INTERTIDAL BARNACLE COMMUNITY OF KETAPANG AND GILIMANUK PORTS THAT SEPARATED BY THE INDONESIAN THROUGHFLOW OF BALI STRAIT

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ABSTRACT

Indonesian Throughflow (ITF) flows from the Pacific Ocean through the western route of Makassar Strait and exit directly to the Indian Ocean through Lombok Strait and Bali Strait or flows eastward through the Banda Sea. Bali Strait separates the Ketapang Ferry Port of Banyuwangi on the Jawa side and Gilimanuk Ferry Port of Bali. Ferries connect Jawa and Bali through those ports as the primary mean of transportation. Ship hull and ballast water of those ships act as a proxy for barnacle distribution in their larval stage from one harbor to another so that it could influence the barnacle community of those two ports. The environmental condition of each seaport defines the barnacle community based on the adaptation ability of barnacle. The purpose of this research was to determine the intertidal barnacle diversity on both Ketapang and Gilimanuk seaports and to compare the barnacle community between Ketapang and Gilimanuk seaports. This study was a survey, and simple random sampling technique was used to collect samples. Sample collection was conducted from July to August 2017, and the sample observation and identification were performed at the Faculty of Agriculture Laboratory at Banyuwangi PGRI University. The diversity indexes including Shannon, Brillouin, Simpson, and Evenness were calculated to determine the level of diversity, and Bray-Curtis similarity coefficient was used to compare the intertidal barnacle community. The result showed the intertidal barnacle diversity of Ketapang and Gilimanuk seaports were low, at the level of 0.89, 0.89, 0.41 and 0.27 at Ketapang Ferry Port and 0.81, 0.80, 0.43, and 0.28 at Gilimanuk Ferry Port based on Shannon, Brillouin, Simpson, and Evenness accordingly. The two ports were having a medium similarity of intertidal barnacle community indicated by the Bray-Curtis similarity coefficient analysis score of 0.58.

KEY WORDS: Balanidae, Chthamalidae, Tetraclitidae, Bali Strait, ITF

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INTRODUCTION

Intertidal barnacles are benthic organisms, commonly found attached to various hard substrates in the intertidal zone. Barnacles belong to subphylum Crustacea, infraclass Cirripedia, and superorder Thoracica (Martin & Davis, 2001). Barnacles are meroplankton, live planktonic life during larval stage and become benthic during the adult period (Chan & Williams, 2004). Throughout their larval stage, planktonic barnacles drift in ocean current expanding their geographic dispersal (Rennema, 2007). Indonesian Throughflow (ITF) is a primary ocean current contributing to the distribution of marine organism larvae in the Indonesian archipelago.

ITF is water movement from Pacific to the Indian Ocean through Indonesian seas, and the only connection between ocean basins in equatorial region (Tillinger & Gordon, 2009). ITF enters Indonesian waters through several pathways, i.e., Makassar Strait, Mollucas, Halmahera, and the South China Sea then exits through Timor passage, Savu Sea, and Lombok Strait (Gordon, 2005). According to Fieux *et al*. (1994) ITF also exits the Indian Ocean through several passages along the Sunda from northwest to southeast passing Malacca, Sunda, and Bali straits whose water depth is less than 70 meters. The range of surface currents of Bali Strait is measured 0.19–1.47 m/sec (Setiady *et al*., 2003), therefore besides its function as a dispersal means for the marine organisms, the current also serves as a barrier for aquatic organism distribution between Java and Bali Islands.

Ports of Ketapang in Banyuwangi and Gilimanuk in Bali are two ports separated by Bali Strait. Both ports are interconnected with the traffic of ferry crossings. Ballast water from those ferries may carry barnacle larvae from Ketapang to Gilimanuk port or vice versa, therefore affecting the composition of barnacle community in both ports. According to Gollasch (2002), apart from ballast water, other sources supplying barnacle larvae in ports are tank sediment and hull fouling. Among those three sources of barnacle larvae, the most significant contribution to invasive species introduction is fouling organisms that reach 59%, while tank sediment is about 25%, and ballast water of 16%. On previous observations, it is acknowledged that ferries crossing between Ketapang and Gilimanuk ports decrease or increase their ballast water accordingly to loading condition. Ballast water will be raised if the ship leans to one side and will be reduced if its volume is considered too excessive, and the adjustment of ballast water may be performed at any time necessary.

