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Community Composition of Zooplankton near Fish Cages in Lampung and South Sulawesi, Indonesia

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Abstract

Fish cage aquaculture may impact on the plankton communities present in the surrounding waters, as a result of changes in water quality from aquaculture wastes. Zooplankton abundance, biomass and copepod species composition were studied in three Indonesian embayments containing fish cages (Awarange Bay, South Sulawesi; Ayong Farm and Hurun Bay, Lampung) over 2 years (dry season, August 2006 and wet season, March 2007). Zooplankton were sampled with vertical net hauls from bottom to surface with a 0.5 m diameter net of 73 µm mesh. Total zooplankton biomass ranged between 36 $mg\cdot m^{-3}$ (Hurun Bay, August 2006) and 877 $mg\cdot m^{-3}$ (Awarange Bay, March 2007). Total zooplankton abundance ranged between 32,745 $individuals\cdot m^{-3}$ (Hurun Bay, August 2006) and 652, 925 $individuals\cdot m^{-3}$ (Awarange Bay, August 2006). Calanoida and Cyclopoida nauplii and juveniles dominated numerically (62-91%), with adult copepods also having high total abundances (6-38%). Non-copepod holoplankton (larvaceans, chaetognaths, ostracods, euphausiid larvae and shrimp larvae) and meroplankton (zoea larvae) made up only a very small amount of the total abundance found at all sites (0.2-7.7%). Thirty seven copepod species were recorded from 12 families, with 5 new records for Indonesia: *Oithona decipiens, Oithona hebes, Oncaea atlantica* group, *Oncaea zernovi* group and *Spinoncaea* spp. The majority of the copepod species present at all sites were <1.0 mm in length, and the community composition was similar to that found in other Asian coastal environments where aquaculture development occurs.

Introduction

The intensification of coastal aquaculture in the tropics has come at a cost to ecosystem goods and services, such as the destruction of coastal mangroves, degradation of coral reefs and deterioration of water quality (Loya et al. 2004; Primavera, 2006). Aquaculture wastes increase turbidity and nutrient concentrations in receiving waters, potentially leading to problems associated with eutrophication such as declining oxygen concentrations and blooms of undesirable and sometimes noxious phytoplankton. In the tropics, separating the effects of aquaculture wastes from natural variability is confounded by the influence of monsoonal climate and tidal mixing (McKinnon et al. 2010). Many of the most commonly measured physico-chemical indicators change depending on the time of day, state of the tide or location of sampling, and are notoriously inconsistent. As an alternative to directly measuring water chemistry, plankton can be used as useful indicators of water quality, since they integrate the effect of changes in water quality that occur over small scales of time and have a response time at a meaningful scale for environmental managers (Rissik and Suthers, 2009). Ultimately, eutrophication may cause large scale shifts in plankton communities (e.g. Uye, 1994).

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A number of studies in the Asian region point to changes in the plankton occurring as a result of aquaculture activities. Chong et al. (2004) reported differences in plankton communities in a Malaysian estuary containing cages from those in a nearby estuary with no aquaculture activities, as well as higher concentrations of zooplankton within sea cages than outside them. In a Chinese bay intensively used by aquaculture of both fish and mussels, Dong et al. (2006) found the zooplankton was dominated by small species, and that diversity was greatest at the outer part of the bay. In the Philippines, de Castro et al. (2005) found lower zooplankton abundances in the wet season in conditions of high nutrient concentrations, high suspended solids and low dissolved oxygen typical of areas of aquaculture development. Unfortunately, there is little information available on copepod community composition in inshore environments in Indonesia, especially concerning the small copepod species (<1 mm in length) that dominate the tropical mesozooplankton (Hopcroft et al. 1998; McKinnon and Duggan, 2001), and no studies concerning the zooplankton of waters receiving aquaculture effluents. During a study of the environmental impact of fish cage aquaculture in Indonesia (Alongi et al. 2009), the plankton communities in both wet and dry seasons (March and August respectively) were surveyed to determine whether there was any indication of change from natural conditions, and if not, to provide baseline data against which future changes could be compared.

Materials and Methods

Study Areas

Two sites, Awarange Bay in South Sulawesi and Ayong Farm in Lampung, southern Sumatra, were sampled during August 2006 (dry season) and March 2007 (wet season). These two time periods were chosen to capture variability in the zooplankton communities associated with changes in the monsoonal climate of the region. An additional site was sampled in Hurun Bay, Lampung, in August 2006 (Fig. 1a). The study sites are microtidal, with weak tidal currents of <0.5 $m^{.}s^{-1}$ (Alongi et al. 2009), and are described below:

1) Hurun Bay is on the northwest coast of the Gulf of Lampung in southern Sumatra (Fig. 1b). The bay is horseshoe-shaped and1.5 km^2 in area with a 1.8 m tidal range. Three small rivers flow into Hurun Bay and the average depth is 12 m. Near the northern inlet of the bay mouth there are sets of fish cages that are operated by BBL (Balai Budidaya Laut laboratory, Mariculture Development Centre, Lampung) for the purpose of developing marine fish culturing techniques.
2) Ayong Farm is a commercial grouper farm located in Lampung Regency to the north of Puhawang Island in southern Sumatra (Fig. 1b). This farm consists of 152 net cages with a total surface area of 2,432 m^2 and is in water depth of 23 m (Alongi et al. 2009).
3) Awarange Bay is located in Barru Regency, South Sulawesi (Fig. 1c). The bay is crescent-shaped, 5.4 km^2 in area with a 1.2 m tidal range and mean depth of 14 m, with fringing coral reefs near the bay entrance and mangroves and seagrass beds at the southern end of the bay. A fish cage farm is located in the southern part of the bay, which consists of 30 net cages with a total surface area of 64.5m^2 (Alongi et al. 2009).

