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Population dynamic of coconut crab (*Birgus latro*) in Sayafi Island, North Maluku of Indonesia

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Abstract

Katang kanari or coconut crab (*Birgus latro*) is economical fish resources in North Maluku, Indonesia. Problems arise when coconut crab was widely captured and caused population declining in number and size. However, information of coconut crab population in North Maluku, including Sayafi Island, has not been recorded properly. The study aims were analyzed and described population dynamics of coconut crab in Sayafi Island for better management. Data collection (total catch, thoracic length, body weight, sex and gonad maturity) was conducted in Sayafi Island from February to September 2013. Analysis of population dynamic of coconut crab included growth, recruitment and mortality parameters. Research result showed that estimation of population size was 43, 434 crabs; density was 26 crabs/ha; $W = 0.007\ ThL^{3.052}$; $ThL_t = 70\ (1 - e^{-0.09(t+0.048)})$, and dominated by young cohort. Value of $Z = 0.704$ year $^{-1}$, $M = 0.388$ year^{-1}, and $F = 0.320$ year $^{-1}$ indicated that crab mortality due to fishing pressure was higher. The highest number of female crab was non ovigerous female with one recruitment pattern during a year. Value of $E_{0.1} = 0.671$; $E_{0.5} = 0.339$; $E_{max} = 0.821$, and $E_{Sayafi} = 0.455$ indicated that exploitation rate of crab has not been optimal. However there was indication of coconut crab population declining in Sayafi Island.

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Introduction

Coconut crab (*Birgus latro* Linnaeus, 1767) which better known as *katang kanari* in North Maluku, is the most successful crustacean which adapted to terrestrial environments. Coconut crab according to Fishery Law No.31 in 2004 is classified in fish and including one of fish resources that has a high economic value. Coconut crab meat from Sayafi Island was not only for local consumption, but it also sold at high prices to restaurants in Ternate and Tidore cities, North Maluku, by simple marketing system. The selling price depends on coconut crab size.

Problems arise when coconut crab was widely hunted and captured, the coconut crab population declining in nature. Several previous studies in other areas have resulted in government policy and exploitation regulation of this resource, among others were in Vanuatu Islands (Fletcher *et al.*, 1991 and Lindner, 2004), national park in Christmas Island since 1978 (James, 2007), but *B. latro* exploitation at outside the national park was still permitted under the regulations from Environment Protection and Biodiversity Conservation Regulations (2000). Then crab trade for commercial purposes has been banned since 1992. Recently, publication of density studies on coconut crab after the ban did not exist (Drew *et al.*, 2010). Previous studies of coconut crab in Central Halmahera were capturing and marketing activities of coconut crabs in Yoi Island (Gebe Islands) by Sulistiono *et al.* (2009), habitat of coconut crab in Gemia coastal village by Murhum and Widiyanti (2009), and coconut crab habitat in Sayafi Island by Talib (2010). However, this indicated lack of coconut crab studies in North Maluku, including Sayafi Island.

The population size of coconut crab in North Maluku Province, including Sayafi Island, has not been recorded properly (unpublished) because this crab was not included in list of fisheries catch. However, according to Rustam and Badar as coconut crab collectors, coconut crab catch has declined both in number and size (personal communication, 2013). There were protection regulation of Indonesia Government for this crab since 1987 based on Decree of Forestry Minister No. 12/Kpts-II/1987 (Pratiwi, 1989) and Government Regulation No. 7 in 1999 which states that this species was one of 16 endangered and protected species. Furthermore, coconut crab in Decree of Forestry Minister No. P.57/Menhut-II/2008 was classified as high priority species for conservation on strategic direction of national species conservation 2008 - 2018. It was necessary for population dynamics study as well as the possibility of cultivation.

The aim of this study were analyzed and described population dynamics of coconut crab (*B. latro*) in Sayafi Island for sustainable and sustainably management of coconut crab resource.

Material and methods

Study Site

Sayafi Island (0°29'36" - 0°33'24" N, 128°48'20" - 128°51'43" E) is a part of Tepeleo Village in North Patani District of Central Halmahera Regency, North Maluku Province of Indonesia. Area of Sayafi Island is 1942.5 ha, 22.1 km for shoreline length and 1-2 m in high above sea level. Morphologically, this island has the character of rugged beaches and white sand, especially the area opposite the Halmahera Sea and the Pacific Ocean. The average of annual temperature ranged between 28-32°C, and 210 mm for average of annual rainfall. Data collection was conducted in Sayafi Island from February to September 2013.

