oxygen (DO) and temperature, and an Ecoscan pH 5 m (Eutech instruments, Singapore) was used to measure pH in the sampled ponds. 100 mL water samples from each pond were collected from 15 to 20 cm deep height to analyse total ammonia nitrogen (TAN), nitrite (NO_2-N), nitrate (NO_3-N) and reactive phosphate (PO_4) and transported with ice in esky. A DR/890 portable colorimeter with Permachem reagents (Hach, USA) were used to analyse the TAN, NO_2-N, NO_3-N and PO_4. TAN, NO_2-N, NO_3-N and PO_4 were analysed at Curtin Aquatic Research Laboratory (CARL; Perth) on the same day. Turbidity was measured with a secchi disc, with clear ponds defined as having 150 cm visibility.

2.1. Plankton collection and analysis

Five litres of water was collected from five different stations (1 L/station; four corners and from the middle) of each pond using 20 L plastic beaker and poured through a plankton net of 20 μm mesh to obtain 100 mL phytoplankton samples. For zooplankton, 15 L of water was collected from five different stations of each pond (3 L/station) same as phytoplankton using a beaker and collecting it in 50 L water capacity plastic bucket and poured through 60 μm mesh zooplankton net to obtain 100 mL sample. Throughout the study time all the samples were collected after four to five hours of sunrise and were transported to the CARL on ice. Phytoplankton were preserved with 3% acetic acid Lugol's within eight hours. Phytoplankton species identification was conducted using a compound microscope at 400X magnification; quantitative analysis was done using haemocytometer. For each phytoplankton sample, 1 mL subsample was transferred to the haemocyte counter and cells were counted within four randomly selected squares, four counts per sample. Phytoplankton were analysed further to obtain the plankton indices. Zooplankton samples were fixed with 70% ethanol and were counted using a dissection microscope at 20x magnification. A 1 mL sub-sample was transferred to a petri dish, two counts were carried out per sample. Phytoplankton and zooplankton were identified to the genus level by using the keys from Lund and Lund (1995) and Ingram et al. (1997). The phytoplankton abundance (cells L^{-1}) and zooplankton abundance (individual L^{-1}) was calculated by using the following equations as described by Ingram et al. (1997) and Tulsankar et al. (2020).

$$\text{Phytoplankton abundance} = \frac{\left(\frac{\text{Number}\times 1000}{\text{Volume of grid (0.1 mm3)}}\right)\times\left(\frac{\text{Concentrated Volume}}{\text{Sub Volume}}\right)}{(\text{Total Volume}\times\text{Number of squares counted})}$$

$$\text{Zooplankton abundance} = \frac{\text{Number}\times\left(\frac{\text{Concentrated volume}}{\text{Sub Volume}}\right)}{\text{Total Volume}}$$

where

Number = Mean number of cells or individuals counted, Total volume = Total volume of water (L) collected from pond, Concentrated Volume = Volume of water (mL) containing concentrated zooplankton after sieving (100 mL), Sub. Volume = Sub sample of water (mL) from concentrated volume in which plankton is counted (1 mL).

To calculate the plankton species diversity (H′), species richness (SR), evenness (J) and predominant indices (D) following formulas by Shanon and Weiner (1949); Margalef (1958); Pielou (1966) and Berger and parker (1970) respectively were used. Berger and Parker; Margalef, 1958; Pielou, 1966; Shannon and Wiener, 1949 were used.

$$H' = -\sum_{i+1}^{s} \frac{N_i}{N} \log_2 \frac{Ni}{N} \; SR = \frac{S-1}{\log N}$$

$$J = \frac{H'}{log_2 S} D = \frac{N_{max}}{N}$$

where

N_i is the number of individuals of the *i'th* species; N_{max}, is the number of individuals of the most abundant species; N is the total number of individuals; S is the total number of species.

H′ value can range from 0 to infinity, with a higher value showing that the ecosystem is healthier. The J value shows a single-species dominance in water body, where, 1 indicates the equal abundance of species or maximum evenness. The D value is the measure of the most abundant species in a water body; it ranges from 0 to 1, where higher value indicates that the species accounts for a higher proportion of total individuals. SR is the number of different species observed in a sample.

2.2. Marron yield data

The marron yield data were collected from the farm records to calculate the growth indices; specific growth rate (SGR g % /day) and Biomass gain percentage (BG; g %) by using following equations:

$$\text{SGR (g \% /day)} = 100 \text{ X } (\ln W_t - \ln W_0)/t$$

$$\text{BG (\%)} = 100 \text{ X } (W_t - W_0)/W_0$$

W_t is the final weight of marron, W_0 is initial weight and t is experimental time (days).

The marron survival rate was not calculated as the farm records did not include the precise number of marron at stocking and harvest times, only the yields in kilograms.