At Hurun Bay sampling only occurred during August 2006, with samples taken at the fish cage as well as following a transect running from HB Site 1 to HB Site 5 (Fig. 1b). Ayong Farm had two sampling stations at the fish cages, which were repeated in the second sampling year (AY-02 and AY-09 during August 2006 and AY-10 and AY-19 during March 2007; Fig. 1b). At Awarange Bay, samples were taken at the fish cages, the seagrass beds, the mouth of the bay (AB Site 3), as well as two other areas throughout the bay (AB Site 1 and AB Site 2; Fig. 1c). These stations were initially sampled in August 2006, with repeat sampling occurring in March 2007.

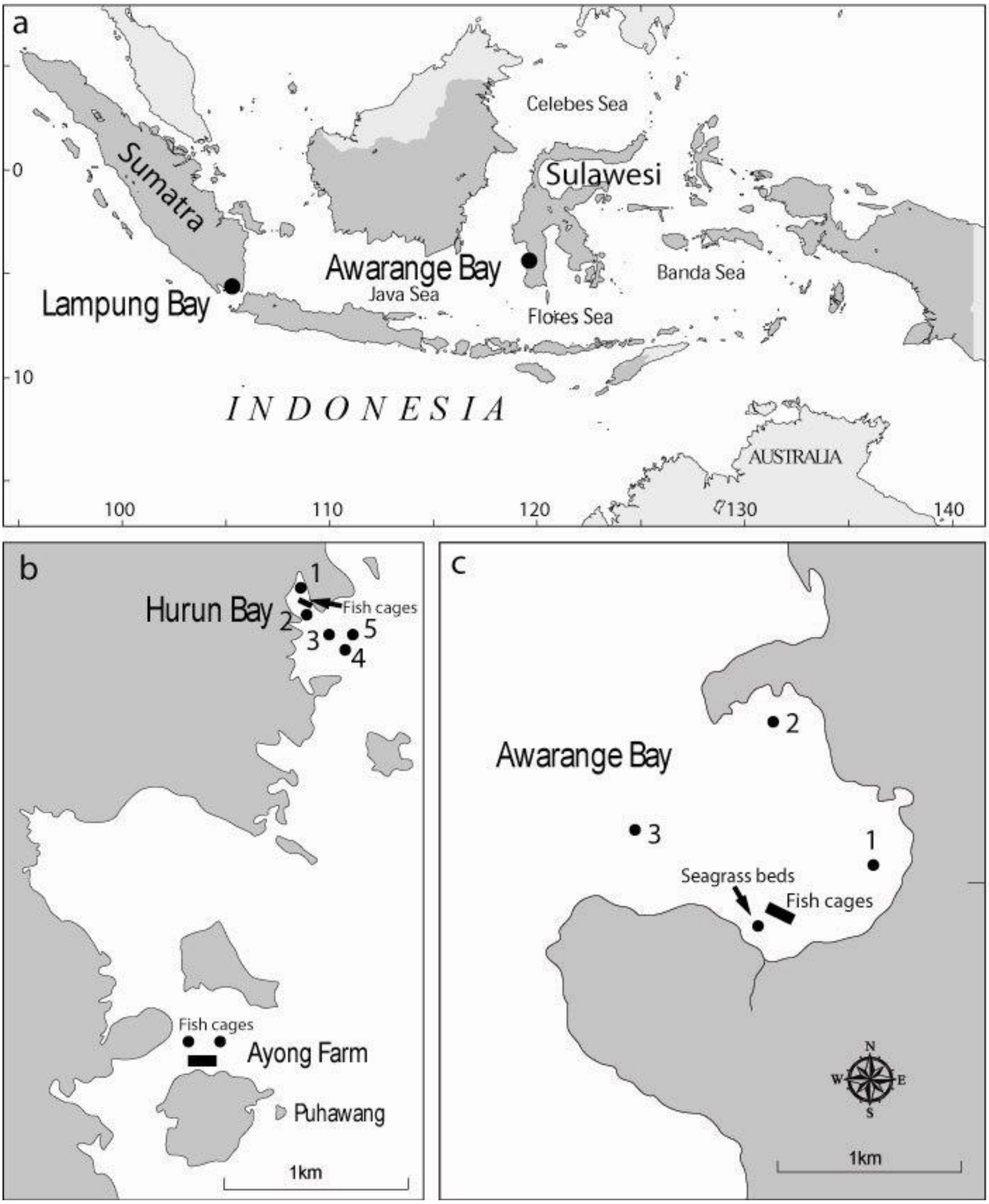

Fig. 1. Map of sampling locations: a) main sites at Awarange Bay, South Sulawesi and Lampung Bay, southern Sumatra; b) sampling stations at Hurun Bay and Ayong Farm; c) sampling stations at Awarange Bay.

Community composition

Zooplankton were sampled with vertical net hauls from bottom to surface with a 0.5m diameter net of 73µm mesh fitted with a Rigosha flowmeter. Zooplankton community structure and total zooplankton biomass were determined by triplicate hauls at all stations, except for the transect at Hurun Bay where only one haul was taken at each station. For all stations, each net sample was split into equal portions; one was preserved in 5% formaldehyde for analysis of community composition and the other filtered onto a pre-weighed disk of 73µm mesh and frozen. In the laboratory, the frozen mesh was dried (65ºC) and re-weighed to estimate zooplankton community biomass. The preserved zooplankton sample was washed to remove formaldehyde and diluted to a known volume with water. A Stempel pipette was used to provide a subsample containing approximately 500 organisms that were then enumerated in a Bogorov tray under a Wild stereomicroscope. All taxa were counted to convenient taxonomic categories, and all nauplii and copepodites of calanoid and cyclopoid copepods counted. Adult copepods were identified to species and sex, and their abundance calculated on the basis of the volume of water filtered by the net and the fraction of sample counted.

