BIODIVERSITAS
Volume 25, Number 2, February 2024
Pages: 502-509

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d250208

Osmoregulation pattern, condition factor, and gonadal maturity level of sea urchins in the various ecosystems of Panjang Island, Jepara, Indonesia

SURYANTI SURYANTI♥, SUTRISNO ANGGORO, CHURUN A'IN, NINIEK WIDYORINI
Department of Aquatic Resources Management, Faculty of Fisheries and Marine Science, Universitas Diponegoro. Jl. Prof. Soedarto, SH., Tembalang, Semarang 50275, Central Java, Indonesia. Tel.: +62-24-7474698, ♥email: suryantidr@gmail.com

Manuscript received: 2 January 2024. Revision accepted: 9 February 2024.

Abstract. *Suryanti S, Anggoro S, A'in C, Widyorini N. 2024. Osmoregulation pattern, condition factor, and gonadal maturity level of sea urchins in the various ecosystems of Panjang Island, Jepara, Indonesia. Biodiversitas 25: 502-509.* Panjang Island has a diversity of ecosystems. It is also famous for its abundance of echinoids, especially sea urchins. Currently, research on sea urchins in Panjang Island is mostly limited to studies on the abundance and maturity of gonads. This study investigates the osmoregulation patterns, condition factors, and maturity indices of sea urchin gonads in different ecosystems that are sea urchin habitats on Panjang Island, Jepara, Indonesia. Sampling is done randomly, while the research method is a case study. The results showed that there are 2 species of sea urchins found on Panjang Island, namely *Diadema setosum* Leske, 1778 and *Echinothrix calamaris* Pallas, 1774. Analysis of osmoregulation patterns showed that sea urchins at station 1 were hyperconformers, while sea urchins at stations 2 and 3 were hypo-conformers. Sea urchins at 3 stations had a positive allometric growth pattern (b>3) and a high condition factor (K>1). The average Gonadosomatic Index (GI) calculation result was 8.72%, while the type of ecosystem of the research stations influenced the color and texture of different gonads. Sea urchins are in immature, mature, and spawning stages, so the sea urchins on Panjang Island were partially spawned.

Keywords: Coral reefs, coral rubble, Echinoidea, growth pattern, seagrass beds

INTRODUCTION

Panjang Island is a natural protection and breeding area for marine life with various ecosystem types, including coral reef and seagrass ecosystems. Several organisms are associated with coral reef and seagrass ecosystems, one of which is benthic. The condition of the coral reefs on Panjang Island is generally moderate, with the percentage of live coral cover ranging from 25-49% (Suryono et al. 2017). In contrast to the condition of coral reefs, the seagrass ecosystems on Panjang Island are in quite good condition, based on Pradhana et al. (2021). One of the benthic animals associated with coral reef and seagrass ecosystems is the sea urchin, which belongs to the phylum Echinodermata (Suryanti et al. 2017; Suryanti et al. 2018). In the ecosystem of coral reefs and seagrass beds on Panjang Island, there are many species of Echinodermata, especially sea urchins of the species *Diadema setosum* Leske, 1778 and *Echinothrix calamaris* Pallas, 1774 (Setyawan et al. 2014; Lutfiyani et al. 2021). Sea urchins receive special attention from the scientific world because of the ecological and nutritional functions of the various complex compounds they possess. The essential ecological function of sea urchins is as a major grazer in coastal areas. Although generally considered herbivorous, sea urchins can be classified as distinct omnivores that also prey on sessile invertebrates (Murie and Bourdeau 2021).

The level of exploitation of sea urchins is increasing, as evidenced by FAO 2019 global production statistics that the total production of sea urchins consumed worldwide in 2015 reached 71,229 tons (Karmilah et al. 2021). Due to sea urchins' limited annual reproductive cycle, sea urchin cultivation is increasingly being developed in various countries. The development of sea urchin cultivation has been characterized by an increase in population followed by research on the growth, nutrition, reproduction, and physiology of sea urchins. However, previous research on sea urchins on Panjang Island, Jepara is still limited and most only examine the abundance and maturity of sea urchin gonads. Research on the physiological response of sea urchins to the environment in Panjang Island has not been conducted. Therefore, this study will analyze the osmoregulation pattern, condition factors, and maturity level of sea urchin gonads on Panjang Island more deeply. The results of this research were conducted to complement previous research and to increase information and knowledge on the osmoregulation patterns, condition factors, and gonadal maturity levels of sea urchins in Panjang Island for academics, researchers, and the general public.

MATERIALS AND METHODS

Study area

Panjang is one of several islands in Ujungbatu Village, Jepara Sub-district, Jepara District, Central Java Province, Indonesia. Sampling was conducted in 3 different ecosystems on Panjang Island, Jepara. Station 1 (06°34'34.5"S 110°37'52.9" E) is a seagrass ecosystem, station 2 (06°34'41.1"S 110°37'53. 6"E) is a coral reef ecosystem, while station 3 (06°34'44.2"S 110°37'44.1"E) is a coral reef area dominated by rubble and sand substrates. The location of the sampling area is shown in Figure 1.

Procedures

Samples are taken randomly, while field samples include sea urchin samples and water media at each station. Sea urchin samples were collected at a depth of 1-2.5 m and a distance of 5-100 m from the coastal landmass. Sea urchin samples were collected using tools like claws and drag nets. The size of sea urchin samples collected varied from 41 to 379 g. The number of sea urchin samples varied depending on each station's species, density, and size composition. For example, 10 samples were collected at station 1, 17 samples were collected at station 2, and 14 samples were collected at station 3. According to the World Register of Marine Species (WoRMs) website, the collected sea urchins are then identified based on morphological characteristics. Water samples were collected at each station using a 100 ml sampling bottle. Water samples are used to measure water quality at research stations. Water quality can be used to measure factors limiting marine organisms' survival and growth.