Data Collection

Coconut crab catching was done once every month for eight months, precisely at night in dark moon using coconut meat as bait traps. In the afternoon, bait was placed near hiding place of crab along transects (10 × 100 m) which will be passed with 10 m of bait intervals. Crab catching in Sayafi Island was more difficult because pathway which through was porous rocks with sharp-pointed. Inspection and catching activities carried out three times (08:00 pm, 11:00 pm and 04:00 am) by two collectors with flashlight.

The data collection of coconut crab included total catch, thoracic length (ThL), body weight (W), sex and gonad maturity. Crabs were weighed using Centaurus analytical balance (accuracy 0.01g) and measured thoracic length (ThL) using Krisbow's digital vernier caliper (accuracy 0.01 mm). Female crabs can be distinguished from male by presence of pleopod and setae at left part of abdomen. Gonad maturity of female crab was known by morphological observation (reproduction condition and pleon expansion) based on Sato and Yoseda method (2009). Female crabs were categorized as non-ovigerous females (undeveloped female, developing female and non-ovigreous female) and ovigerous female (Sato and Yoseda, 2008; Sato *et al.*, 2008).

Data Analysis

Analysis of coconut crab (*B. latro*) population included frequency distribution of thoracic length (King, 1995; Sparee and Venema, 1998), length weight relationship (Effendi, 1979), sex ratio (Effendi, 1979), and development of reproduction organ (Sato and Yoseda, 2008; Sato *et al.*, 2008). Estimation of monthly *B. latro* recruitment patterns used statistical software FISAT II (menu recruitment pattern).

Thoracic length and weight relationship of coconut crab used formula $W = a\ ThL^b$ (King, 1995; Sparee and Venema, 1998), where W is the body weight of crab (g), ThL is the thoracic length of crab (mm), a is the condition factor (intercept) and b is the allometric constants (slope). Population density estimation of coconut crab used formula P = S (A/a) (Schiller, 1992), where P is the population density (crab/ha), S is the crab number (crab), A is the total research area (ha) and a is the sampling area (ha).

Growth parameters of coconut crab consisted of ThL_∞ (the asymptotic thoracic length of crab), K (the crab growth coefficient of thoracic length per year) and t_o (the hypothesized age in year when thoracic length of crab is zero) was estimated based on Von Bertalanffy Growth Formula or VBGF (Sparre and Venema, 1998; Sugilar *et al.*, 2012).

$$ThL_t = ThL_\infty (1 - \exp^{-K(t-to)})$$

Where, ThL_t is the thoracic length of crabs (mm) at age t (years), ThL_∞ is the asymptotic thoracic length of crabs (mm), K is the growth coefficient of thoracic length per year, t is the age of crabs (years) and t_o is the hypothesized age in year when thoracic length of crab is zero. T_o estimation used Pauly's empirical formula (Pauly and Binohlan, 2000).

$$\log_{10}(-t_o) = 0.3922 - 0.2752 \log_{10}(ThL_\infty) - 1.038 \log_{10}K$$

Total mortality estimation of coconut crab used Beverton and Holt formula (Sparre and Venema, 1998).

$$Z = \frac{K\ (ThL_\infty - \overline{ThL})}{\overline{ThL} - ThL_c}$$

Where, Z is the total mortality (per year), K is the growth coefficient of thoracic length per year, ThL_∞ is the asymptotic thoracic length of crabs (mm), $\overline{ThL}$ is the average of crab thoracic length (mm), ThL_c is the thoracic length of crab at first capture (mm). The natural mortality was calculated with Richer and Efanov's formula (Sparre and Venema (1998).

$$M = \frac{1.521}{T_m 50\%^{\ 0.720}} - 0.155\ per\ year$$

Where, M is the natural mortality (per year) and Tm 50% is the age when the biomass of cohort is maximal (the optimum age in year). Fishing mortality was calculated using F = Z – M formula, where F is the fishing mortality (per year), Z is the total mortality (per year) and M is the natural mortality (per year). FISAT II Software was used to estimate recruitment pattern, Y'/R and B'/R relative value (Gayanilo *et al.*, 2005).

$$Y'/R = EU^{M/K}[1 - \frac{3U}{(1+m)} + \frac{3U^2}{(1+2m)} + \frac{U^3}{(1+3m)}]$$

Where E is exploitation rate (F/Z), U is 1 –

(ThL_c/ThL_∞), m is (1-E)/(F/K), F is the fishing mortality (per year), Z is the total mortality (per year), ThL_c is the thoracic length of crab at first capture (mm), ThL_∞ is the asymptotic thoracic length of crabs (mm), M is the natural mortality (per year) and K is the growth coefficient of thoracic length per year (per year).

$$\bar{B}/R = (Y'/R)/F$$

Where, $\bar{B}$ is the biomass average for the year, R is the recruitment, Y' is the Yield and F is the fishing mortality (per year). The result analysis of Y'/R ($E_{0.1}$, $E_{0.5}$ and E_{max}), and $\bar{B}/R$ were compared to exploitation rate of *B. latro* in Sayafi Island (E_{Sayafi}).

