Aquaculture 445 (2015) 11–21

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aqua-online

Trophic interactions and productivity of copepods as live feed from tropical Taiwanese outdoor aquaculture ponds

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ARTICLE INFO

Article history:
Received 31 March 2015
Accepted 3 April 2015
Available online 15 April 2015

Keywords:
Aquaculture ponds
Pelagic food web
Pseudodiaptomus annandalei
Live feed for fish larvae

ABSTRACT

The present study describes three outdoor ponds for mass rearing of copepods in tropical southern Taiwan. The systems are designed for culturing and harvesting of copepods, which are used as live feed in the production of groupers in the region. However, the production of the most common copepod species *Pseudodiaptomus annandalei* (Sewell 1919) has, according to the pond managers, decreased over the last 10 years for no apparent reasons.

In order to understand the limitations in terms of production, the present study was carried out. A one month comprehensive monitoring of abiotic factors, inorganic nutrients, phytoplankton and zooplankton as well as the spatial patchiness of zooplankton in the ponds was conducted. The ultimate aims were to: (I) obtain a better understanding of the variability and the interactions among the trophic levels in the pelagic; (II) obtain a sampling practice to enable a correct description of the copepods ecology and a preliminary evaluation of the status of the pond management; and (III) provide advices for improved management leading towards a higher and more stable output of *P. annandalei*.

Copepods were experiencing prey *ad libitum* since the quantity of phytoplankton available in the ponds was high (value of chlorophyll *a* in average 97.7 ± 10.9 μg L^{-1}) and dominated by diatoms, flagellates and pico-algae. The estimated abundance and biomass of adult copepods and copepodites of *P. annandalei* was on average 93 ± 40 individuals L^{-1} and 214 ± 98 μg C L^{-1}, respectively. *P. annandalei*'s specific growth rate in the ponds, thus the secondary productivity, was 0.89 ± 0.1 d^{-1} (average ± S.D.). The average harvest (21 kg of copepods wet weight per pond every second to fifth day), was a relatively low quantity to satisfy the demand of the fish farmers, especially during high season. This harvest, in terms of biomass, corresponded to 20–40% of the copepod standing stock, which indicates a sustainable management when compared to the secondary productivity of the copepods. To further increase the copepod production of the ponds, better water quality must be achieved. Moreover, improved harvesting techniques are recommended.

1. Introduction

In terms of biomass, marine copepods can represent up to 80% of the meso-zooplankton (Hwang et al., 2006; Lee et al., 2010; Mauchline, 1998) and play a pivotal role in the pelagic by linking the microbial food web to the highest levels, such as fish larvae. Copepods are thus attractive as a food item in aquaculture systems where they are superior as live feed for fish larvae (Drillet et al., 2011; Payne et al., 2001; Wilcox et al., 2006). Many fish cultures do not only depend on the quantity of fish eggs that are spawned by the brood stock, but also on the quality and the quantity of the live feed available for the fish at the early stages when the survival of the larvae is often very low (Drillet et al., 2006; Lee et al., 2010). Several species of copepods are used in aquaculture and native species are usually preferred due to their adaptation to the local climate and culture conditions.

In Taiwan, the calanoid copepod *Pseudodiaptomus annandalei* is commonly used as live feed for commercially important species such as grouper larvae (Chen et al., 2006; Lee et al., 2010). *P. annandalei* is found in coastal, estuarine and brackish waters of the subtropical and tropical Indo-Pacific region (Beyrend-Dur et al., 2011). This copepod is robust and adapted to changing conditions: it is euryhaline (salinity 3–30), can support heavy physical disturbance, presence of sediment

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http://dx.doi.org/10.1016/j.aquaculture.2015.04.003

and suspended solids and high ammonia levels (Beyrend-Dur et al., 2011; Hwang et al., 2010). *P. annandalei*, among other copepod species, has been cultivated successfully in Taiwan in copepod ponds for several decades at relatively high densities. When the local grouper hatcheries require live feed, copepods are collected, transported, sold and used directly to feed the fish larvae. The pond managers, however, have expressed that the productivity of copepods has been decreasing in the last 10 years, causing serious supply issues and economic challenges. Unfortunately, in the light of the commercial importance of these copepod ponds, surprisingly little is known of the ponds intricacies, species interactions and the ecology of the key copepod species *P. annandalei* apart from various behavioral studies (Dur et al., 2010; Lee et al., 2008, 2010, 2011) and laboratory studies relating to its feeding and fitness (Beyrend-Dur et al., 2011; Chen et al., 2006; Dhanker et al., 2012, 2013; Golez et al., 2004; Lee et al., 2010; Li et al., 2009; Su et al., 2007). To our knowledge, there are no reports on the biology and tolerance limits of *P. annandalei* when cultured in ponds. Temperature and salinity are speculated to be the main factors that can adversely affect the reproductive performance of this copepod species and, consequently, its population growth rate (Beyrend-Dur et al., 2011; Chen et al., 2006). Other factors like oxygen, ammonia levels and zooplankton species competition are also of interest. To establish necessary fundamental knowledge, the present study aims at describing the pelagic food web dynamics in ponds and is also supported by an additional paper focusing on the most predominant copepod, *P. annandalei* (Rayner et al., 2015). The description of the pond ecosystem in these two studies will allow for further justification and rationalization of future studies as well as serve as a base for better management of copepod productions in extensive pond systems.