Osmolarity measurements include milleu interieur and milleu exterieur osmolarity measurements. The osmolarity of the milleu interieur was obtained from the osmotic pressure value of the hemolymph, while the osmolarity of the milleu exterieur was obtained from the osmotic pressure measurements of seawater samples. Hemolymph of sea urchins was collected from the perivisceral coelom with a 23-gauge syringe containing 0.1 mL. Osmolarity was measured using a Roebling automatic micro-osmometer. The sample is then weighed and dissected; the results of the section in the form of gonads and stomach contents are each separated on a separate zipper. Next, the gonads, stomach contents, and water media are weighed, labeled according to the sample code, and then preserved with ice in the cooler to prevent damage. As supporting data, electrolyte media measurements of Na^+, Cl^-, Mg^{2+}, Ca^{2+}, and K^+ ions were also measured using an electrolyte counter osmometer. The environmental parameters calculated in this study were temperature, pH, and dissolved oxygen, measured with a Water Quality Checker, while salinity was calculated with a handheld refractometer.

Data analysis

The OWL analysis follows the formula of Anggoro et al. (2018):

OWL = [P Osm milleu interieur - P Osm milleu exterieur]

Where:

P Osm milleu interieur = osmotic pressure of the hemolymph

P Osm milleu exterieur = osmotic pressure of the external environment

Once the osmotic work of the sea urchin was known, the conversion was made to find the range of isoosmotic salinity based on the equation of Anggoro (1992):

$$Osm = -5.4081 + 29.3489\ S$$

Where:

Osm = the osmolarity of the interstitial fluid, and

S = the external salinity

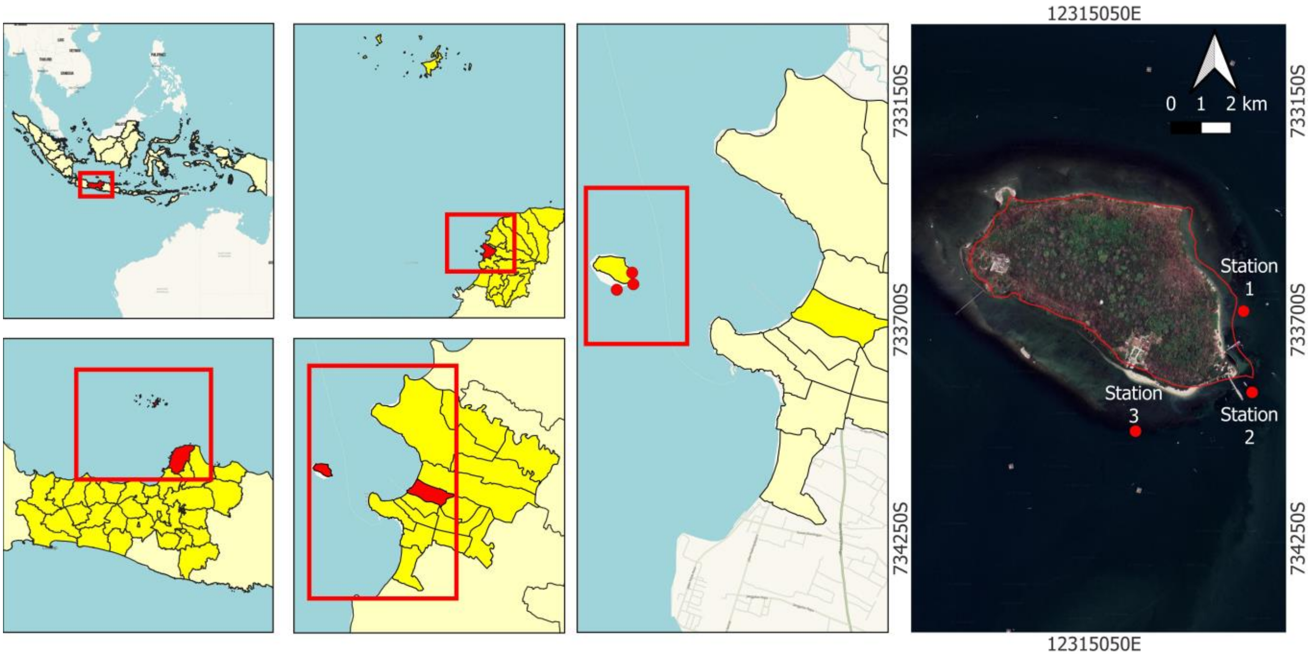

Figure 1. Map of study site in Panjang Island, Jepara District, Central Java, Indonesia

Analysis of the length-weight relationship follows the equation

$W = aL^b$

Where:
W : sea urchin weight (g)
L : diameter (cm),
a : coefficient related to body form (intercept)
b : an exponent indicating isometric growth (slope)

The b value of the length-weight relationship was tested by t-test at a 95% confidence level. The condition factor uses Fulton's equation (Suleiman et al. 2018), which is:

$K = W/L^3. 100$

Where:
K : condition factor
W : urchin weight (g)
L : diameter (mm)
3 : the length coefficient).

Meanwhile, the Gonadosomatic Index (GI) is derived from the ratio between the gonad weight and the total body weight of the sea urchin. The calculation and analysis of GI followed the GI evaluation GI = [gonad wet weight (g)/sea urchin wet weight (g)] × 100. SPSS 25.0 version software was used for statistical analysis.