Result and discussion

Cohort and Population Structure

Coconut crab capture in Sayafi Island showed that number of male crabs (326 crabs) more than female crabs (282 crabs) with sex ratio 1.07 : 0.93. Smaller number of female crabs could occur because female crab was easy caught, especially ovigerous females, while they drink and moisten their eggs with sea water on the beach. This was evidenced by two captured ovigerous female crabs near the shore at high tide during observation.

Population of Coconut crab in Sayafi Island has reduced. According to coconut crab catcher, Ridwan, Rustam and Jafar (personal communication, 2013), they were difficult to catch coconut crab by weight above 0.5 kg.

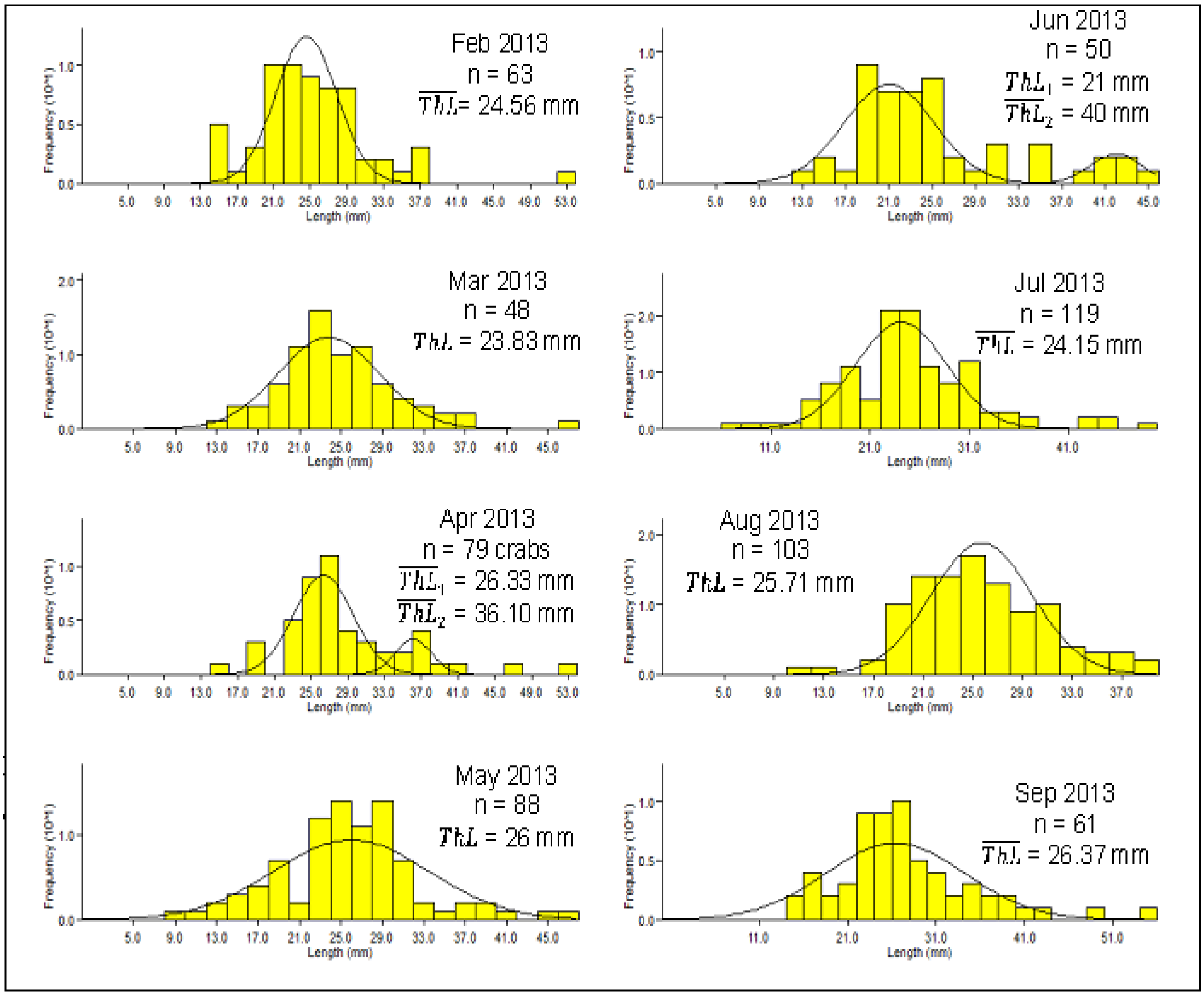

Fig. 1. *Birgus latro* cohorts in Sayafi Island (February – September 2013), n is crabs number, $\overline{ThL_j}$ is average of cohort thoracic length, j is cohort number.

The estimation of crab population size was 43, 434 crabs and crab density was 26 crabs/ha. The result of *B. latro* cohort analysis according to ThL frequency distribution data was presented in Figure 1. The monthly crab capture was small, ranging from 47 to 119 crabs. Because of that, result of cohort analysis was unable to produce a good pattern of normal distribution. However, based on *B. latro* ThL distribution every month, 1-2 cohorts were obtained from Sayafi Island's crab sample.