2.3. Marron health indices

Six marron per pond were collected at the time of harvest and were transported in thermocol box with ice packs. Marron were collected with average weight of 66.5 to 73.1; average orbit carapace length (OCL) of 54.4 to 65.2 and average total length of 135.6 to 143.2. The individual marron weight, OCL and total length were recorded before dissecting for health indices analyses. The health indices analyses were performed at CARL within three days until then were stored at −75 °C freezer. The tail muscle and hepatopancreas from individual marron were weighted and to obtain dry weight the samples were dried in crucibles at 105 °C in the oven for 24 hrs. The organosomatic indices and moisture content were analysed using the following equations as described by (Fotedar, 2004),

$$\text{Tail muscle moisture (TM \%)} = (T_w\text{-}T_d) \times 100/T_w$$

$$\text{Hepatopancreas moisture (HM \%)} = (H_w\text{-}H_d)/H_w$$

$$\text{Wet tail muscle indices } (TMi_w) = T_w \times 100/BW$$

$$\text{Wet hepatopancreas indices } (Hi_w) = H_w \times 100/BW$$

$$\text{Dry tail muscle indices } (TMi_d) = T_d \text{ x}100/BW.$$

where T_w: Tail muscle wet weight; T_d: Tail muscle dry weight; H_w: Hepatopancreas wet weight; H_d: Hepatopancreas dry weight; BW; Body weight.

2.4. Statistical analysis

The data were processed using statistical software IBM® SPSS 25. One-way ANOVA with LSD post hoc tests were used to analyse temporal variations of water parameters and plankton for all six ponds altogether. Kruskal-Wallis tests were used when data did not conform to the assumptions of normality and homogeneity of variance. Independent t-tests were used to compare the significance of physical and chemical parameters and plankton between old and new ponds. Tests were considered statistically significant at $p < 0.05$.

3. Results

3.1. Water quality parameters and plankton in two aged ponds

The water quality parameters were within the suitable range for marron as shown by Morrissy et al. (1984), Morrissy (1990), Villarreal and Peláez (1999), Environment protection Policy (2003), Cole et al. (2019). Temporal variations significantly affected all environmental parameters (Table 1). DO was higher in colder months (<20 °C; July and September). pH and nutrients concentrations fluctuated over the sampling time. Pond age influenced the turbidity, being lower in newer ponds than older (Table 2). Total phytoplankton abundance (cells L^{-1}) did not show significant difference between older and newer ponds, while Trebouxiophyceae abundance (cells L^{-1}) was higher in older ponds than newer. Overall, phytoplankton diversity was higher in newer ponds and zooplankton abundance in older.

3.2. Plankton taxa

A checklist of the plankton recorded in marron ponds (Table 3). The identified phytoplankton community were composed of eight groups namely Chlorophyceae, Trebouxiophyceae, Euglenoidea, Eustigmatophyceae, Bacillariophyceae, Zygnematophyceae, Coscinodidiscophyceae and Cyanophyceae. The zooplankton community were composed of three groups namely, Rotifera, Copepoda and Cladocera. A total of twenty-six different genera of phytoplankton, six of zooplankton and unidentified species of Copepod nauplii was recorded. The higher number of different genera was recorded in the class Chlorophyceae.

3.3. Plankton abundance and their temporal variations

The phytoplankton abundance ranged from $208.3 \pm 17.8 \times 10^4$, $180.5 \pm 31.7 \times 10^4$, $218.8 \pm 37.6 \times 10^4$, $368.1 \pm 80.6 \times 10^4$, $225.7 \pm 14.6 \times 10^4$ and $329.9 \pm 58.5 \times 10^4$ (cells L^{-1}) from July to May respectively and was maximum in January (summer) (Fig. 1). Plankton abundance and phytoplankton species diversity were affected due to the temporal variations, where no significant difference in zooplankton species diversity was observed.

3.4. Plankton succession

Temporal phytoplankton succession showed that Chlorophyceae were the only taxonomic group recorded during all sampling months. Cyanophyceae and Coscinodiscophyceae groups were observed during January to May (Fig. 2a). *K. quadrata* and copepod nauplii abundance were recorded in most of the months

Table 1
The comparison of water quality parameters of old and new aged marron ponds over sampling months, conducted on commercial marron farm in Manjimup (means ± S. E; n = 6).