RESULTS AND DISCUSSION

Identification of sea urchin samples

Two species of sea urchins are found along the coast of Panjang Island, *D. setosum* and *E. calamaris* (Figure 2). *D. setosum* was found in large numbers and varying sizes at 3 research sites. *D. setosum* inhabits the shallow sublittoral zone (Vafidis et al. 2021); this species is widely found in large populations at depths of about 4-6 m. Large *D. setosum* is found in coral reef areas, while smaller sizes are found in sandy areas or coral fragments (rubble). The average size of *D. setosum* at station 1 has a weight range of 47-253 g and a 5-8 cm diameter; at station 2 it ranges from 41-254 g with a diameter range of 5-9 cm, while at station 3, the weight ranges from 85-224 g, and the diameter range reaches 6-8 cm. A species of sea urchin also found on Panjang Island is *E. calamaris*, a pentagonal with white patterns on the interambulacral part (Suryanti et al. 2020); many are found in shallow waters, around rocks, and in seagrass beds. Only a few *E. calamaris* were found on Panjang Island, with 2, 1, and 5 individuals at stations 1, 2, and 3, respectively. Compared to 3 ecosystems, *E. calamaris* is most abundant in coral reef areas. The size of *E. calamaris* at station 1 is 379 and 423 gr and 11 cm in diameter. At station 2, only 1 individual weighs 280 gr with a diameter of 9.5 cm; at Station 3, there are 5 individuals with a weight range of 230-345 gr with a 9-11 cm diameter.

Osmoregulation patterns

Echinodermata, mainly sea urchins, can live optimally at 25-30°C, 30-34 ppt salinity, and pH of 6.5-8.5. From the results of measuring the water quality on Panjang Island, pH, salinity, temperature, and dissolved oxygen (Table 1), it can be concluded that these environmental conditions follow the criteria of echinoderm living habitat.

One of the environmental quality parameters that can be a limiting factor for the survival and growth of marine organisms is salinity (Honeycutt and Pomory 2019; Permata et al. 2021). Sea urchins are osmoconformers with a limited ability to overcome large salinity gradients in the external environment (Juinio-Meñez et al. 2008; Suckling and Richard 2020). As osmoconformers, the sea urchin extracellular fluid concentration follows changes in environmental salinity through water and transepithelial ions (Castellano 2017). The results of this study show that sea urchins are osmoconformers; the concentration of milleu interieur is slightly different from the concentration of external media, so sea urchins perform osmotic regulation with hyper-conformer and hypo-conformer patterns.

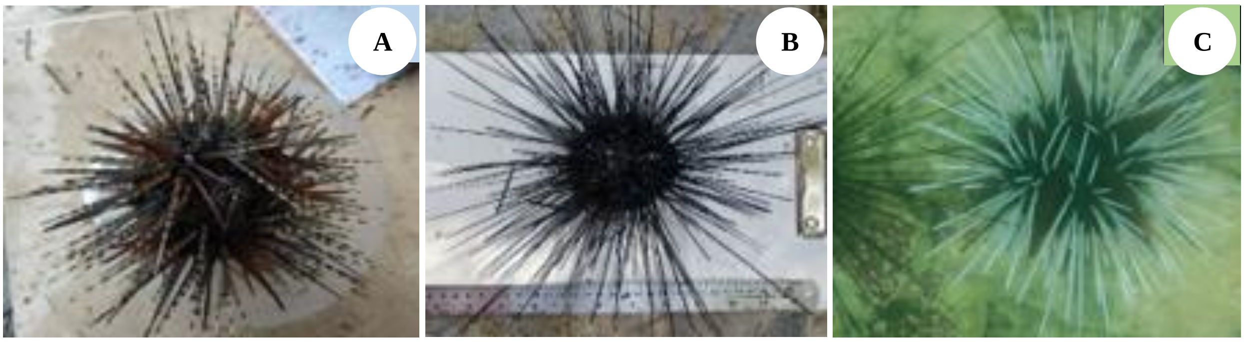

Figure 2. A. *Echinothrix calamaris*; and B. *Diadema setosum* on the; C. Coral reef ecosystem of Panjang Island, Jepara District, Central Java, Indonesia

Table 1. Results of water quality measurements at the research station in Panjang Island, Jepara District, Central Java, Indonesia

Station	Ecosystem	pH	Salinity (°/₀₀)	Temperature (°C)	DO (mg L^{-1})
1	Seagrass beds	6,85	30	27,4	6,56
2	Coral reefs	5,62	35	31,0	6,47
3	Sand and rubble	5,99	34	30,7	6,56

Based on the osmotic work level calculation, the sea urchins at station 1 are hyper-osmoconformers, and osmoregulatory patterns occur when the osmolarity of body fluids is slightly higher than the osmolarity of the external environment. Hyper-conformers differ from hyper-regulators in that they have the ability to persist over a wide range of external salinities (Šidagytė et al. 2017). As osmoconformers, sea urchins can only tolerate salinity up to a certain level, depending on habitat conditions. Therefore, to maintain the concentration of essential electrolytes under osmotic stress, the biota perform active transport by increasing the activity of the enzyme Na^+-K^+-ATPase to survive at low salinity (Saraswathy et al. 2021). Maintaining internal ion homeostasis in hypersaline conditions requires 20-50% of the body's metabolic energy (Jiang et al. 2000; Sabilu et al. 2021). The further the external salinity ranges from the isoosmotic salinity of the biota, the higher the energy expenditure. The comparison of media salinity and isoosmotic salinity of sea urchins on Panjang Jepara Island is visualized in Figure 3.