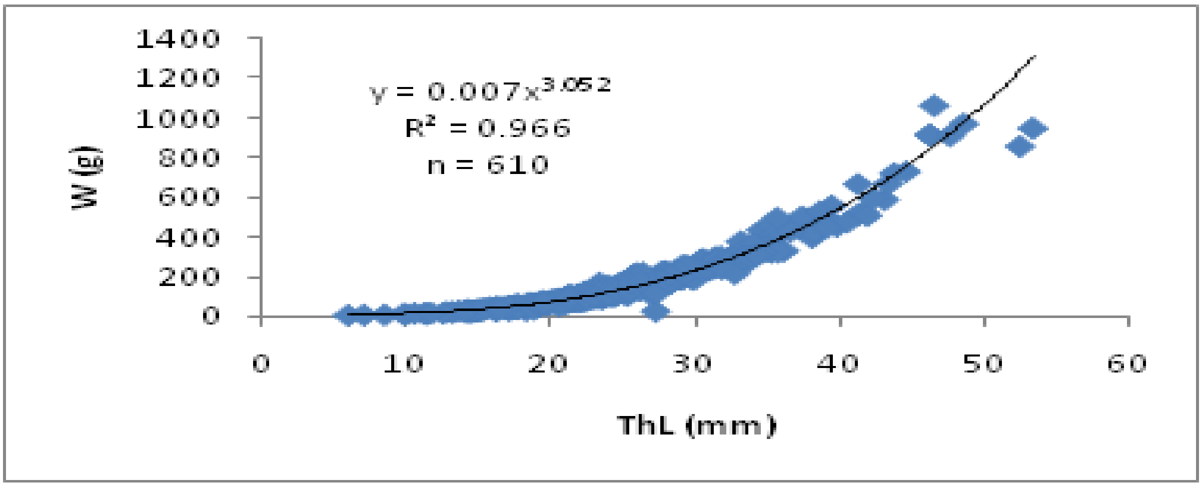

Fig. 2. Length (ThL, mm) and weight (W, g) relationship of *B. latro* in Sayafi Island.

Coconut crabs which found among Pandanus roots usually clustered with varying THL size (crab in small size). The small crabs have entered fishing ground although those crabs were under catch size (under consumption size). Unlike young or small crab, adult crab or big-sized crabs usually lived alone, hiding in fallen tree, hole of bottom trunk or digging the soil. The value range of $\overline{ThL}$ cohort was 21-40 mm and dominated by approximately 24-26 mm. The dominance of these cohort showed that coconut crab included in developing and adult stages (Sato and Yoseda, 2008; Sato *et al.*, 2008). In addition, ThL size <39.61 mm included in under catchable size or size of consumption (Widiyanti *et al.*, 2015). This dominance also was an indication of crab population decline due to fishing activities or natural mortality.

Growth Parameters

Relationship of ThL and weight formula for *B. latro* was $W = 0.007ThL^{3.052}$ (Figure 2). It showed that growth pattern of coconut crab was isometric (b =3.052). According to different sex, there were relationship of length and weight formula $W = 0.006\ ThL^{3.091}$ for male crab (Figure 3) and $W = 0.0010\ ThL^{2.957}$ for female crab (Figure 4). Weight gain for female crab was faster than male crab although their growth pattern were isometric (b>3).