Data analysis

Differences in biomass and total zooplankton abundances between the different sites (Awarange Bay, Ayong Farm and Hurun Bay) in August 2006 were investigated using one-way, fixed factor analysis of variance (ANOVA). No sampling occurred at Hurun Bay during March 2007, so no comparisons could be made between this site and the other two sites for this time period. Biomass and total zooplankton abundances were also compared between Awarange Bay and Ayong Farm for the two different sampling times (August 2006 and March 2007) using two-way fixed factor analysis of variance (ANOVA). Prior to analysis the data was tested for heteroscedasticity by Cochran's procedure and square-root transformed as needed. The biomass sample from the seagrass station at Awarange Bay during August 2006 was removed from the data analysis due to contamination of the sample by sand.

Results

Species composition

A total of 37 species of copepods and 6 non-copepod taxa were identified during this study. The non-copepod taxa present included larvaceans, chaetognaths, euphausiid larvae, ostracods, shrimp larvae, and zoea larvae. Compared to the other non-copepod taxa, larvaceans were present in the highest abundances throughout the entire study period, especially at Ayong Farm (AY-09) in August 2006 (6.7%) and Awarange Bay (Cage station) in March 2007 (4.1%, Table 1). The other non-copepod taxa were present in only very small percentages at all stations and times (0.0-1.2%, Table 1).

Of the 37 species of copepods collected, 15 were calanoids, 20 were cyclopoids and 2 were harpacticoids (Table 2). Amongst the calanoids, the family Paracalanidae was the most speciose (7 spp.). The species of *Bestiolina* collected was unable to be identified from the comparative table given in Ali et al. (2007) and it is likely to be a new species. The family Oithonidae was the most speciose of the cyclopoid families (8 spp.), with Corycaeidae and Oncaeidae containing the same number of species (6 spp.). Small species (0.25-0.38 mm in length) of Oncaeidae closely related to *Oncaea atlantica* (referred to here as *O. atlantica* group, cf. Böttger-Schnack et al. 2004) and *O. zernovi* (*O. zernovi* group) were collected. The taxonomy of these groups, which contain species that differ only in very slight morphological details, is yet to be established. The Harpacticoida were represented by only two genera, *Microsetella* spp. and *Euterpina acutifrons*. Taxonomic uncertainties within the genus *Microsetella* resulted in no attempts being made to identify the species within these groups.

Awarange Bay contained the most number of copepod species (31 spp.) with Hurun Bay and Ayong Farm each having 22 spp. of copepods present, though these differed in their composition. The high abundance of adult copepods at Awarange Bay was due to the high numbers of Oithonidae present in this area, mainly *Dioithona rigida*, *Oithona simplex* and *O. nana*. All the calanoids found in the present study (Table 2) also occurred in the study of Cornils et al. (2010), with the exception of *Pseudodiaptomus sulawesiensis,* which is endemic to Indonesia (Nishida and Rumengan, 2005). In contrast, the congeneric *P. aurivilli* has been recorded previously in Indonesian and Australian waters, but not in China Seas or Japanese waters. Of the cyclopoids, 75% have been previously recorded in Indonesian seas. These results constitute new records for *Oithona decipiens*, *O. atlantica* group, *O. zernovi* group and *Spinoncaea* spp. in Indonesian seas, and for *Oithona hebes* in the Indo-Pacific.

The most common copepods identified belonged to the genera *Oithona, Parvocalanus, Oncaea, Euterpina, Microsetella, Bestiolina* and *Acartia* (Table 3). These species were common to all locations, with the exception of *Oncaea paraclevei* and *Paracalanus aculeatus minor*, which were only ranked in the top ten most abundant at Ayong Farm, and *Spinoncaea* spp. that was ranked in the top ten only at Awarange Bay. All of these species (with the exception of *Acartia pacificia*) were <1.0 mm in length (Table 2).

Table 1. Relative percentage composition of zooplankton identified at Lampung (Ayong Farm and Hurun Bay) and South Sulawesi (Awarange Bay) during August 2006 and March 2007. CAL = Calanoida nauplii and juveniles; CYL = Cyclopoida nauplii and juveniles; Copepods = adult copepods; C = chaetognaths, EUL = euphausiid larvae; L = larvaceans; O = ostracods; Shrimp = shrimp larvae; Zoea = zoea larvae.