The results of the study at stations 2 and 3 are consistent with the results of the study at station 1, where the osmolarity of the sea urchin's milleu interieur is not always iso-osmotic with the osmolarity of the milleu exterieur. The results of the osmolarity pattern, osmotic work level (OWL), and osmoregulation pattern of sea urchins on Panjang Island Jepara can be seen in Table 2 as follows:

Table 2. Osmolarity, osmotic work level (OWL), and osmoregulation patterns of sea urchins in Panjang Island, Jepara District, Central Java, Indonesia

Station	Species	Sample code	Osmolarity milleu exterieur (mOsm L^{-1} H_2O)	Osmolarity milleu interieur (mOsm L^{-1} H_2O)	OWL	Osmoregulation patterns
1	*Diadema setosum*	D.1-1	880	941	61	Hyper-conformer
		D.1-2	879	939	60	
		D.1-3	879	940	61	
		D.1-4	880	939	59	
		D.1-5	879	939	60	
		D.1-6	879	940	61	
		D.1-7	879	941	62	
		D.1-8	879	941	62	
	Echinothrix calamaris	E.1-1	880	942	62	
		E.1-2	880	938	58	
2	*Diadema setosum*	D.2-1	1026	959	67	Hypo-conformer
		D.2-2	1026	960	66	
		D.2-3	1026	960	66	
		D.2-4	1025	959	66	
		D.2-5	1025	958	67	
		D.2-6	1026	960	66	
		D.2-7	1026	959	67	
		D.2-8	1025	959	66	
		D.2-9	1026	958	68	
		D.2-10	1026	958	68	
		D.2-11	1026	960	66	
		D.2-12	1026	959	67	
		D.2-13	1025	959	66	
		D.2-14	1026	958	68	
		D.2-15	1026	959	67	
		D.2-16	1026	959	67	
	Echinothrix calamaris	E.2-1	1026	961	65	
3	*Diadema setosum*	D.3-1	997	946	51	Hypo-conformer
		D.3-2	997	945	52	
		D.3-3	997	946	51	
		D.3-4	996	944	52	
		D.3-5	996	947	49	
		D.3-6	997	946	51	
		D.3-7	997	946	51	
		D.3-8	997	948	49	
		D.3-9	997	947	50	
	Echinothrix calamaris	E.3-1	996	948	48	
		E.3-2	996	948	48	
		E.3-3	996	947	49	
		E.3-4	997	948	49	
		E.3-5	997	948	49	

At stations 2 and 3, sea urchins perform hypoosmotic osmoregulation, so sea urchins must compensate for ion influx through hypoosmotic mechanisms (Chen et al. 2019). Several studies in aquatic invertebrates have shown that disturbances caused by hypersalinity indirectly affect tissue hypoxia or respiration rate changes (Freire et al. 2011; Rivera-Ingraham et al. 2016; Rivera-Ingraham et al. 2017). The osmotic working level (OWL) of the 3 stations ranges from 48-68 mOsm L^{-1} H_2O-1, which means that even as an osmoconformer, the internal osmolarity of the body is not the same as the osmolarity of its external medium. Research by Ventura et al. (2012) demonstrated that epithelial tissues in Echinodermata handle ions in different ways, so the internal body fluid in echinoderm osmoconformers is not very homogeneous in the osmo-ionic adjustment of the body (Ventura et al. 2012). Sea urchins can tolerate about a 30% decrease in salinity of the external medium for 5 days but are unable to maintain large ion gradients, especially Na^+ and Cl^- (Freire et al. 2011). The ion content of external media can influence sea urchins' high and low internal osmolarity. As supporting data, the results of electrolyte media calculations for Na^+, Cl^-, Mg^{2+}, Ca^{2+}, and K^+ are also presented, the results are presented in Table 3.

The higher the water-electrolyte content, the higher the salinity. This can be seen in the results of this study in Figure 3, where the internal osmolarity of sea urchins increases with increasing salinity. Based on the calculation results, sea urchins will perform iso-osmotic osmoregulation at salinities of 32‰ for sea urchins at stations 1 and 3 and 33‰ for sea urchins at station 2 (Figure 4).

Table 3. Electrolyte content in media water

Electrolyte	Station 1 (gL^{-1})	Station 2 (gL^{-1})	Station 3 (gL^{-1})
Na^+	9.12	10.64	10.33
Cl^-	16.59	19.37	18.82
Mg^{2+}	1.11	1.30	1.25
Ca^{2+}	0.35	0.41	0.38
K^+	0.32	0.38	0.37

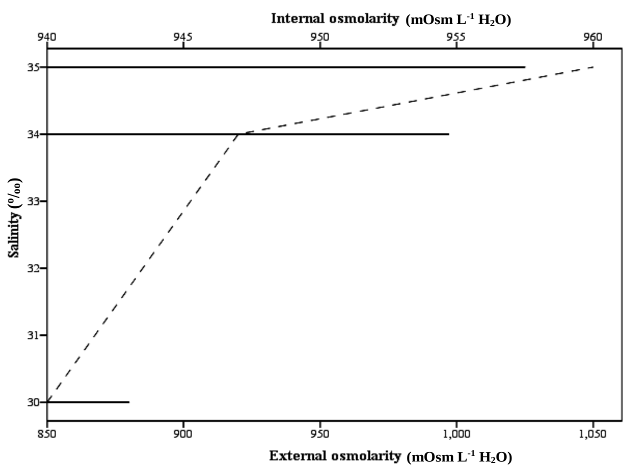

Figure 3. The relationship between salinity, external osmolarity, and internal osmolarity