Parameters	July		September		November		January		March		May	
	Old	New	Old	New	Old	New	Old	New	Old	New	Old	New
DO (mg L^{-1})	12.4 ± 0.56	11.9 ± 0.41	11.3 ± 0.06	11.1 ± 0.66	7.38 ± 0.55	7.85 ± 0.59	7.33 ± 0.21	8.80 ± 0.11	7.24 ± 0.11	7.86 ± 0.24	8.65 ± 0.42	9.63 ± 0.37
Turbidity (cm)	61.7 ± 21.3	91.7 ± 38.1	70.0 ± 15.3	118 ± 31.7	68.3 ± 16.4[a]	150 ± 0.00[b]	34.0 ± 5.57	96.7 ± 26.7	26.7 ± 3.33	68.3 ± 6.01	36.7 ± 6.01	71.7 ± 13.6
Temperature (°C)	11.5 ± 0.21	10.6 ± 0.41	17.4 ± 0.23	18.6 ± 0.52	23.0 ± 0.03	24.0 ± 0.52	21.0 ± 0.15	23.1 ± 1.94	23.3 ± 0.12	22.3 ± 0.27	22.4 ± 0.17	21.2 ± 0.15
pH	8.41 ± 0.11	8.41 ± 0.11	7.43 ± 0.09	7.63 ± 0.12	7.83 ± 0.13	8.01 ± 0.22	8.22 ± 0.22	8.29 ± 0.03	8.42 ± 0.09	8.54 ± 0.01	8.29 ± 0.04	8.37 ± 0.06
NH_3N (mg L^{-1})	0.12 ± 0.08	0.15 ± 0.03	0.05 ± 0.01	0.05 ± 0.03	0.19 ± 0.04	0.15 ± 0.02	0.02 ± 0.00	0.01 ± 0.01	0.54 ± 0.09	0.23 ± 0.03	0.33 ± 0.003	0.03 ± 0.03
NO_2N (mg L^{-1})	0.01 ± 0.01	0.02 ± 0.02	0.01 ± 0.00	0.01 ± 0.00	0.02 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.00	0.13 ± 0.08	0.02 ± 0.01	0.04 ± 0.01	0.01 ± 0.00
NO_3N (mg L^{-1})	0.50 ± 0.15	0.80 ± 0.55	0.80 ± 0.10	0.47 ± 0.18	1.23 ± 0.29	0.87 ± 0.27	0.73 ± 0.38	0.50 ± 0.29	0.97 ± 0.03[b]	0.53 ± 0.13[a]	4.00 ± 1.82	1.00 ± 0.64
Reactive phosphate (mg L^{-1})	0.24 ± 0.07	0.23 ± 0.15	0.17 ± 0.17	0.20 ± 0.15	0.04 ± 0.03	0.01 ± 0.01	0.18 ± 0.00	0.09 ± 0.88	0.26 ± 0.06	0.13 ± 0.01	0.12 ± 0.01	0.12 ± 0.02

The values in the same row with different superscripts letters represent the significant difference ($p < 0.05$) between old and new pond.

Table 2
The comparison of water quality parameters and plankton abundance, diversity between the old and new aged marron ponds from a commercial marron farm in Manjimup (means ± S. E; n = 3).

Parameters	Old	New
pH	8.10 ± 0.10	8.20 ± 0.10
DO (mg L^{-1})	9.00 ± 0.50	9.50 ± 0.40
Temperature (°C)	20.1 ± 1.10	20.3 ± 1.20
Turbidity (cm)	49.6 ± 6.20[a]	96.9 ± 10.9[b]
NH_3N (mg L^{-1})	0.16 ± 0.05	0.10 ± 0.02
NO_2N (mg L^{-1})	0.04 ± 0.02	0.01 ± 0.00
NO_3N (mg L^{-1})	1.20 ± 0.40	0.60 ± 0.20
Reactive Phosphate (mg L^{-1})	0.20 ± 0.03	0.13 ± 0.04
Phytoplankton abundance (X10^4 cells L^{-1})	278 ± 3.80	233 ± 1.70
Zooplankton abundance (Ind. L^{-1})	180 ± 24.4[b]	77.1 ± 9.70[a]
Phytoplankton Species diversity	5.28 ± 0.50[a]	7.40 ± 0.30[b]
Zooplankton species diversity	3.10 ± 0.20	3.30 ± 0.30
Chlorophyceae (X10^4ind. L^{-1})	101 ± 11.4	109 ± 12.5
Trebouxiophyceae (X10^4ind. L^{-1})	65.7 ± 9.70[b]	41.7 ± 4.70[a]
Eustigmatophyceae (X10^4ind. L^{-1})	70.3 ± 22.2	46.9 ± 17.0
Zignematophyceae (X10^4ind. L^{-1})	72.9 ± 25.7	37.5 ± 8.10
Euglenoidea (X10^4ind. L^{-1})	6.30 ± 1.80	4.40 ± 0.80
Bacillariophyceae (X10^4ind. L^{-1})	35.7 ± 7.50	26.0 ± 2.70
Cyanophyceae (X10^4ind. L^{-1})	85.6 ± 30.4	25.0 ± 4.20
Coscinodiscophyceae (X10^4ind. L^{-1})	62.5 ± 24.1	20.1 ± 0.00
Rotifera (ind. L^{-1})	13.9 ± 3.00[b]	6.4 ± 1.40[a]
Cladocera (ind. L^{-1})	1.00 ± 0.50	1.00 ± 0.50
Copepod adults (ind. L^{-1})	3.80 ± 0.90	2.80 ± 0.80
Copepod nauplii (ind. L^{-1})	8.40 ± 1.20[b]	4.10 ± 0.70[a]