Site	Location	Date	CAL	CYL	Copepods	C	EUL	L	O	Shrimp	Zoea
Awarange Bay	Cage	Aug-06	20.1	70.9	8.5	0.0	0.1	0.4	0.0	0.0	0.0
	Cage	Aug-06	22.6	68.9	8.0	0.0	0.0	0.6	0.0	0.0	0.0
	Seagrass	Aug-06	1.6	81.2	17.3	0.0	0.0	0.0	0.0	0.0	0.0
	AB Site 1	Aug-06	23.3	67.2	9.3	0.1	0.0	0.1	0.0	0.0	0.0
	AB Site 2	Aug-06	21.9	60.7	16.8	0.0	0.0	0.5	0.0	0.0	0.1
	AB Site 3	Aug-06	13.7	69.8	13.7	0.6	0.0	2.2	0.0	0.0	0.0
	Cage	Mar-07	31.9	51.3	12.3	0.0	0.3	4.1	0.0	0.0	0.1
	Cage	Mar-07	49.8	39.1	10.2	0.0	0.2	0.4	0.2	0.0	0.0
	Seagrass	Mar-07	38.2	41.8	16.5	0.0	0.0	3.4	0.0	0.0	0.1
	AB Site 1	Mar-07	53.2	36.7	7.9	0.1	0.1	2.0	0.1	0.0	0.0
	AB Site 2	Mar-07	47.9	33.3	17.3	0.2	0.1	1.0	0.0	0.2	0.0
	AB Site 3	Mar-07	42.0	40.1	13.5	0.2	0.5	3.5	0.3	0.0	0.0
Ayong Farm	AY-02	Aug-06	20.8	70.3	5.9	0.6	0.4	1.8	0.1	0.0	0.0
	AY-09	Aug-06	21.3	57.2	13.8	0.7	0.3	6.7	0.0	0.0	0.0
	AY-10	Mar-07	19.7	60.7	17.4	1.0	0.5	0.7	0.0	0.0	0.0
	AY-19	Mar-07	23.9	54.2	16.5	1.2	0.3	3.5	0.0	0.3	0.0
Hurun Bay	Cage	Aug-06	13.2	56.4	30.0	0.2	0.0	0.1	0.0	0.0	0.0
	HB Site 1	Aug-06	13.7	47.9	38.2	0.0	0.0	0.2	0.0	0.0	0.0
	HB Site 2	Aug-06	34.6	55.5	9.0	0.1	0.1	0.7	0.0	0.0	0.1
	HB Site 3	Aug-06	32.3	52.6	13.2	0.4	0.3	1.1	0.0	0.1	0.0
	HB Site 4	Aug-06	30.3	54.4	12.8	0.8	0.0	1.7	0.0	0.0	0.0
	HB Site 5	Aug-06	26.2	55.2	15.8	0.8	0.6	1.3	0.0	0.1	0.0

Table 2. Copepod species recorded from Lampung (Ayong Farm and Hurun Bay) and South Sulawesi (Awarange Bay) during this study. Previous records from Indonesian waters, Australian waters, China Seas and Japanese waters are also shown (Razouls et al. 2005-2011; McKinnon et al. 2008;Cornils et al. 2010). P = present at that site or region. Length measurements are total lengths of females from Razouls et al. (2005-2011), except for species with a * that are measured from this study.

	Species	**Length**	**Site**			**Previous records**			
		mm	Ayong Farm	Hurun Bay	Awarange Bay	Indonesian waters	Australian waters	China Seas	Japanese waters
CALANOIDA									
ACARTIIDAE	*Acartia negligens* (Dana, 1847)	0.91-2.07			P	P	P	P	P
	Acartia pacifica (Steuer, 1915)	1.0-1.51		P	P	P	P	P	P
CALANIDAE	*Canthocalanus pauper* (Giesbrecht, 1888)	1.1-1.75	P	P		P	P	P	P
CENTROPAGIDAE	*Centropages furcatus* (Dana, 1849)	1.38-1.9		P		P	P	P	P
PARACALANIDAE	*Acrocalanus gibber* (Giesbrecht, 1888)	0.74-1.28	P	P		P	P	P	P
	Acrocalanus gracilis (Giesbrecht, 1888)	0.81-1.80	P	P	P	P	P	P	P
	Bestiolina sp. *	0.54-0.64	P	P	P	P			
	Paracalanus aculeatus major (Sewell, 1929)	0.78-1.36	P	P		P	P	P	P
	Paracalanus aculeatus minor (Sewell, 1929)	0.69-0.86	P	P	P	P	P		
	Parvocalanus crassirostris (F. Dahl, 1894)	0.42-0.82	P	P	P	P	P	P	P
	Parvocalanus dubia (Sewell, 1912)	0.74	P	P	P	P	P	P	
PONTELLIDAE	*Labidocera minuta* (Giesbrecht, 1889)	1.76-2.26			P	P	P	P	P
PSEUDODIAPTOMIDAE	*Pseudodiaptomus aurivilli* (Cleve, 1901)	1.2-1.3		P		P	P		
	Pseudodiaptomus sulawesiensis * (Nishida and Rumengan, 2005)	1.1			P	P			
TORTANIDAE	*Tortanus barbatus* (Brady, 1883)	1.32-2.1			P	P	P	P	
CYCLOPOIDA									
OITHONIDAE	*Dioithona rigida* (Lindberg, 1950)	0.60-1.00	P	P	P	P	P	P	P

Table 2 (contd.)