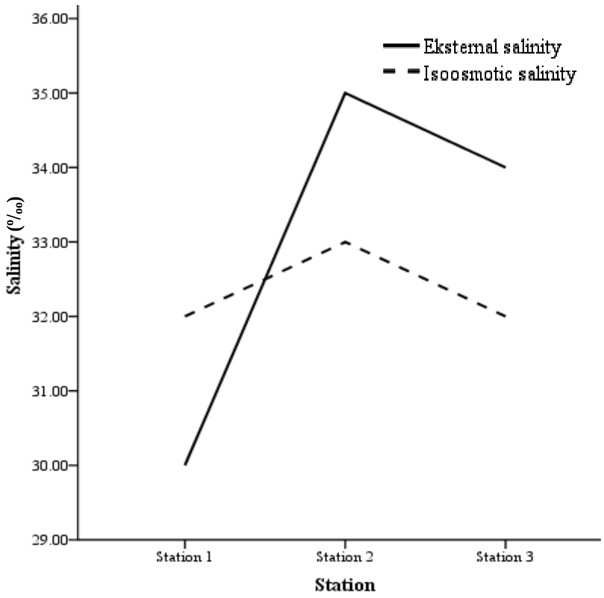

Figure 4. Comparison between internal salinity and isoosmotic salinity of each station in Panjang Island, Jepara District, Central Java, Indonesia

Growth patterns and condition factors

There are 3 types of growth patterns, and this pattern can be known based on the value of b (weight at unit length). The growth pattern is called negative allometric (b<3) when the growth in length occurs faster than the growth in weight. According to Patrick et al. (2021), when growth in length and weight occurs simultaneously, it is called isometric growth (b=3). Suppose a b value greater than 3 (b>3) indicates a positive allometric growth pattern, where weight growth occurs faster than length growth. The results of the analysis of the growth patterns of sea urchins on Panjang Island are shown in Figure 5.

The coefficient b's value at stations 1, 2, and 3 is 2.575, 2.202, and 2.4228, respectively. The growth pattern of sea urchins at 3 stations showed a negative allometric growth pattern (b<3), where the growth in length was faster than the growth in weight. This is following the research of Tupan and Silaban (2017) in Ambon waters, which showed that sea urchins have a negative allometric growth pattern (b<3). The regression analysis results showed that the relationship between the length and weight of sea urchins at stations 1, 2, and 3 has a strong relationship. This is evidenced by the high value of the coefficient of determination (R2), which is 0.9732, 0.9586, and 0.9436 for stations 1, 2, and 3, respectively. Moreover, several condition factors are morphometric indices used to assess the health status of fish in their environment based on their body plumpness (Olatunji 2021). Internal and external environmental conditions generally influence these condition factors, including age, sex, climate, and food availability (Das et al. 2021). Figure 6 shows the graph of the Fulton Condition Factor calculation of sea urchins at 3 stations (Figure 6) showing healthy conditions (K>1). The condition factor at station 1 ranged from 5.67 to 6.69, while at stations 2 and 3, the Fulton condition factor ranged from 5.90 to 7.40 and 5.25 to 6.68, respectively.

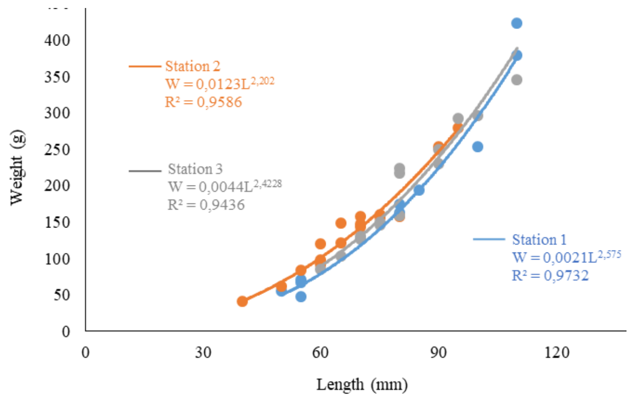

Figure 5. Analysis of sea urchin growth patterns on Panjang Island, Jepara District, Central Java, Indonesia

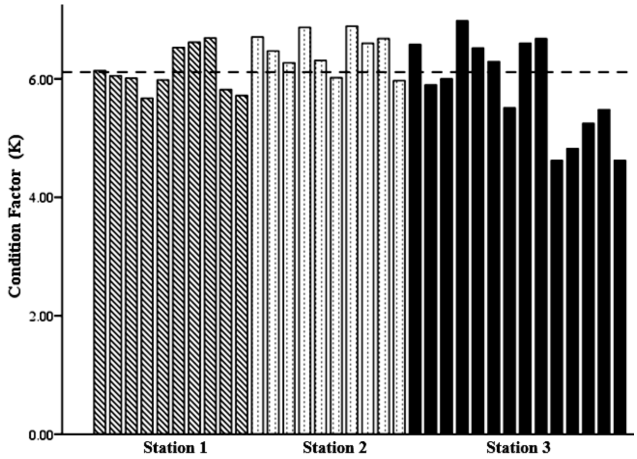

Figure 6. Sea urchin condition factors in Panjang Island, Jepara District, Central Java, Indonesia

The largest average factor of sea urchin condition is found in coral reef ecosystems (6.57), followed by seagrass beds (6.12) and rubble fields (5.85). As key grazer animals, sea urchins grow well and optimally when food requirements are met and habitat conditions are suitable. The research by Suryono et al. (2017) and Pradhana et al. (2021) shows that the status of coral reefs and seagrass beds in sea urchin habitat on Panjang Island is still in good condition. In coral reef ecosystems, sea urchins are an important species as microalgal population controllers (Suryono et al. 2017; Pérez-Portela et al. 2020; Pradhana et al. 2021). In seagrass ecosystems, sea urchins are mutually symbiotic with seagrass, where sea urchins acquire a place to forage, shelter, spawn, and protect from predatory threats (Jinks et al. 2019), while seagrass-associated biota obtains energy sources from the feeding process by sea urchins (Yorke et al. 2019). The water conditions of the sea urchin habitat (Table 1) also meet the optimal water quality, except for the pH, which is slightly lower than the optimal value. Therefore, the high value of the condition factor for sea urchins living on coral reefs and seagrass beds can be attributed to the abundant availability of food and fairly good environmental conditions.