The comparison of intertidal barnacle communities in Ketapang and Gilimanuk port has not been reported previously. Thus, it will be very intriguing to observe them along with ITF as a barrier, and ferry traffic as a means for crossing the barrier. Study on intertidal barnacles in Indonesian ports is relatively limited, for example (Prabowo & Yamaguchi, 2005) who discover the new mangrove barnacle species near Pototano port of Sumbawa. Prabowo (2010) reports the introduction of invasive species native to Taiwan in Teluk Bayur port of

Padang. Wijayanti *et al.* (2010), Prabowo *et al.* (2011), and Mudzni *et al.* (2015) measure the intertidal barnacle diversity in various ports located in Sumatera Island.

Barnacle community can be assessed by measuring the values of diversity, evenness, and dominance of a particular species in a community. The communities can be compared with each other by measuring their similarity level (difference or distance) between their constituting components as a coefficient for either binary (presence-absence) or nominal data. Bray-Curtis is a coefficient value commonly used for measuring similarity level between communities based on either binary or nominal data of abundance (Magurran, 2004).

This study aimed to determine the diversity of intertidal barnacles in Ketapang and Gilimanuk Port, as well as to observe the level of dissimilarity between intertidal barnacle communities from those two ports which are separated by Bali Strait and ITF, yet interconnected by the shipping channel of ferry crossings.

METHODS

This research was carried out by survey method and simple random sampling technique. The sampling procedure was done by searching for a hard substrate such as seaport piers or barnacle-fouled rocks. A 25 x 25 cm^2 square plot was used for measuring its density (Chan & Williams, 2004; Chan *et al.*, 2007). Barnacles were collected from the substrate using a cutter or scrapper then kept on a jar containing 96% ethanol. Ethanol was renewed every 24 hours for three days to discharge water from the barnacle body tissue. The barnacle samples were gathered from Ketapang Port of Banyuwangi (S 08° 13.591’ E 1140 22.361’) and Gilimanuk Port of Bali (S 08° 09.708 E 1140 26.178’) in July–Agustus 2017 (Figure 1).

Species identification of barnacle is based on (Darwin, 1851; Darwin, 1854; Chan, 2006; Hagner & Vezo, 2006; Chan *et al.*, 2009; da Silva *et al.*, 2009; Wares *et al.*, 2009; Yamaguchi *et al.*, 2009; Shahdadi & Sari, 2010; Wijayanti *et al.*, 2010; Prabowo *et al.*, 2011; Reis *et al.*, 2011; Tsang *et al.*, 2012; Shahdadi *et al.*, 2014).

Biodiversity analysis was performed with Shannon's, (H’) and Brillouin's diversity indices, Simpson’s dominance index (D), and Pielou’s evenness index (E). Comparison between barnacle communities of Ketapang and Gilimanuk ports was measured with Bray-Curtis coefficient (B) and similarity index (1-B). The analysis was carried out using Past3 software (Hammer *et al.*, 2001). The formulas used for calculating the values of indices mentioned above and coefficient according to (Magurran, 2004) are as follows:

$$H' = \sum_{i=1}^{s} \left(\frac{ni}{N} \ln \frac{ni}{N}\right)$$

H’ = Shannon diversity index
S = Numbers of barnacle species
N = Total individuals of barnacles
ni = Total individuals of the i^{th} species

$$D = \sum_{i=1}^{s} \frac{(ni(ni-1)}{(N(N-1)}$$

$$Is = 1 - D$$

D = Simpson dominance index
ni = Total individuals of the i^{th} species
N = Total individuals
Is = Simpson evenness index

$$E = \frac{H'}{Hmax} = \frac{H'}{\ln S}$$

E = Pielou similarity index
H = Shannon diversity index
S = Total taxon (species) in a sample