	Oithona aruensis (Fruchtl, 1923)	0.40-0.46	P	P	P	P	P	P	P
	Oithona attenuata (Farran, 1913)	0.66-1.78			P	P	P	P	P
	Oithona decipiens (Farran, 1913)	0.55-0.81	P		P		P	P	P
	Oithona hebes (Giesbrecht, 1891)	0.47-0.61		P	P				
	Oithona nana (Giesbrecht, 1892)	0.42-0.95	P	P	P	P	P	P	P
	Oithona plumifera (Baird, 1843)	0.70-1.54	P	P	P	P	P	P	P
	Oithona simplex (Farran, 1913)	0.30-0.46	P	P	P	P	P	P	P
CORYCAEIDAE	*Ditrichocorycaeus andrewsi* (Farran, 1911)	0.65-1.07	P		P	P	P	P	P
	Ditrichocorycaeus asiaticus (F. Dahl, 1894)	1.04-1.40		P	P	P	P	P	P
	Ditrichocorycaeus dahli (Tanaka, 1957)	0.85-1.21	P	P	P	P	P	P	P
	Ditrichocorycaeus erythraeus (Cleve, 1904)	0.85-1.10	P		P	P	P	P	P
	Onychocorycaeus catus (F. Dahl, 1894)	0.87-1.18	P	P	P	P	P	P	P
	Onychocorycaeus pacificus (F. Dahl, 1894)	1.04-1.22			P	P	P	P	P
ONCAEIDAE	*Oncaea atlantica* group (cf. Böttger-Schnack et al. 2004)	0.25-0.26			P		P		
	Oncaea clevei (Fruchtl, 1923)	0.62-0.76	P			P	P	P	P
	Oncaea paraclevei (Böttger-Schnack, 2001)	0.65-0.66	P		P	P	P		
	Oncaea scottodicarloi (Heron & Bradford-Greve, 1995)	0.50-0.78			P	P	P		P
	Oncaea zernovi group (Shmeleva, 1966	0.31-0.38			P		P		P
	Spinoncaea spp.	0.30-0.34			P		P		
HARPACTICOIDA									
ECTINOSOMATIDAE	*Microsetella* spp.	0.65- 0.72	P	P	P				
EUTERPINIDAE	*Euterpina acutifrons* (Dana, 1848)	0.41-0.86	P	P	P	P	P	P	P

Table 3. The ten most common copepod species from Lampung, Sumatra (Ayong Farm and Hurun Bay) and South Sulawesi (Awarange Bay).

Site	Species Name
Awarange Bay	*Dioithona rigida*
	Parvocalanus crassirostris
	Oithona simplex
	Oithona nana
	Parvocalanus dubia
	Euterpina acutifrons
	Spinoncaea spp.
	Bestiolina sp.
	Acartia pacifica
Ayong Farm	*Oithona nana*
	Euterpina acutifrons
	Parvocalanus dubia
	Oithona simplex
	Microsetella spp.
	Parvocalanus crassirostris
	Oncaea paraclevei
	Bestiolina sp.
	Paracalanus aculeatus minor
	Oithona aruensis
Hurun Bay	*Dioithona rigida*
	Oithona simplex
	Oithona nana
	Parvocalanus dubia
	Euterpina acutifrons
	Parvocalanus crassirostris
	Bestiolina sp.
	Oithona aruensis
	Acartia pacifica
	Microsetella spp.

Abundance

Total zooplankton abundance ranged between 32,745 individuals$\cdot$m^{-3} (HB Site 4, Hurun Bay, August 2006) and 652, 925 individuals$\cdot$m^{-3} (Seagrass station, Awarange Bay, August 2006; Fig. 2). The highest abundances occurred at Awarange Bay during both sampling periods (Fig. 2); but overall there was no significant difference between sites or seasons. Nauplii and juveniles of calanoid and cyclopoid copepods were the most numerous taxa (62-91% of the total abundance), with adult copepods comprising 6-38% (Table 1, Fig. 2). Holoplankton and meroplankton made up only a very small amount of the total abundance found at all sites (0.2-7.7%, Table 1, Fig. 2). Awarange Bay had the highest abundances of adult copepods, especially at the seagrass station, followed by Hurun Bay, while Ayong Farm had the lowest adult copepod abundances (Fig. 2). Awarange Bay had high abundances of Oithonidae, especially at the seagrass station during both sampling times, and also high abundances of Paracalanidae (mainly

P. crassirostrus and *P. dubia*). High abundances of both these families were also found at Hurun Bay and Ayong Farm, with this latter site also having relatively high abundances of *E. acutifrons* (Fig. 3).