The gonadal maturity level of sea urchins

Early gonadal maturation indicates fish's response to physiological reproductive conditions until they develop into eggs and hatch into larvae (Hutagalung 2023). The development of sea urchin gonads can be identified by an increase in the Gonadosomatic Index (GI) value (Lutfiyani 2021). The GI values range is used to reference the maturity of the sea urchin gonads. The maximum value of GI is reached by sea urchins when it is close to the spawning time and decreases from spawning until spawning is completed (Nasrullah 2018). When the population is depleted, the GI will increase again as long as the reproductive cells increase and reach a maximum at maturity. The results of GI calculations show differences between research stations (Table 4).

The highest average GI is found at station 2, which has rubble and sand areas, followed by coral reef ecosystems, and the lowest at station 1, which has seagrass ecosystems. The color, size, and texture of the gonads classify the maturity of sea urchin gonads. The gonads color of *D. setosum* and *E. calamaris* in Panjang Island, Jepara, varies from pale yellow to greenish-yellow. The size of the gonads is quite different according to the body size of the sea urchins, while the texture of the gonads can be distinguished according to their habitat. Sea urchins that live in rubble or sand areas have gonads that tend to be easily destroyed and pale in color; the size of the gonads tends to be small. Sea urchins living in seagrass and coral reef areas have large gonads, a denser and more compact texture, and color varied from yellow to greenish-yellow. Most sea urchin samples from Panjang Island showed gonads that had reached maximum volume and size had a yellow to orange color. The maturity of sea urchin gonads consists of six developmental stages, namely developing (0), recovering (I), growing (II), premature (III), mature (IV), and spawning (V) (Tupan and Silaban 2017). Some individuals have gonads in the stages of premature (III), mature (IV), and spawning (V), indicating that sea urchins on Panjang Island have partially spawned. This is consistent with a study conducted by Puspitaningtyas et al. (2018), which found that the gonadal maturity of sea urchin species *D. setosum* and *E. calamaris* on Panjang Island in May 2017 was in the spawning stage, characterized by a tendency for the gonadal color to pale and shrink. The gonadal maturity of sea urchins on Panjang Island is shown in Figure 7.

Table 4. Gonadosomatic Index (GI) calculation

Station	GI range (%)	GI average (%)
1	5.63-12.73	7.54
2	3.94-23.57	9.57
3	3.48-18.82	9.05
Total GI average		8.72

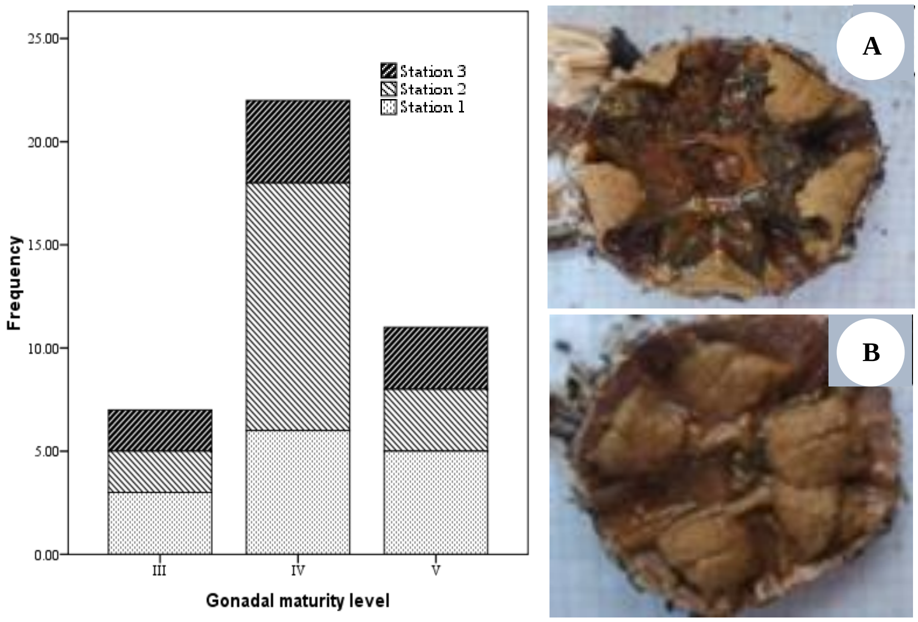

Figure 7. The level of maturity of sea urchin gonads in Panjang Island, Jepara; A. *E. calamaris* urchin gonads; and B. *D. setosum*

Analysis of osmoregulation patterns showed that urchins from station 1 were hyperconformers, while urchins from stations 2 and 3 were hypoconformers. Sea urchins from 3 stations had a positive allometric growth pattern (b>3). Analysis of condition factor of Echinoidea (sea feathers) on Panjang Island, Jepara, high condition factor (K>1). The average result of the gonadosomatic index (GI) calculation is 8.72%. The maturity of sea urchin gonads consists of six developmental stages, which indicate that sea urchins in Panjang Island Jepara have partially spawned. This is also consistent with the research conducted by Lutfiyani et al. (2021), which states that most sea urchins in the waters of Panjang Island Jepara are premature in December-January. Therefore, combined with these research results, it can be seen that the pattern of gonad maturity levels of sea urchins in Panjang Island enters the premature period in December and partially begins to spawn in May. In future research, it is hoped to obtain an overview of the gonadal maturity of other species of sea urchins on Panjang Island with more varied research times to complete the information about sea urchins on Panjang Island.