The values in the same row with different superscript letters represents the significant difference ($p < 0.05$) between old and new ponds. Abbreviation: Ind = Individuals.

(Fig. 2b). Cladoceran's abundance was pre-dominantly observed only when the temperature were below <20 °C; *Daphnia* spp. was recorded during the July and November sampling only in new ponds, though *Moina* spp. were recorded during July to November sampling in both aged ponds**.** The well-established zooplankton communities were, Rotifers (*Keratella* spp.) and Calanoid copepods. Rotifera spp. (*K. quadrata, K. cochlearis*) and Copepoda nauplii abundance was higher in older ponds (Table 2), while *E. dialata* was observed only in newer ponds.

3.5. Plankton community composition

Phytoplankton community composition (%) in both aged ponds were dominated by Chlorophyceae followed by Trebouxiophyceae and Eustigmatophyceae (Fig. 3a and b). Rotifera dominated zooplankton composition while cladoceran's had the lowest abundance of individuals (Fig. 3c and d). Rotifera and Copepoda were more abundant groups. *Keratella quadrata, K. cochlearis* and Copepoda nauplii were most abundant in older ponds, while *Euchlanis dilatata* was observed only in newer ponds.

3.6. Plankton indices

Planktons diversity (H′), predominance index (D), species evenness (J), and species richness (SR) were compared between old and new ponds (Fig. 4). The average values (mean ± S. E.) of phytoplankton H′, D, J and SR for older ponds were 2.10 ± 0.1, 0.38 ± 0.0, 0.90 ± 0.0 and 2.0 ± 0.2 respectively, and for newer ponds 2.66 ± 0.1, 0.30 ± 0.0, 0.92 ± 0.0 and 3.0 ± 0.2 respectively. The phytoplankton species dominance was significantly higher in older ponds, but phytoplankton diversity and species richness were higher in newer ponds. Zooplankton species richness was higher in newer ponds (Fig. 4).

Table 3
The total plankton taxa found in commercial marron ponds over the sampling time of a year (N = 6).

Phytoplankton groups	Class	Genus	Zooplankton groups	Family	Genus
Chlorophyta	Chlorophyceae	*Eudorina* spp.	Rotifera	Branchionidae	*Keratella quadrata*
Chlorophyta	Chlorophyceae	*Monoraphidium* spp.	Rotifera	Branchionidae	*Keratella cochlearis*
Chlorophyta	Chlorophyceae	*Scenedesmus* spp.	Rotifera	Euchlanidae	*Euchlanis dilatata*
Chlorophyta	Chlorophyceae	*Tetraedron* sp.	Copepoda	Cyclopoida	*Cyclops* sp.
Chlorophyta	Chlorophyceae	*Volvox* spp.	Copepoda	Centropagidae	*Boeckella* sp.
Chlorophyta	Chlorophyceae	*Selenastrum* spp.	Cladocera	Daphniidae	*Daphnia* spp.
Chlorophyta	Chlorophyceae	*Haematococcus* sp.	Cladocera	Moinidae	*Moina* spp.
Chlorophyta	Chlorophyceae	*Sphaerocystis* sp.			
Chlorophyta	Chlorophyceae	*Pandorina* sp.			
Chlorophyta	Chlorophyceae	*Pediastrum* sp.			
Chlorophyta	Chlorophyceae	*Chlamydomonas* spp.			
Chlorophyta	Trebouxiophyceae	*Chlorella* spp.			
Chlorophyta	Trebouxiophyceae	*Actinastrum* sp.			
Chlorophyta	Trebouxiophyceae	*Micratinium* sp.			
Euglenozoa	Euglenoidea	*Euglena* spp.			
Euglenozoa	Euglenoidea	*Peranemopsis* sp.			
Ochrophyta	Eustigmatophyceae	*Nannochloropsis* sp.			
Ochrophyta	Bacillariophyceae	*Navicula* spp.			
Ochrophyta	Bacillariophyceae	*Nitzschia* spp.			
Ochrophyta	Coscinodiscophyceae	*Aulacoseira* spp.			
Charophyta	Zygnematophyceae	*Spirogyra* spp.			
Charophyta	Zygnematophyceae	*Cosmarium* spp.			
Charophyta	Zygnematophyceae	*Micrasterias* spp.			
Charophyta	Zygnematophyceae	*Closterium* spp.			
Charophyta	Zygnematophyceae	*Mesotaenium* sp.			
Cyanobacteria	Cyanophyceae	*Chroococcales* spp.			