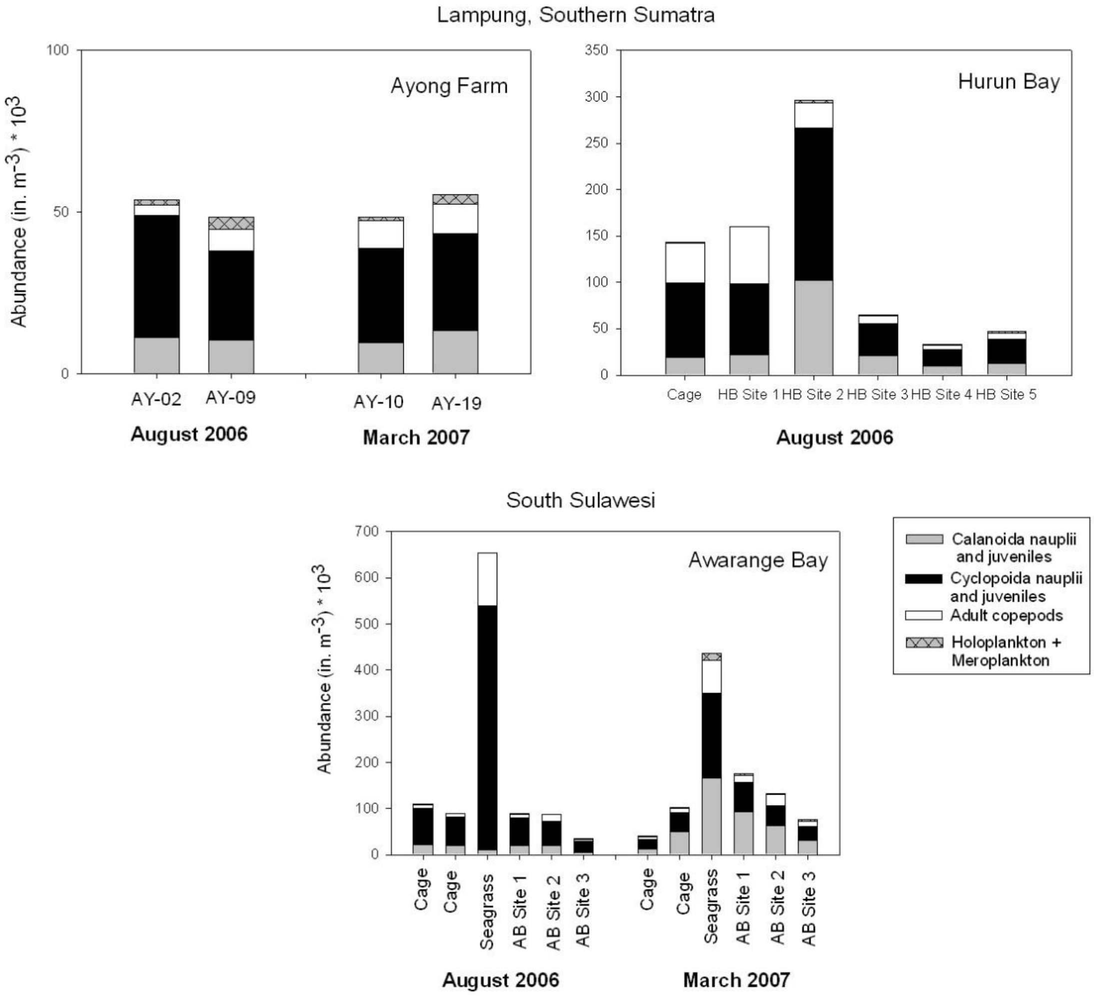

Fig. 2. Total zooplankton abundance (individual·m^{-3}) at Lampung (Ayong Farm and Hurun Bay) and South Sulawesi (Awarange Bay) during August 2006 and March 2007.

Biomass

Total zooplankton biomass ranged between 36 mg·m^{-3} (HB Site 4, Hurun Bay, August 2006) and 877 mg·m^{-3} (seagrass station, Awarange Bay, March 2007), with the majority of stations having total biomass <250 mg·m^{-3} (Fig. 4). No significant differences were found between any of the sites or seasons in regards to total zooplankton biomass. The highest total zooplankton biomass was found at the seagrass station at Awarange Bay during March 2007 (Fig. 4), which corresponds to the total zooplankton abundance data also.

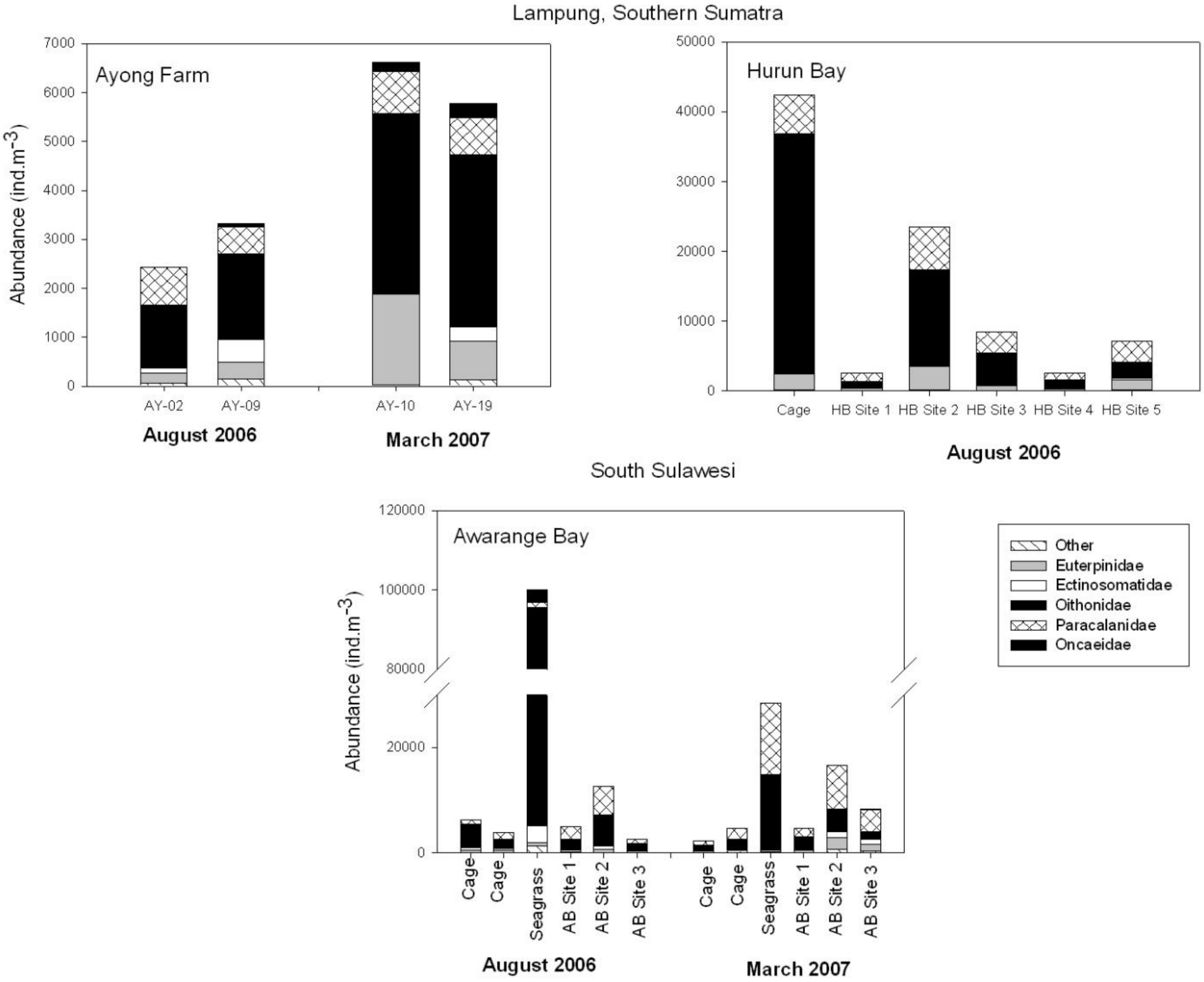

Fig. 3. Adult copepod abundance (individual·m^{-3}) at Lampung (Ayong Farm and Hurun Bay) and South Sulawesi (Awarange Bay) during August 2006 and March 2007.