Sayafi Island had swamp as source of fresh water. Sea water can reached into center of coconut crab habitat through rock crevices. Sea and fresh water availability in Sayafi Island were favorable for coconut crab because those can kept their body moisture. Food availability of coconut crab varied every month. Variation was depended on type and amount of food organism, including fruiting season. Growth pattern of coconut crab every month was also influenced by season. Coconut crab growth tended to isometric or positive allometric (February - May) in rainy season (February - June), but growth declined (negative allometric) in transition season (June). Coconut crab growth or weight in rainy season more increased than in dry season. Microhabitat condition of coconut crab in rainy season was more humid and cooler temperature, it can trigger growth hormone that increases crab appetite, thus increasing growth rate. This statement was supported by Hartnoll's statement (Hartnoll, 2001) that crustacean growth was also affected by growth hormone, age and external factors (temperature, food availability, and environment).

Estimation of *B. latro* growth parameters included the asymptotic thoracic length (ThL_∞), the growth coefficient of thoracic length per year (K) and the hypothesized age in year when thoracic length of crab is zero (t_0). Result analysis of *B. latro* growth parameters using ELEFAN I method (ThL_∞, K) in FISAT II software showed that ThL_∞= 70 mm and K = 0.09 year $^{-1}$. Based on Binohlan and Pauly criteria (2000) on growth parameters K, indicated that *B. latro* K value in Sayafi Island was low (0.05 to 0.15). Estimation value of *B. latro* t_0 using the empirical Pauly's Formula (Pauly and Binohlan, 2000) was -0.048 year. Thus, Von Bertalanffy Growth Formula for coconut crab in Sayafi Island was $ThL_t = 70 (1 - e^{-0.09 (t+0.048)})$. Figure 5 showed ELEFAN I graph of *B. latro* in Sayafi Island.

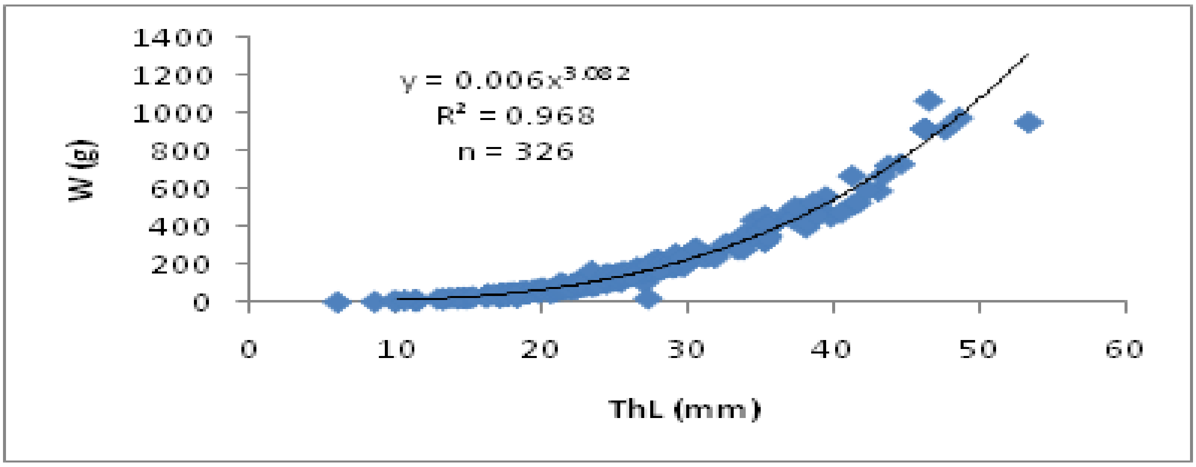

Fig. 3. Length (ThL, mm) and weight (W, g) relationship of male *B. latro* in Sayafi Island.

If these compared with Sato *et al.* result (2013) in Hatoma Island (Japan), ThL_∞ value (male 69.87 mm; female 42.79 mm) and K value (male 0.061 year $^{-1}$; female 0.091 year $^{-1}$), *B. latro* in Hatoma Island was more smaller than *B. latro* growth parameters value in Sayafi Island (ThL_∞ = 70 mm; K = 0.09 year $^{-1}$). ThL_∞ male crab in northern Vanuatu Islands was 80.00 mm (Fletcher *et al.*, 1991) and ThL_∞ female crab in Sato *et al.* study (2013) also ± 10 mm smaller than Fletcher result (Fletcher, 1993). However, when these compared with the parameter value in Vanuatu Islands, ThL_∞ parameter value of *B. latro* in Sayafi Island was lower.