Table 4
Marron growth SGR (g; %/day), biomass gain (%) and health indices hepatopancreas moisture content (%), hepatopancreas wet weight indices (%), hepatopancreas dry weight indices (%), marron tail muscle moisture content (%), tail muscle wet weight indices (%) and tail muscle dry weight indices (%) grown in a commercial marron ponds for a year (means ± S. E.; n = 6).

Pond age	SGR	BG	HM	Hiw	Hid	TM	TMiW	TMiD
Old	0.21 ± 0.02	111.6 ± 22.6	66.3 ± 2.40	4.00 ± 0.34	1.30 ± 0.12	79.2 ± 0.96	29.3 ± 1.18	6.10 ± 0.41
New	0.19 ± 0.04	98.9 ± 26.0	62.4 ± 2.40	3.50 ± 0.27	1.30 ± 0.10	78.3 ± 0.50	29.2 ± 0.97	6.30 ± 0.31

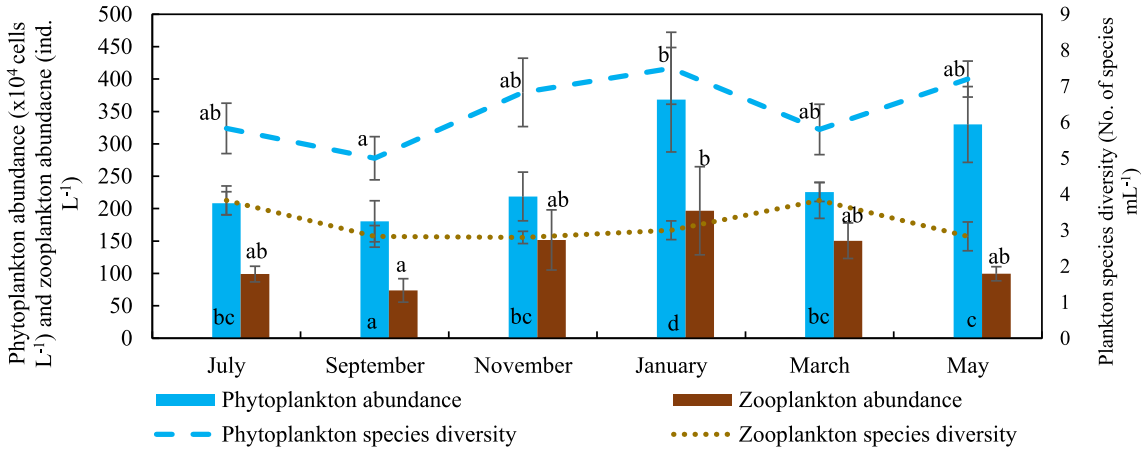

Fig. 1. Temporal variations of the phytoplankton (x10^4 cells L^{-1}), zooplankton abundance (L^{-1}) and species diversity (Number of species/1mL) in a commercial marron ponds (means ± S. E.; n = 6). Letters a, b, c shows the significant difference in plankton abundance and species diversity over the different sampling times.

3.7. Marron weight and health indices.

No significant differences ($p < 0.05$) were observed in marron growth and health indices between old and new ponds. Weight gain was slightly but not significantly higher in older ponds (Table 4).

4. Discussion

This study was a first attempt to understand the plankton abundance, diversity, evenness and richness in two distinctly aged semi-intensive earthen ponds and their responses to the changes in environmental parameters. Generally in Australian ponds, Rotifera and Copepoda are more abundant than Cladocera (Boon et al., 1994; Casanova et al., 1997) whereas, Cladocerans are more common in northern hemisphere (Boon et al, 1994). Rotifera is the most important zooplankton groups in the food web of lentic water bodies, providing a food source to Copepoda (Wallace et al., 2006; Lokko et al., 2017; Wen et al., 2017). The plankton abundance and their community structure is regulated by water quality and various biotic and abiotic environmental factors.