$$B = \frac{\sum_{i=1}^{n} |Xij - Xik|}{\sum_{i=1}^{n} (Xij + Xik)}$$

Bray-Curtis Similarity Index = 1–B

B = Bray-Curtis coefficient

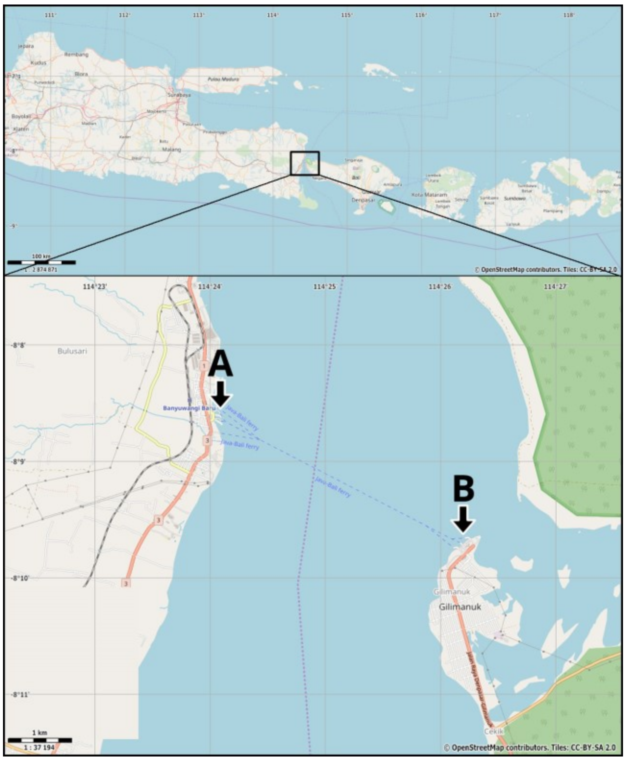


Figure 1. Sampling localities, Ketapang Ferry Port (A) and Gilimanuk Ferry Port (B)

RESULTS AND DISCUSSION

Bali Strait is shallow on the northern side’s region and steep on the southern side (Berlianty & Yanagi, 2011). It is located between Java and Bali and connected to the Java Sea through a narrow northern inlet of width about 2 km, then broadens southward about 5 km in a trumpet shape toward the outlet to the Indian Ocean. The northern part is characterized by a strong tidal current (Syamsudin *et al.*, 2017).

Ketapang Port is a dock complex surrounded by wave-breaker rocks with a sandy substrate. On its border, the depth of water during the lowest tide is approximately 2 meter. Therefore, the harbor pier stays submerged despite low water level. Ketapang Port consists of four docks, i.e., Marine Base (MB)1, MB2, MB3, and Dermaga Ponton. During research, barnacles were only observed in Dermaga Ponton.

Gilimanuk Port is a dock complex surrounded by a concrete structure with relatively a broad small steep sandy substrate. A relatively broad backshore is dry during high tide, therefore during low tide, the shore becomes broader. The condition of sampling sites in

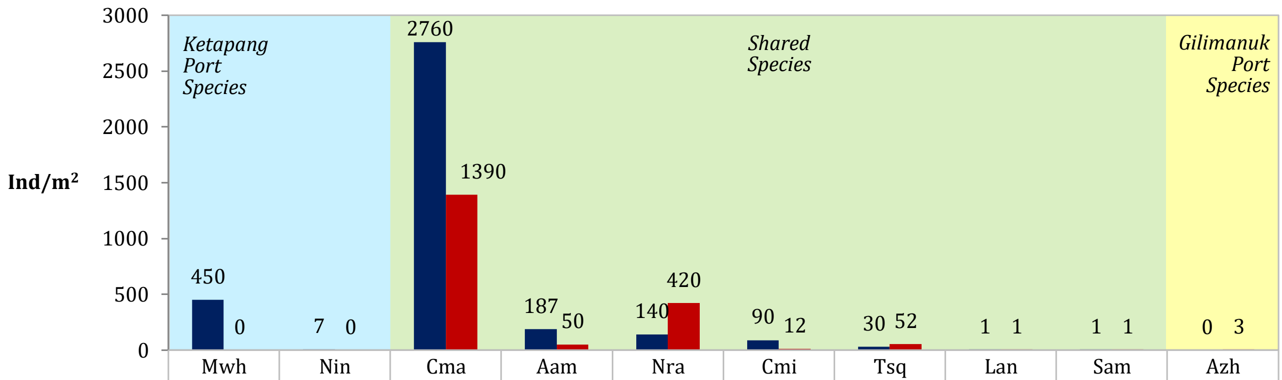
Ketapang dan Gilimanuk is illustrated in Figure 2.

The identification based on morphological characters showed that barnacle community in both ports consisted of 10 species in total (Figure 3 and 4). In Ketapang Port, they reached nine species whereas, in Gilimanuk Port, they were eight species. The seven same barnacle species were found in both ports. Two species were found only in Ketapang Port, i.e., *Microeuraphia withersii* and *Nesochthamalus intertextus*, while one species, *Amphibalanus zhujiangensis*, was found only in Gilimanuk Port. The presence of *Amphibalanus zhujiangensis* in the shoreline of Bali Strait was a new record.