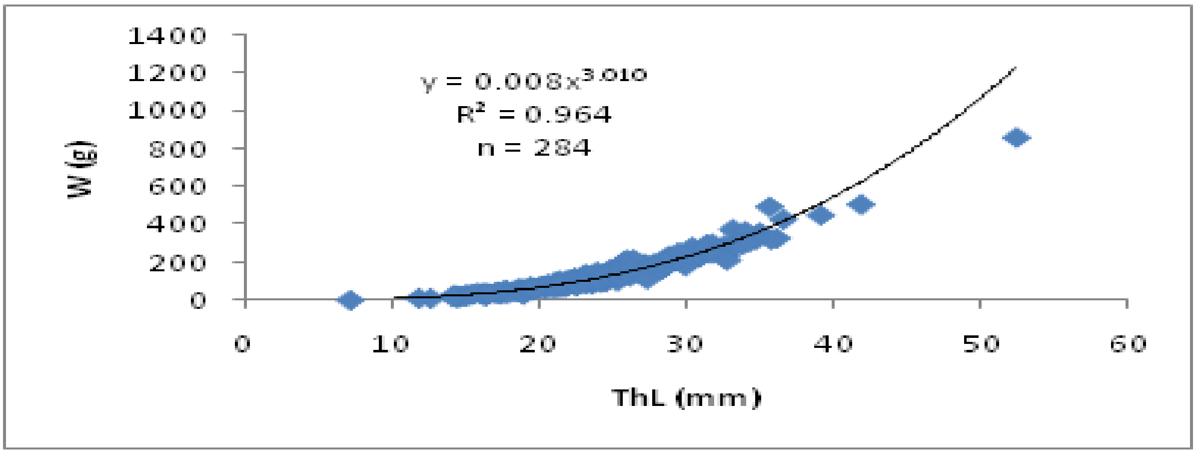

Fig. 4. Length (ThL, mm) and weight (W, g) relationship of female *B. latro* in Sayafi Island.

Decapoda growth was described in two components, there were frequency of molting (intermolt period) and size increase in each molting (molting increment) (Aiken, 1980). Temperature was main environmental factor that can influence crustacean growth (Hartnoll, 1982). The average annual temperature were 25 °C at Port Vila (Vanuatu) (Vanuatu Climate Center, www meteo.Gov.vu.) and 23.7 ± 3.7 °C at Hatoma Island (T. Sato unpublished data).

Those were still lower than average temperature during research in Sayafi Island (27.36 ⁰C). The different temperatures among regions can affected frequency of crab molting so that growth patterns differed.

Fig. 5. ELEFAN I analysis result for *B. latro* in Sayafi Island, ThL is Thoracic Length (mm) and t is age (year).

The differences of *B. latro* growth among regions were also affected by availability of food sources, both in number and type (Drew *et al.* 2010). Differences in abundance and diversity of food between Vanuatu Islands, Hatoma Island and Sayafi Island can leaded to different growth patterns. The population density can also affected growth rates through competition in getting food. In addition, population density can be affected by fishing pressure (Sato *et al.* 2013).