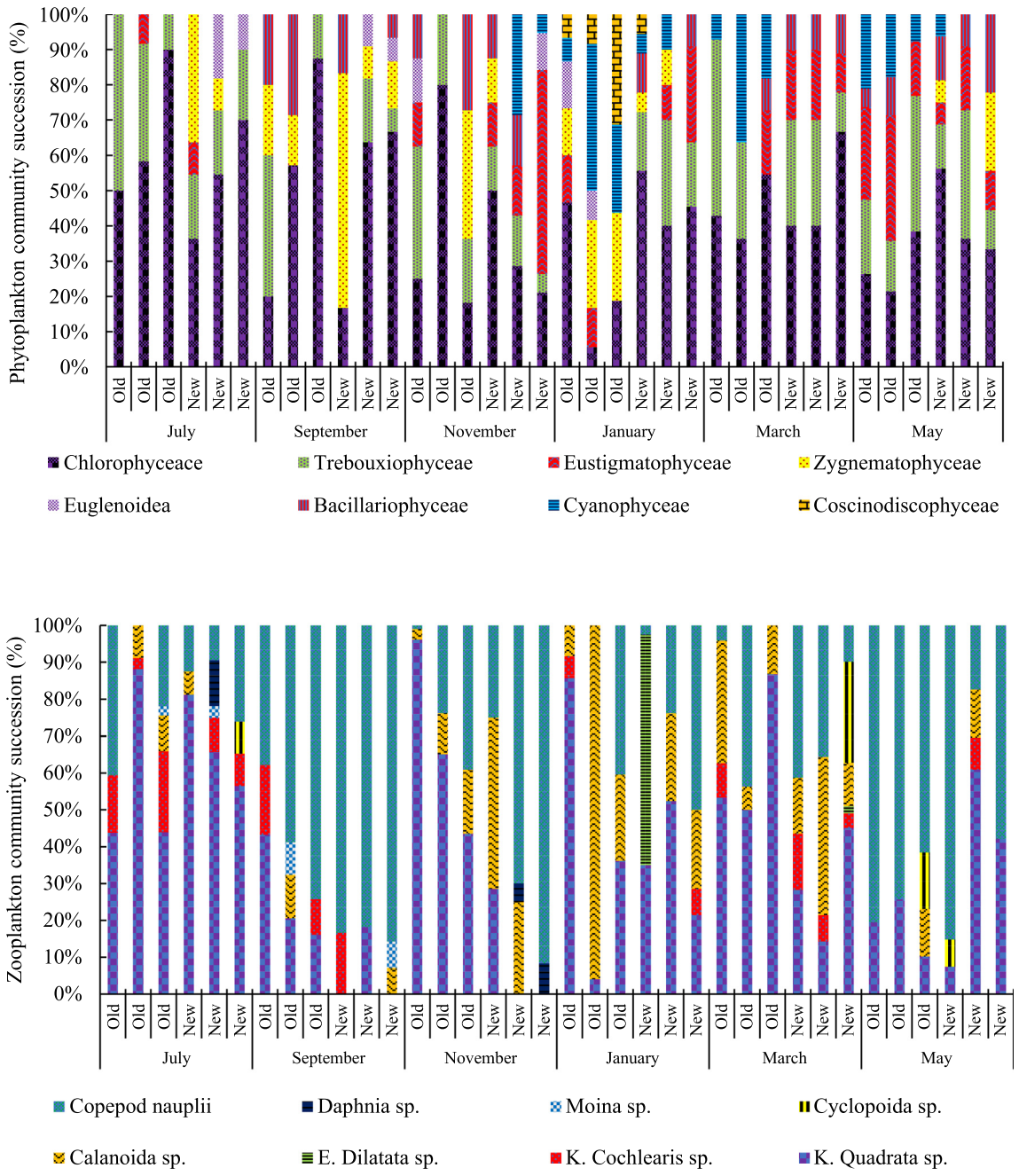

Fig. 2. (a) Phytoplankton community succession in old and new aged commercial marron ponds from Manjimup over the variations in temperature around the year (n = 6). (b) Zooplankton community succession in old and new aged commercial marron ponds from Manjimup over the variations in temperature around the year (n = 6).

Turbidity, zooplankton and Trebouxiophyceae abundance were lower in newer ponds. Addition of gypsum and fermented barley straw to the new ponds, made them relatively clear (Hargreaves, 1999). Zooplankton abundance was significantly higher in old ponds, as observed by Cole et al. (2019) on the same farm but different ponds and different sampling times. The stabilization of fewer more abundant plankton such as Trebouxiophyceae, rotifers and copepod nauplii adapted in the long term to the stable environmental conditions showed a higher DP in older ponds. An ecosystem with low plankton diversity indicates the presence of dominant species (Yanuhar et al., 2018; Kulabtong et al., 2019), whereas this conditions may have not yet stabilized in new ponds. Newly established plankton communities showed ephemerous high diversity in newer ponds before stabilizing species numbers and relative abundance. Markwell and Fellows (2008) observed higher macrophyte diversity in newer ponds than older (Australia). Shannon diversity index in marron ponds was moderate ($1 < H' < 3$), which shows that the pond's ecosystem was in good condition (Yanuhar et al., 2018).