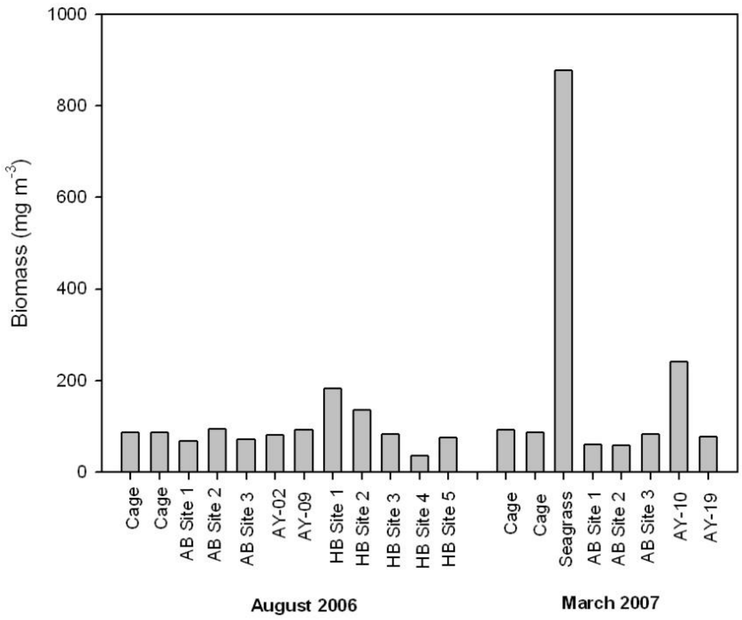

Fig. 4. Total zooplankton biomass (mg·m^{-3}) at all sites during August 2006 and March 2007.

Discussion

Zooplankton in waters surrounding the fish cages in this study was dominated by small copepods (<1 mm in length), as has been seen in earlier studies from China (Dong et al. 2006), Malaysia (Chong et al. 2004), and the Philippines (de Castro et al. 2005). However, since zooplankton, especially small copepod species, has been poorly studied in the waters surrounding Indonesia, it is difficult to judge whether the composition of the zooplankton had been altered by changes in water quality arising from the presence of these fish cages or not.

Alongi et al. (2009) concluded that the relatively small scale fish cage aquaculture in Awarange Bay and at Ayong Farm had only a marginal impact on the cycling of carbon, nitrogen and phosphorus in these environments. Though there were some differences in water column nutrients and chlorophyll concentrations seasonally and between farms, there were no strong indications that these departed from the range of natural variability (e.g. NH_4^+ 0.46-0.79µM; chlorophyll *a* 0.41-1.24 µg·L^{-1}), given the other inputs to coastal environments in the region (Alongi et al. 2009).

Cornils et al. (2010) described the zooplankton communities of the Spermonde Archipelago, directly adjacent to Awarange Bay, where there are no fish cages present. These authors separated shelf zooplankton sampled with a 200µm net into three communities; offshore, shelf and coastal. All but two species occurring in the present study occurred within the species group identified as inshore-coastal (Fig. 4 of Cornils et al. 2010). Of the 15 calanoid species identified in the present study, only *P. sulawaensis* was not recorded by Cornils et al. (2010); though there is doubt about three paracalanid species (*Bestiolina* sp., *P. aculeatus minor* and *P. dubia/elegans*), possibly because of taxonomic inconsistencies. Unfortunately Cornils et al. (2010) did not identify the cyclopoid species beyond genus; the present study determined eight species of *Oithona*, four of *Ditrichocorycaeus*, two of *Onychocorycaeus* and six oncaeid species.

The mean abundance of zooplankton in this study was ~130,000·m^{-3}, approximately 4-fold higher than the mean at the coastal stations of Cornils et al. (2010), probably because of the differences in communities sampled by nets of different mesh sizes (e.g. Tseng et al. 2011).The majority of the total zooplankton found in this present study was composed of copepods (nauplii, juveniles and adults). The fine-meshed nets (73 µm) used will capture all adults and most juveniles of the 37 small copepod species recorded, but these will be under-represented when nets with coarser mesh (e.g. >200 µm) are used. Additionally, small copepod species such as Oithonidae and Oncaeidae, which are often much less than 800 µm in length (see Table 2), are difficult to identify routinely in plankton counts.

Although copepods were the clear dominants in the zooplankton, larvaceans were the second most abundant taxon (Table 1), as was the case in the study of Cornils et al. (2010). These pelagic tunicates are very important in tropical waters because of their ability to feed directly on the dominant picoplankton (e.g. Jaspers et al. 2009). Chaetognaths were the only other common non-crustacean component of the zooplankton. Ostracods were probably under-represented in these samples because they tend to be demersal, and the crustacean larval stages of euphausiids and decapods (‘shrimp’ and zoea) represent the planktonic phase of animals that are primarily benthic in habitat. The results of the present study contrast with those of Dong et al. (2006) in the much lower representation of meroplankton, such as larvae of polychaetes and molluscs.