The most abundant barnacle species was *Chthamalus malayensis* reaching 2,760 individuals/m^2 in Ketapang Port and 1,390 individuals/m^2 in Gilimanuk Port. Species with the lowest abundance was *Striatobalanus amaryllis* and *Lepas anatifera*, consisted only of one individual in each port (Figure 3). *Chthamalus malayensis* is an intertidal barnacle capable of living up to the supralittoral zone where such region is only submerged at the highest tide which occurs during full and new moon (Webber & Thurman, 1991; Prabowo, 2010). The species was rather common to find in Ketapang Port than in Gilimanuk Port. It may have been caused by the condition of Ketapang port which was dominated by a hard substrate such as rocks in the intertidal zone. In contrast, Gilimanuk Port that was dominated by an even and broad sandy substrate might have created a suspension of sand in seawater when waves crashed. This situation most likely prevented barnacle larvae from attaching to rocks. The comparison between *Chthamalus malayensis* population from both study sites is presented in Figure 5 and Figure 6.

The second most abundant species was *Microeuraphia withersii* which only lived in Ketapang Port. This species mostly inhabited the upper level of the intertidal zone, but only under the dock with no direct sunlight exposure (Figure 7). In contrast, *Chthamalus malayensis* occupied all highest tide levels including regions with direct sunlight exposure. These results were similar to the finding by Prabowo *et al*., (2011) who reported that *Microeuraphia withersii* found in Mentawai Port lived in shaded piers without direct sunlight exposure.

Figure 2. Sampling sites at Ketapang Ferry Port (left) and Gilimanuk Ferry Port (right)



	Mwh	Nin	Cma	Aam	Nra	Cmi	Tsq	Lan	Sam	Azh
■ Ketapang Port	450	7	2760	187	140	90	30	1	1	0
■ Gilimanuk Port	0	0	1390	50	420	12	52	1	1	3

Figure 3. The number of individuals of each intertidal barnacle species found at Ketapang Ferry Port and Gilimanuk Fery Port. (*Mwh: Microeuraphia withersii, Nin: Nesochthamalus intertextus, Cma: Chthamalus malayensis, Aam: Amphibalanus amphitrite, Nra: Newmanella radiata, Cmi: Capitulum mitella, Tsq: Tetraclita squamosa, Lan: Lepas anatifera, Sam: Striatobalanus amaryllis, Azh: Amphibalanus zhujiangensis.*)