The total plankton abundance was highest in warmer months as observed by Elakkanai et al. (2017) and Cole et al. (2019). The increased daylight hours and water temperatures can trigger an increase in phytoplankton abundance (Sommer et al., 2012), in turn providing a source of nutrition for zooplankton (Coman et al., 2003). Plankton abundance was lower during the colder months due to less sunlight, calm weather and low temperatures (Falkowski and Raven, 2007; Li et al., 2019). The highest recorded zooplankton abundance in the marron ponds was comparatively

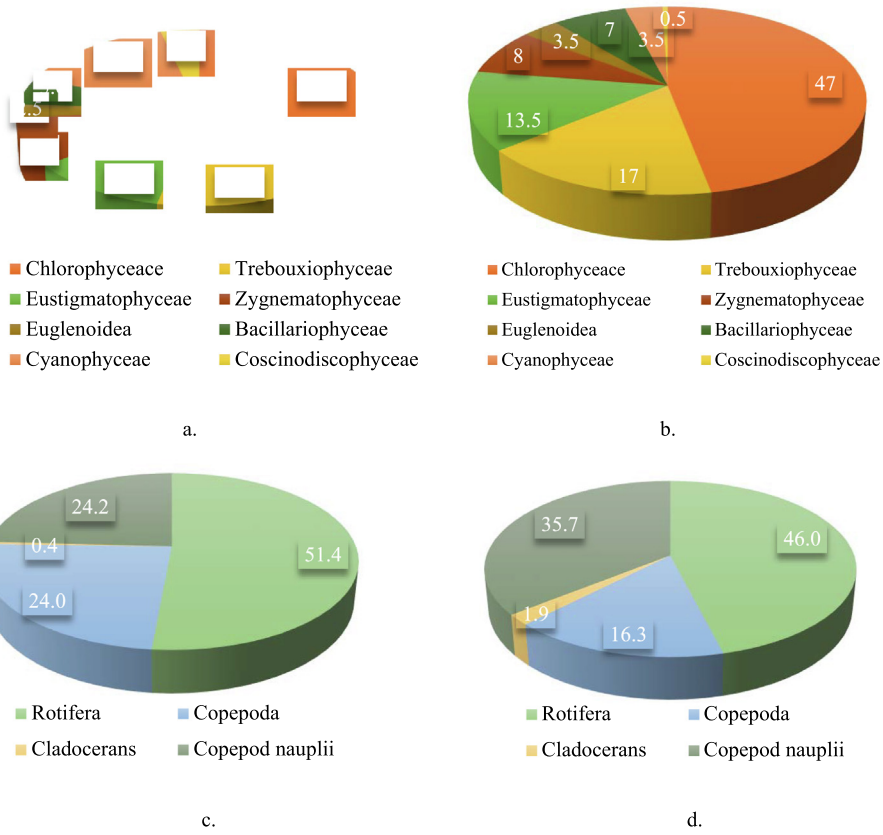

Fig. 3. Phytoplankton (a and b) and zooplankton (c and d) community composition (%) recorded for old (a and c) and new (b and d) commercial semi-intensive marron ponds (n = 3).

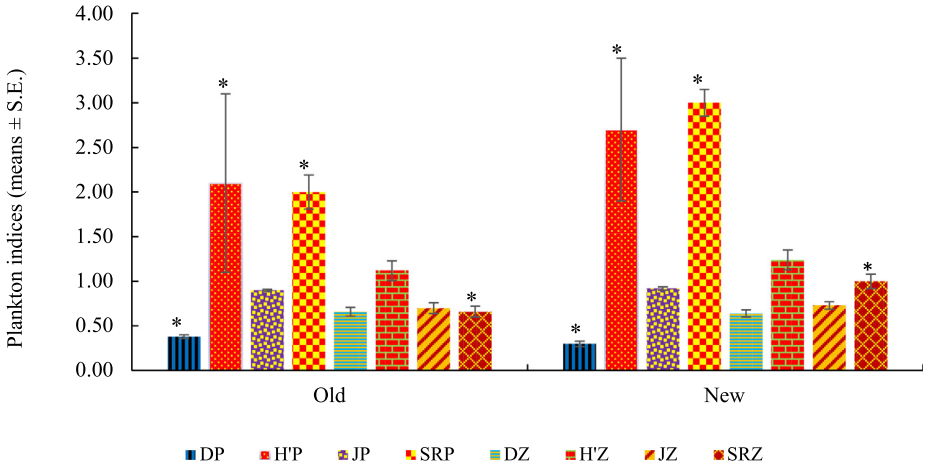

Fig. 4. Mean ± S. E. of different plankton indices for old and new aged semi-intensive commercial ponds. Where, DP, H'P, JP and SRP represents the phytoplankton indices and DZ, H'Z, JZ and SRZ represents the zooplankton indices. Abbreviations: DP = predominant indices of phytoplankton, H'P = Shannon Wiener diversity index of phytoplankton, JP = phytoplankton evenness, SRP = phytoplankton species richness; DZ = predominant indices of zooplankton, H'Z = Shannon Wiener diversity index of zooplankton, JZ = zooplankton evenness and SRZ = zooplankton species richness. *represents the significant difference of plankton indices between the old and new ponds ($p < 0.05$; n = 3).

similar with the finding of (Abdel-Tawwab) in freshwater ponds (Sharqia, Egypt).