No significant differences were found between the total zooplankton biomass at the different sites, though the seagrass station at Awarange Bay did have much higher biomass than the other stations. In contrast, de Castro et al. (2005) found significantly higher biomass in the dry season than in the wet season (227 vs. 52 $mg{\cdot}m^{-3}$ at Bolinao, 57 vs. 27 $mg{\cdot}m^{-3}$ at Dagupan). These data are directly comparable to those of the present study since similar mesh sizes were used (63 µm), though de Castro et al. (2005) estimated biomass of formalin-preserved zooplankton, in which there is likely to be some weight loss (Postel et al. 2000), whereas the present study directly measured the dry weight of the biomass sampled. The range in biomass found for this area (36-877 $mg{\cdot}m^{-3}$) is similar to what has been found previously at the Great Barrier Reef, Australia (57-1200 $mg{\cdot}m^{-3}$, McKinnon et al. 2005) and in Darwin Harbour, Australia (52-1363$mg{\cdot}m^{-3}$, Duggan et al. 2008). Tranter (1962) also found mean zooplankton biomass for Australasian waters to range between 82 and 213 $mg{\cdot}m^{-3}$, depending on the area and year studied.

The results of the present study are directly comparable with those of Dong et al. (2006), who recorded 60 species (compared with 31 species collected at Awarange Bay and 22 species collected at Hurun Bay and Ayong Farm) from Zhelin Bay, China, using a similar fine-mesh net. In both studies, small copepods such as *P. crassirostris* dominated the plankton; 60% were <0.6mm in length. The higher diversity in their study probably had its origin in the greater contribution of open water plankton in the outer part of the bay. Chong et al.(2004) sampled with a pump system running through a153µm plankton net, and identified 50 zooplankton taxa at their Malaysian study site but did not identify the copepod component to species level. Possibly because of the pump method of sampling, abundances in the study of Chong et al. (2004) were very low; 3,000-20,000$\cdot m^{-3}$.

Dioithona rigida and *A. pacifica* were more abundant at Awarange Bay and Hurun Bay than at Ayong Farm, possibly reflecting their inshore affinities. *Microsetella* spp. and *O. aruensis* were present at all stations, but were only classified in the top 10 most abundant species at the Lampung stations. Previously unrecorded species in Indonesian waters were located at Awarange Bay (*O. atlantica* group, *O. zernovi* group *and Spinoncaea* spp.) while *O. decipiens* and *O. hebes* were found both at Awarange Bay and Lampung. *O. hebes* has been previously unrecorded in Indonesian waters, Australian and Japanese waters and in China Seas (Table 2). The majority of the *Oncaea* species were only recorded at Awarange Bay (*O. atlantica* group, *O. scottodicarloi, O. zernovi* group and *Spinoncaea* spp.), although *O. paraclevei* was also found at Ayong Farm and *O. clevei* was present only at Ayong Farm. *O. clevei* is the only *Oncaea* species that has been previously recorded from Indonesia, Australian and Japanese waters, as well as China Seas, though all of the *Oncaea* species identified have been identified previously in Western Australian waters (McKinnon et al. 2008). Since *O. paraclevei* was only described in

2001 (Böttger-Schnack, 2001**)**, these species may have been confused with other species in earlier accounts.

Of the 10 species of *Corycaeus* species recorded by Mulyadi (2006) in Indonesian waters, five occurred in this study (*Corycaeus andrewsi, C. asiaticus*, *C. catus, C. erythraeus* and *C. pacificus*), with *C. dahli* not being identified during Mulyadi's (2006) study, possibly because of its smaller size (0.85-1.21 mm), and the larger meshed nets used. Most of the species found in Mulyadi's (2006) study occurred in eastern Indonesian waters; however of the group common to both these studies only *C. asiaticus* was found from the Java Sea region. *Corycaeus asiaticus* was found to commonly occur in Mulyadi's study (2006), whereas *C. pacificus* was found at only a few sites. A similar pattern of these two species was seen in the present study, with the former being present at both Lampung and Awarange Bay, whereas the latter was present only at Awarange Bay. All of the six *Corycaeus* species identified were present at Awarange Bay, with the other sites having differing species composition and only *C. dahlia* and *C. catus* being located at all three sites. Mulyadi (2006) was the first to record *C. erythraeus* in Indonesian waters, and this species was also present in this study at both Lampung and Awarange Bay. All six *Corycaeus* species have also been located previously in Australian waters, China Seas and Japanese waters. The frequency of occurrence and mean abundance of the *Corycaeus* species found during the Cornils et. al (2010) study was higher in the coastal regions than the offshore regions, though no direct comparisons can be made between the *Corycaeus* species found in these two studies due to Cornils et al. (2010) not identifying these to species level.

Conclusion

The zooplankton communities in waters adjacent to fish cage farms at three locations in Indonesia have been described, and the dominant small copepods identified to species. These data provide baseline information for the evaluation of future change in water quality and plankton composition in the coastal environments of Indonesia. However, this study has not demonstrated any influence of aquaculture on the composition of the zooplankton at any of the three study sites. In a parallel study, Alongi et al. (2009) found only moderate enrichment of the benthos in the immediate dispersal area, and calculated that up to 77% of the organic input into the receiving environment was accounted for by gross primary production in the water column. Despite this, there is no indication of significant changes in the zooplankton from that found in similar environments both in the immediate vicinity (Spermonde Archipelago; Cornils et al. 2010) and in nearby countries with apparently similar coastal environments (Malaysia; Chong et al. 2004, and Philippines; de Castro et al. 2005).

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