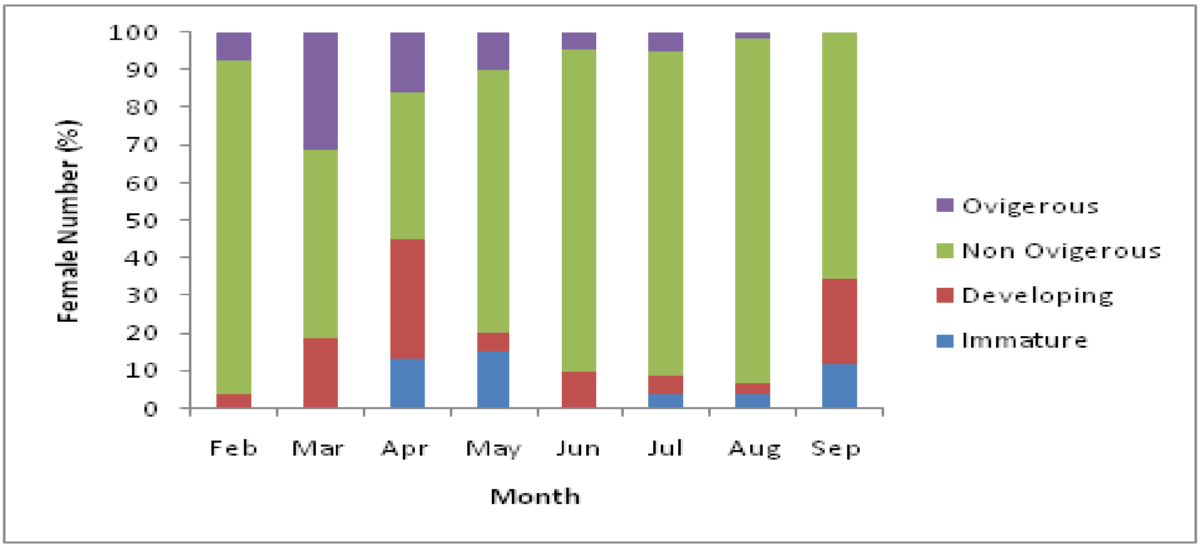

Fig. 6. *Birgus latro* female number (%) based on development of secondary reproductive organ in Sayafi Island.

Mortality

Natural mortality value of *B. latro* in Sayafi Island was 0.388 year $^{-1}$. Generally, coconut crabs broke coconut by dropping coconut from high place or tree. Most coconut crab chose trees to hide, by making a hole in the bottom of tree trunk (near roots) until certain height.

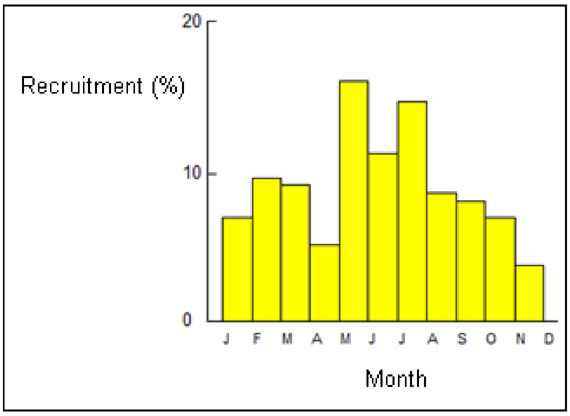

Fig. 7. Recruitment pattern of *B. latro* in Sayafi Island.

This crab behavior can caused tree fall down during windy rain. Littoral forest condition of Sayafi Island made crab easily to break coconut shell down from the top of tree. Coconut crabs hid in crevices of porous pointy rocks. Coconut crab predation in Sayafi Island was lower because crab was easier to save itself by hiding among the rocks. It made predators, such as wild boar, cuscus (*Phalanger* sp.), tree lizard (*Hydrasaurus* sp.) or coconut crab in larger size, difficult to reach crab hiding place. Higher value of natural mortality in Liwo Island possibly was caused by predator which easily catch coconut crab in its habitat (littoral forest on sand substrate) compared with littoral forest on rocky form which had many cracks in Sayafi Island. Small size of coconut crabs which usually hid in cracks of pandanus roots were more easily preyed by predators such as wild boar, cuscus (*Phalanger* sp.), tree lizard (*Hydrasaurus* sp.) or larger coconut crab (Widiyanti, 2015 unpublished data).

Result analysis of total mortality (Z) showed that total mortality (Z) value of *B. latro* in Sayafi Island was 0.704 year $^{-1}$. This value was influenced by natural mortality (M) and fishing mortality (F). Value fishing mortality (F) of *B. latro* in Sayafi Island was 0.320 year $^{-1}$. This indicated that coconut crab mortality due to fishing pressure in Sayafi Island was higher. Factually, conditions of littoral forest in Sayafi Island was not be barrier for coconut crab catcher. They used certain fishing techniques by inserting a stick into crack rocks which thought as crab hiding place. Coconut crabs usually will bit stick or foreign objects that enter their hiding place.

Coconut crab catching a cyclical pattern that is formed during the year in Vanuatu Islands shows the level of fishing activities by *B. latro* attendance throughout the year, not the effect of catching method used. *B. latro* number of catches in the dry season (June to August) little or nothing compared to the total catch in the wet season in relation to the availability of food. Areas that have a high arrest rate in the islands of Vanuatu is an area that has a large percentage of the presence of crabs larger in population (Fletcher *et al.*, 1991).

Recruitment

To maintain existence of coconut crab in this island, we determined crab gonad maturity according to observation of secondary reproductive organ. Development of *B. latro* secondary reproductive organ in Sayafi Island was presented in Figure 6.