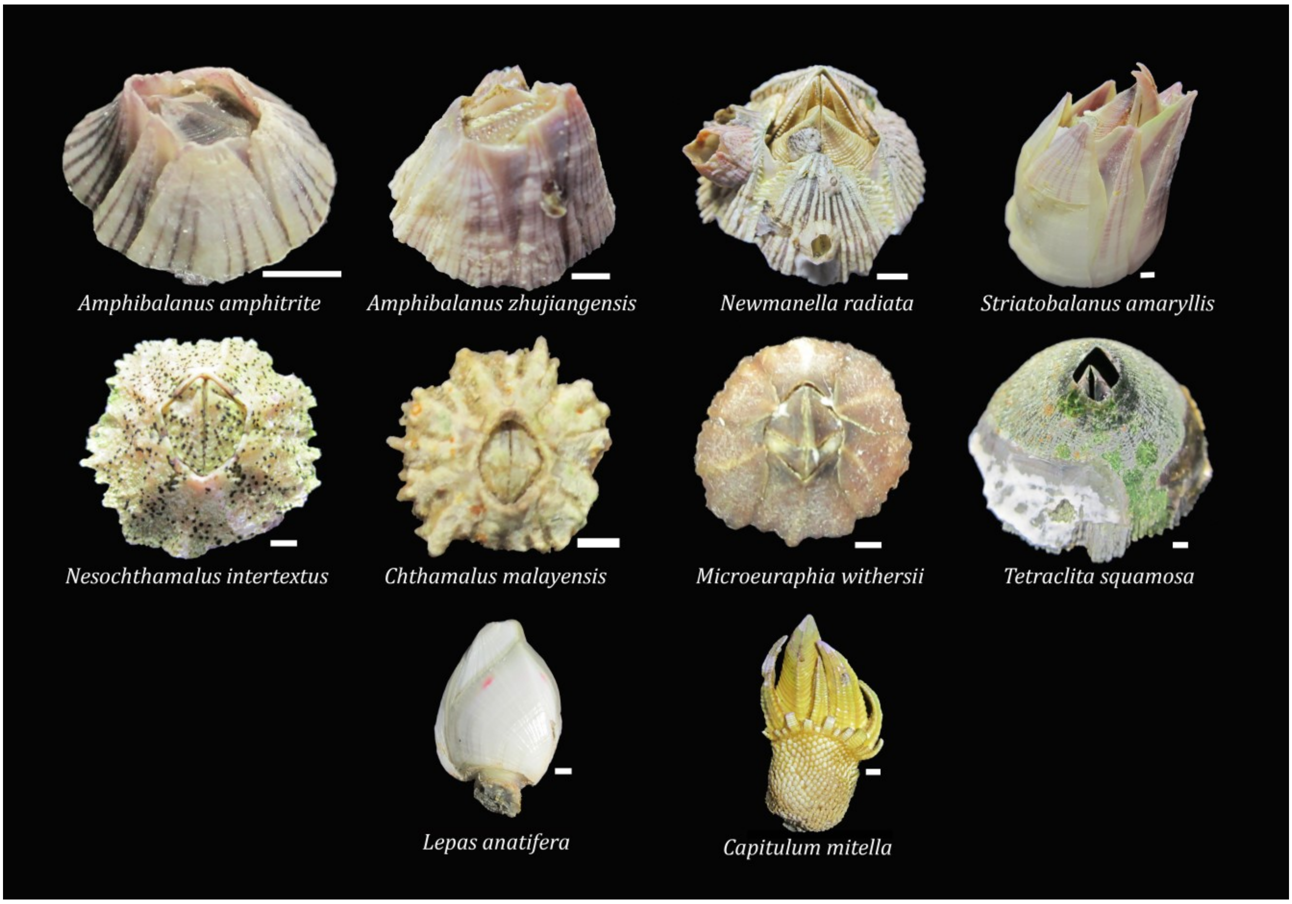


Figure 4. The species diversity of intertidal barnacles found at Ketapang Ferry Port and Gilimanuk Ferry Port. Scale bars 1mm

***Figure* 5.** *Chthamalus malayensis* at Ketapang Ferry Port

***Figure* 6.** *Chthamalus malayensis* at Gilimanuk Ferry Port

Figure 7. *Microeuraphia withersii* at Ketapang Ferry Port

The lowest abundance species were *Lepas anatifera* and *Striatobalanus amaryllis*, with only one individual in each port. It was possibly because both species commonly live outside the intertidal zone. *Lepas anatifera* is a pelagic barnacle that lives attaching to various floating objects in sea water. On this study, *Lepas anatifera* were mostly observed attaching to ferry hull on the ports of Ketapang–Gilimanuk ship channel. Meanwhile, *Striatobalanus amaryllis* is a barnacle commonly found living in the subtidal zone which is sometimes found beyond the upper level of the subtidal zone.

Intertidal barnacle communities in Ketapang and Gilimanuk ports were shown in Tabel 1. Based on Shannon dan Brillouin indices, the community of intertidal barnacles in Ketapang port had relatively low species diversity, i.e., 0.89 for both indices (9 species from 3.666 individuals), with Pielou's evenness index of 0.27. This evenness value indicated that the number of individuals of each barnacle species within a community of Ketapang Port was unequal. There were particular species dominated, i.e., *Chthamalus malayensis* and *Microeuraphia withersii* (Figure 3). This finding was supported by relatively high Simpson's dominance index (D) of 0.59.

Intertidal barnacle diversity in Gilimanuk Port was also considered low, with the values of Shannon's and Brillouin's indices 0.81 and 0.80, respectively, (8 species from 1.926 individuals). Similarly, Pielou's index of 0.28 showed the unevenness of individuals species constituting the barnacle community in Gilimanuk Port. This finding coincided with Simpson's dominance index of 0.57, indicating that one or more species in the community, *Chthamalus malayensis* and *Newmanella radiata*, had a total individual of much higher than other species (Figure 3).

The comparison between barnacle communities of Ketapang and Gilimanuk ports based on Bray-Curtis similarity index of 0.58 indicated that the species which made up the barnacle communities in both ports were relatively similar at a level of 58%, both in the number of species and the number of individuals of each species. Seven out of ten barnacle species found in both ports were *Chthamalus malayensis, Amphibalanus amphitrite, Newmanella radiata, Capitulum mitella, Tetraclita squamosa, Striatobalanus amaryllis,* and *Lepas anatifera* (Figure 3).