ACKNOWLEDGEMENTS

This research is supported by funding from funds other than the APBN of the Faculty of Fisheries and Marine Sciences, Universitas Diponegoro, in 2021 with number: 383-/UN7.5.10.2/HK/2021. Thanks are also given to Winda Mega Permata for her assistance during the research.

REFERENCES

Anggoro S, Suprapto D, Purwanti F. 2018. Osmoregulation pattern of fingerling vanname shrimp (*Litopenaeus vannamei*) rearing in three molt stage iso-osmotic media. Jurnal Ilmu Kelautan 23 (3): 119-122. DOI: 10.14710/ik.ijms. 23.3.119-122. [Indonesian]

Anggoro S. 1992. The Osmotic Effect of Various Levels of Media Salinity on Hatchability and Vitality of Tiger Prawn Larvae, *Penaeus monodon* Fabricius. [Dissertation]. Institut Pertanian Bogor, Bogor, Indonesia. [Indonesian]

Castellano GC, Lopes EM, Ventura CRR, Freire CA. 2017. Early time course of variation in coelomic fluid ionic concentrations in sea urchins abruptly exposed to hypo- and hyper-osmotic salinity challenges: Role of size and cross-section area of test holes. J Exp Zool Part A: Ecol Integr Physiol 327 (9): 542-550. DOI:10.1002/jez.2138.

Chen X, Chen J, Shen Y, Bi Y, Hou W, Pan G, Wu X. 2019. Transcriptional responses to low-salinity stress in the gills of adult female *Portunus trituberculatus*. Comp Biochem Physiol Part D Genomics Proteomics 29: 86-94. DOI: 10.1016/j.cbd.2018.11.001.

Das SK, Mersing M, Xiang T, Noor NM, De M, Samat A. 2021. Length-weight relationship, condition factor, and age estimation of commercially important trawl species from Mersing coastal waters, Johor, Malaysia. Sains Malays 50 (1): 1-7. DOI: 10.17576/jsm-2021-5001-01.

Freire CA, Santos IA, Vidolin D. 2011. Osmolality and ions of the perivisceral coelomic fluid of the intertidal sea urchin *Echinometra lucunter* (Echinodermata: Echinoidea) upon salinity and ionic challenges. Zoologia 28: 479-487. DOI: 10.1590/S198446702011000400009.

Honeycutt NR, Pomory CM. 2019. Effects of salinity and feeding on arm regeneration in the starfish *Luidia clathrata* (Say, 1825) (Echinodermata: Asteroidea). Mar Freshw Behav Physiol 52 (1): 37-51. DOI: 10.1080/10236244.2019.1629296.

Hutagalung RA, Anggoro S, Suryanti, Muskananfola MR. 2023. Vitellogenesis activity of *Channa marulioides*, Bleeker, 1851, impact of folicle stimulating hormone as reproductive domestication. Iraqi J Agric Sci 54 (2): 589 - 597. DOI: 10.36103/ijas.v54i2.1735.

Jiang DH, Lawrence AL, Neill WH, Gong H. 2000. Effects of temperature and salinity on nitrogeneous excretion by *Penaeus vannamei* juvenile. J Exp Mar Biol Ecol 253: 193-209. DOI: 10.1016/s0022-0981(00)00259-8.

Jinks KI, Brown CJ, Rasheed MA, Scott AL, Sheaves M, York PH, Connolly RM. 2019. Habitat complexity influences the structure of food webs in Great Barrier Reef seagrass meadows. Ecosphere 10 (11): 1-12. DOI: 10.1002/ecs2.2928.

Juinio-Meñez M, Bangi, HG, Malay MC. 2008. Effect of type of feed, stocking density and grow-out site on gonad index, growth and survivorship of cultured sea urchin (*Tripneustes gratilla*). Philipp Agric Sci 91: 439-449.

Karmilah, Musdalipah, Daud NS, Reymon, Fauziah Y. 2021. Identification of sea urchin gonads chemical compounds using thin-layer chromatography from Bokory Island, Southeast Sulawesi. J Phys: Conf Ser 1899: 012050. DOI: 10.1088/1742-6596/1899/1/012050.

Lutfiyani E, Pringgenies D, Endrawati H. 2021. Studi histologi tingkat kematangan gonad jantan and betina bulu babi *Diadema setosum* di Pulau Panjang Jepara. Majalah Ilmiah Biologi BIOSFERA: Sci J 38: 29-33. DOI: 10.20884/1.mib.2021.38.1.120. [Indonesian]

Murie KA, Bourdeau PE. 2021. Energetic context determines the effects of multiple upwelling-associated stressors on sea urchin performance. Sci Rep 11: 11313. DOI: 10.1038/s41598-021-90608-6.

Nasrullah R, Sari W, Mellisa S. 2018. Tingkat kematangan gonad bulu babi (*Tripneustes gratilla*) di Pantai Ahmad Rhangmayang Kecamatan Mesjid Raya Kabupaten Aceh Besar. Jurnal Ilmiah Mahasiswa Kelautan dan Perikanan Unsyiah 3 (1): 23-32. [Indonesian]

Olatunji AM. 2021. Length-weight relationship and condition factor of long neck croaker-*Pseudotolithus typus* (Bleeker, 1863) from Lagos Lagoon, Nigeria. Intl J Fish Aquat Stud 9 (2): 09-13. DOI: 10.22271/fish.2021.v9.i2a.2433.

Patrick AES, Kuganathan S, Edirisinghe U. 2021. Length-weight relationships and growth patterns of local fishes of the medium perennial Vavuniya Reservoir, Sri Lanka. Pak J Zool 2021: 1-9. DOI: 10.17582/journal.pjz/20181106161128.