2. Methods

2.1. Study site

Sampling was conducted from June 18th to July 13th, 2012, in Tungkang, southern Taiwan (22°28′57.78 N; 120°26′06.71E) where 3 copepod rearing ponds were visited and samples collected (Fig. 1). Samples were processed and analyzed at Tungkang Biotechnology Research Center, Fisheries Research Institute and National Taiwan Ocean University (NTOU) in Taiwan, at Roskilde University (RUC) and Århus University (AaU) in Denmark and University of Szczecin in Poland.

These ponds are situated close to the Kaoping estuary and have been used for decades to grow shrimps/fish and copepods together as described in the present study. The ponds are typical shrimp ponds, ~0.7 ha and 1 m deep, filled with coastal brackish water (salinity up to 15–20) and underground water provided by a channel system. To ensure a high productivity (phytoplankton and subsequently zooplankton and shrimps), the ponds are fertilized with fish meat-meal (sometime fermented) as nutrient input. Paddle wheels were used to control the oxygen in the water.

2.2. Measurements of abiotic factors

In situ loggers were used for every day monitoring of light, temperature and salinity.

HOBO Pendant® data loggers from ONSET measured light and temperature at 5 min interval in each pond just below the surface and at the bottom, and in air at 2 m above the ground adjacent to the ponds. Surface salinity was measured with a hand held refractometer (ATAGO, Tokyo, Japan, 0.5 units in resolution) while 2 salinity Star-Oddi DST-CTD loggers (SeaStar software), mounted at 0.5 m depth, were monitoring the salinity in the ponds every 10 min. Oxygen and pH were measured every other day. Measurements were performed with OxyGuard probes (Handy pH and Handy Polaris 2 from Water Management Technologies, WMT). For continuous oxygen measurements (15 min interval), the probe was mounted at approximately 0.5 m depth in the pond for 2 days in rotation between the ponds during the whole period.

2.3. Sampling and measurements of biotic factors

2.3.1. Water sampling

Water samples for inorganic nutrients and phytoplankton were also collected every other day. The water for these analyses was sampled from the ponds using a 3 L NISKIN water bottle (67 cm in length) at 5 randomly chosen and evenly distributed sampling points to collect a representative sample. The sampled water was pooled in a 20 L plastic container and processed in the laboratory for inorganic nutrients, Chl-*a* analyses, HPLC plant pigment analysis and particulate carbon and nitrogen content analyses. Seston sub-samples representing the "total" and fractions below 15 μm (except the first two sampling dates), in order to observe the fraction of algae biomass available for the copepods (sensu Berggreen et al., 1988), were concentrated on

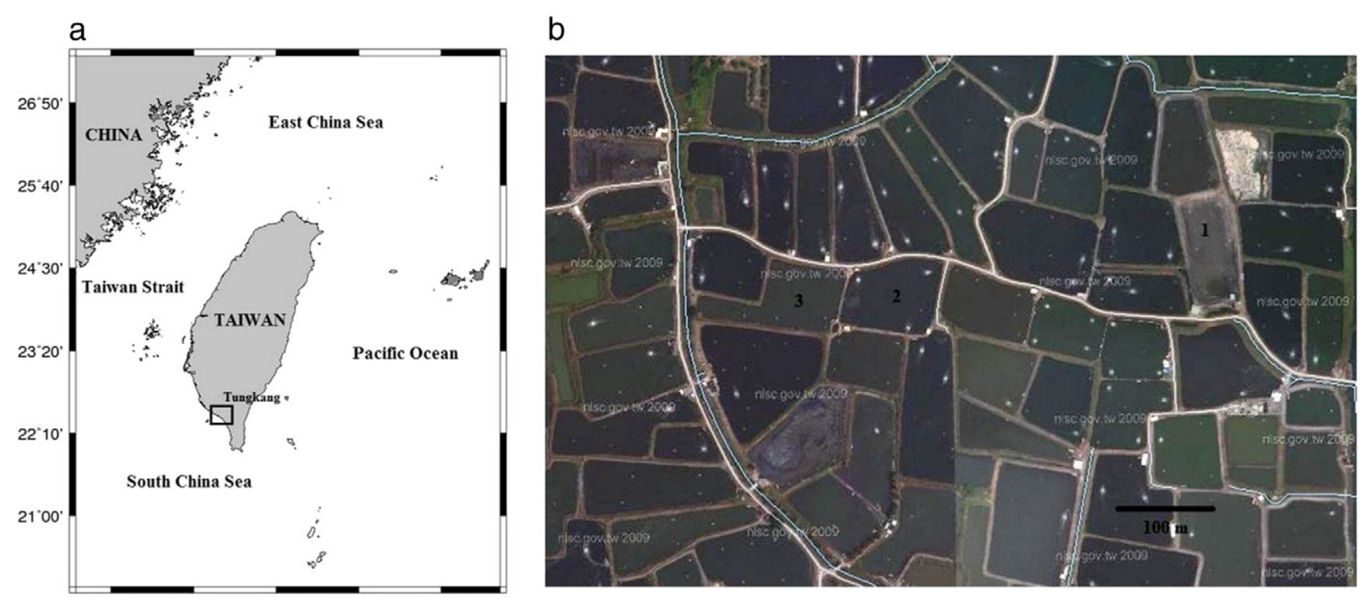

Fig. 1. A. Sampling location in copepod ponds at Tungkang in Southern Taiwan. NOAA National Geophysical Data Center, Coastline extracted (e.g.: WVS, GSHHG), date retrieved, http://www.ngdc.noaa.gov/mgg/shorelines/shorelines.html. B. Aerial view of the three copepod ponds visited (http://maps.nlsc.gov.tw/).