Despite no previous record on barnacle community in the study sites, the similarity level of barnacle community between both ports is likely caused by the traffic from ferry crossings which indirectly becomes a link of barnacle larval distribution through ballast water. When ballast water is filled on the origin port and is discarded on the destination port, it gives barnacle larvae a chance to live in the destination port. A similar scenario will happen when adult individuals adhering to the ship hull and sediment tank release the larvae (Gollasch, 2002). Ships play a role in barnacle translocation, for examples, there is broader dispersal area of invasive species *Austrominius modestus* in Europe, where regions of the highest abundance are located on artificial marine structures related to ships (Gallagher *et al*., 2015). The introduction of *Chthamalaus proteus* from Atlantic to Hawaiian coastline (Southward *et al*., 1998). Introduction of several alien species to Osaka Bay (Otani *et al*., 2007), and *Megabalanus coccopoma* to Japan (Yamaguchi *et al*., 2009). Presence of invasive species native to Taiwan, *Striatobalanus taiwanensis*, in Teluk Bayur Padang port (Prabowo, 2010), and the introduction of several barnacle species in Port of Recife Pernambuco (Farrapeira *et al*., 2007).

Table1. Diversity indices of intertidal barnacles observed at Ketapang and Gilimanuk Ferry Ports

	Ketapang Ferry Port	Lower Margin	Upper Margin	Gilimanuk Ferry Port	Lower Margin	Upper Margin
Number of species (S)	9			8		
Number of individuals	3,666			1,929		
Shannon (H)	0.89	0.86	0.93	0.81	0.77	0.85
Brillouin	0.89	0.85	0.92	0.80	0.76	0.84
Dominance (D) (0-1)	0.59	0.57	0.61	0.57	0.55	0.59
Simpson (1-D) (0-1)	0.41	0.39	0.43	0.43	0.41	0.45
Evenness (e^H/S) (0-1)	0.27	0.26	0.31	0.28	0.27	0.37

Table2. Bray-Curtis coefficient (B) of intertidal barnacles found at Ketapang and Gilimanuk Ferry Ports

No	Species	Number of individuals per m^2		Xij-Xik	Xij+Xik	B
		Ketapang Ferry Port	Gilimanuk Ferry Port			
1	*Chthamalus malayensis*	2,760	1,390	1,370	4,150	
2	*Microeuraphia withersii*	450	0	450	450	
3	*Amphibalanus amphitrite*	187	50	137	237	
4	*Newmanella radiata*	140	420	280	560	
5	*Capitulum mitella*	90	12	78	102	
6	*Tetraclita squamosa*	30	52	22	82	
7	*Nesochthamalus intertextus*	7	0	7	7	
8	*Lepas anatifera*	1	1	0	2	
9	*Striatobalanus amaryllis*	1	1	0	2	
10	*Amphibalanus zhujiangensis*	0	3	3	3	
	TOTAL	3,666	1,929	2,347	5,595	0.42

The similarity of barnacle communities indicates that ITF barrier in Bali Strait is crossable by means of attaching to the ferry that crosses between Ketapang and Gilimanuk ports. In addition, the water condition of Ketapang dan Gilimanuk ports was relatively similar. Water salinity reached 33 ppt, and the water temperature was 26°C in Ketapang port and 27°C in Gilimanuk port.

The oceanographic condition in Bali Strait is influenced by Western and Eastern Wind Seasons. During Western Wind Season, water masses from the Indian Ocean move eastward, and some enter Bali Strait indicated by an increase in salinity and temperature in Bali Strait. The water movement carries zooplankton from the southern side of Bali Strait to the northern side (Khasanah *et al*., 2013). In that condition, according to (Berlianty & Yanagi, 2011), currents move from north to south during the lowest tide. The temperature of Bali Strait waters on the second seasonal transition (November–January) is lower than that during Western Wind Season (February–April). A high abundance of phytoplankton follows this low temperature that may be caused by the second seasonal transition which occurs after Eastern Wind Season with similar water condition. Oxygen level on the water surface during the second seasonal transition is higher than that during Western Wind Season because, through photosynthesis, phytoplankton produces oxygen (Khasanah *et al*., 2013). The relatively similar environmental condition causes no limiting factor for barnacle larvae to survive if they happen to move between two ports through ballast water. Prabowo *et al*., (2011) state that the species composition of barnacle community between adjacent regions of several coasts in Sumatera Island tends to be similar due to their similar biodiversity history.

CONCLUSION

The Intertidal barnacle species richness was ten species, with similarity level of 0.58, based on Bray-Curtis similarity index. ITF in Bali Strait showed no limit to the barnacle larvae dispersal between the eastern end of Java and the western end of Bali Islands, which was strongly presumed due to the routine traffic of ferry crossings between Ketapang–Gilimanuk ports.

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