Pérez-Portela R, Riesgo A, Wangensteen OS, Palacín C, Turon X. 2020. Enjoying the warming Mediterranean: Transcriptomic responses to temperature changes of a thermophilous keystone species in benthic communities. Mol Ecol 29: 3299-3315. DOI: 10.1111/mec.15564.

Permata WM, Anggoro S. and Suryanti S. 2021. Osmoregulation pattern and condition factor of Indian white shrimp (*Penaeus indicus*) in the mangrove eco-edutourism area of Tapak, Semarang. AACL Bioflux 14 (4): 2198-2210.

Pradhana HDW, Endrawati H, Susanto AB. 2021. Analysis of the suitability of seagrass ecosystems as a support for marine ecotourism in Panjang Island, Jepara Regency. J Mar Res 10: 213-22. DOI: 10.14710/jmr.v10i2.30118.

Puspitaningtyas IH, Rudiyanti S, Sulardiono B. 2018. Aspects reproduction of sea urchin in the Waters of Menjangan Kecil Island, Karimunjawa Islands, Jepara. Manag Aquat Res J 6 (4): 564-571. DOI: 10.14710/marj.v6i4.21349.

Rivera-Ingraham GA, Barri K, Boël M, Farcy E, Charles AL, Geny B, Lignot JH. 2016. Osmoregulation and salinity-induced oxidative stress: Is oxidative adaptation determined by gill function? J Exp Biol 219: 80-89. DOI: 10.1242/jeb.128595.

Rivera-Ingraham GA, Lignot JH. 2017. Osmoregulation, bioenergetics and oxidative stress in coastal marine invertebrates: Raising the questions for future research. J Exp Biol 220: 1749-1760. DOI: 10.1242/jeb.135624.

Sabilu K, Supriyono E, Nirmala K, Jusadi D, Widanarni W. 2021. Sedimentary waste nutrients, water quality and production profiles of intensive *Penaeus vannamei* culture reared in low salinities. Aquacult Aquarium Conserv Legis 14 (2): 683-694. DOI: 10.1088/1742-6596/1899/1/012050.

Saraswathy R, Muralidhar M, Balasubramanian CP, Rajesh, R, Sukumaran S, Kumararaja P, Vijayan KK. 2021. Osmo-ionic regulation in whiteleg shrimp, Penaeus vannamei, exposed to climate change-induced low salinities. Aquacult Res 52 (2): 771-782. DOI: 10.1111/are.14933.

Setyawan B, Sulardiono B, Purnomo PW. 2014. Abundance of sea urchins in coral reef and seagrass ecosystems on Panjang Island, Jepara. Manag Aquat Resour J 3 (2): 74-8. DOI: 10.14710/marj.v3i2.5005.

Šidagytė E, Solovjova S, Šniaukštaitė V, Šiaulys A, Olenin S, Arbačiauskas K. 2017. The killer shrimp *Dikerogammarus villosus* (Crustacea, Amphipoda) invades Lithuanian waters, South-Eastern Baltic Sea. Oceanologia 59 (1): 85-91. DOI: 10.1016/j.oceano.2016.08.004.

Suckling CC, Richard J. 2020. Short-term exposure to storm-like scenario microplastic and salinity conditions does not impact adult sea urchin (*Arbacia punctulata*) physiology. Arch Environ Contam Toxicol 78: 495-500. DOI: 10.1007/s00244-020-00706-1.

Suleiman N, Yola I, Ahmed I. 2018. Biodiversity and condition factor of fish species from Challawa Gorge Dam. Intl J Fish Aquat Stud 6 (3): 112-117.

Suryanti S, Ain C, Laifah N, Febrianto S. 2017. Mapping of sea urchin abundance as control of algae expansion for the balance of coral reef ecosystem in Karimunjawa Islands. J Appl Environ Biol Sci 7 (12): 120-127.

Suryanti S, Ain C, Latifah N. 2018. relationships between of sea urchins abundance, macroalgae and coral closure on the Cemara Kecil Island. IOP Conf Ser: J Phys 1025: 1-7. DOI: 10.1088/1742-6596/1025/1/012038.

Suryanti S, Fatimah PN, Rudiyanti S. 2020. Morphology, anatomy and ecological index of sea urchins at the Panjang Beach, Gunungkidul Regency, Yogyakarta. Marina. Oceanogr Bull 9: 93-103. DOI:10.14710/buloma.v9i2.31740.

Suryono S, Munasik M, Ario R, Handoyo G. 2017. Bio-ecological inventory of coral reefs in Panjang Island, Jepara Regency, Central Java. Trop Mar J 20: 60-64. DOI:10.14710/ik.ijms.26.2.125-134.

Tupan J, Silaban B, B. 2017. The physical-chemical characteristics of *Diadema setosum* from some waters at Ambon Island. Jurnal TRITON 13 (2): 71-78. [Indonesian]

Vafidis D, Antoniadou C, Voulgaris K, Varkoulis A, Apostologamvrou C. 2021. Abundance and population characteristics of the invasive sea urchin *Diadema setosum* (Leske, 1778) in the South Aegean Sea (Eastern Mediterranean). J Biol Res-Thessaloniki 28: 11. DOI: 10.1186/s40709-021-00142-9.

Ventura CRR, Borges M, Campos LS, Costa-Lotufo LV, Freire CA, Hadel VF, Tiago CG. 2012. Echinoderm from Brazil: Historical research and the current state of biodiversity knowledge. Echinoderm Res Divers Latin Am 301-344. DOI: 10.1007/978-3-642-20051-9_9.

Yorke CE, Page HM, Miller RJ. 2019. Sea urchins mediate the availability of kelp detritus to benthic consumers. Proc R Soc B 286 (1906): 1-7. DOI: 10.1098/rspb.2019.0846.