The varied environmental conditions also influenced the plankton community structure, as during the colder months Chlorophyceae, Trebouxiophyceae and Zygnematophyceae were more abundant, especially Chlorophyceae. Whereas, during the warmer months (>20 °C) Cyanophyceae dominated, indicating that they thrive at higher temperatures than eukaryotic phytoplankton (Kosten et al., 2012), however, Coscinodiscophyceae were observed only in January (Fig. 2a). Increased water temperature causes a decrease in surface water viscosity, promoting the sinking of non-motile phytoplankton and the capacity of adjusting buoyancy helps Cyanophyceae to dominate plankton communities (O'Neil et al., 2012). Decreased NO_3-N and increased phosphorus concentrations during the January and March may have also boosted the Cyanophyceae abundance (Li et al., 2019). Cladocerans were observed only during the colder months. Favourable temperature ranges hastens the abundance of certain Cladocerans, such as

Daphnia (Li et al., 2019). Daphnia from a Mediterranean climate (Castelló d'Empúries, Spain) were found to be at optimum filtration capacity when the temperature was 20 °C (Müller et al., 2018). Gillooly and Dodson (2000) observed the maximum daphnia abundance when the mean water temperature was 18.5 °C in freshwater lakes from Florida to Alaska. Daphnia was recorded only when lakes water temperatures were below 20 °C (Lake Chilwa and Lake Chad, Africa) (Kalk, 1979; Dumont, 1994). These results support our finding of observing Daphnia spp. in colder months. Copepoda abundance was dominated by the copepod nauplii and adults Calanoida around the year. The presence of copepod nauplii can relate to recruitment through reproduction in the ponds over time as the adult copepods were recorded in all months. Phytoplankton abundance can support copepod nauplii growth as they are herbivorous unlike the more carnivorous adults (Siti and Sharip, 2019).

The phytoplankton composition was dominated by Chlorophyceae (48.7%), as observed by Kobayashi et al. (2015) in experimental outdoor freshwater ponds (Kyoto University, Japan). Rotifera dominated the zooplankton composition as observed by Mathias (1991) in a tropical freshwater lake (India), followed by Copepoda while Cladocerans had the lowest abundance of any zooplankton group. Copepoda abundance was dominated by Calanoida, which have vital implications for the structure and productivity of freshwater bodies in energy transfer from primary producers to consumers in aquatic ecosystems (Kobayashi et al., 2018).

Studies have shown that crayfish growth is a result of consumption of algae and zooplankton (Jones et al., 1995; Kreider and Watts, 1998; Lawrence, 1998; Duffy et al., 2011). Correia et al. (2002) recorded higher prawn (*Macrobrachium rosenbergii*) weight gain and biomass in older ponds than newer, due to the availability and consumption of natural food by prawns. In our study, the pond age did not affect the SGR, weight gain or organosomatic indices of cultured marron, likely due to the marron ponds being managed differently for each pond causing high variations. Our results about HM and TM were similar to the findings of Fotedar (2004). Our study showed similar SGR to the findings of Qin et al. (2001) for adult marron in commercial marron ponds. Feeding contributes to the health of marron and our results of marron HM % were similar to the findings of Foysal et al. (2020) for adult marron of 63.5 ± 2.24%.

The variations in environmental parameters affected the plankton abundance and their community structures, however the impacts of the farming practices were not studied in details. Over the time, plankton communities among the aquaculture ponds fluctuates, partly due to the reactive or experience based pond management that results in every pond being fertilized at a different time, with different doses or different feed types with varied nutritional compositions, and stocked animals (Coman et al., 2003; Casé et al., 2008; Boyd, 2009). A detailed study on addition of this locally available and used organic fertilizers such as fermented barley straw and its impact on plankton productivity and marron could provide definitive information about the semi-intensive freshwater culture ponds ecosystems in Australia.

5. Conclusion

Temporal variations and pond age influences the plankton abundance and their composition in freshwater earthen semi-intensive marron ponds. The temperature had a high influence on the plankton abundance and community structure.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sjbs.2020.11.075.

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