The highest number of *B. latro* female during study was non ovigerous females (75.27%), followed by developing females (10.95%), ovigerous females (7.07%) and immature females at the last (6.71%). The ovigerous females in Sayafi Island was obtained every month, except in September, with the highest number (%) in March (31.21%) and April (15.79%).

Estimation of monthly *B. latro* recruitment patterns used statistical software FISAT II (menu recruitment pattern). *B. latro* recruitment patterns in Sayafi Island during the year showed 1 recruitment pattern (Figure 7), with the highest percentage of recruitment in May (16.10%) and July (14.56%).

Thoracic length at the first capture (ThL_c) of *B. latro* in Sayafi Island was 24.79 mm and estimated age of *B. latro* recruits at first capture was 4.9 years (Widiyanti, unpublished data, 2015). Therefore *B. latro* sample which caught during research believed from spawning in 4.7 - 4.9 years ago. This result closed to results of Fletcher research (1993) that glaucothoe and juvenile as recruits entered *B. latro* population in Vanuatu Islands in 5-10 years.

There was still lack of *B. latro* recruitment data, particularly recruitment estimates based on length frequency data. Glaucothoe collecting (juvenile in gastropod shell) has been carried out over two years by Fletcher *et al.* (1991) in littoral and supra littoral habitats of Vanuatu Islands, but those were not found. This problem also experienced by previous researchers, there was difficulty for finding small crabs (ThL <10 mm) and only slightly glaucothoe reported. Reese (1987) added that glaucothoe and juveniles were difficult to find because their hiding behavior, therefore it needed to use data of size frequency for estimating recruitment rate of crab populations. This information will be useful in effectively management of crab population when connected with their reproductive biology.

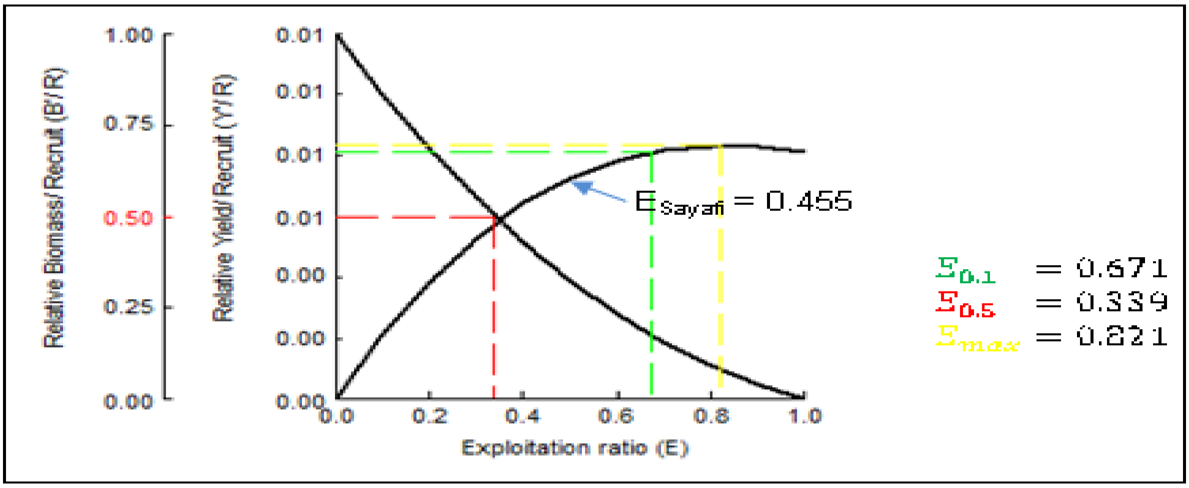

Fig. 8. Y'/R and B'/R graph of coconut crab in Sayafi Island.

The exploitation rate (E)

The exploitation rate (E) can be estimated from analysis of Yield per Recruit (Y'/R) and Biomass per Recruit (B'/R) of *B. latro*. Input data that required were ThL_c/ThL_∞ ratio and M/K ratio. The results were value of maximum exploitation rate (E_{max}), exploitation rate when stock has been reduced to 50% of biomass before exploitation ($E_{0.5}$) and exploitation rate at marginal rate or exploitation rate when increasing of Y'/R relative reached 10% of its value in when E = 0 ($E_{0.1}$). 2D display of Yield per Recruits (Y'/R) and Biomass per recruit (B'/R) analysis of *B. latro* was a graph of Y'/R and B'/R values with value of exploitation rate (E) was presented in Figure 8. The value of marginal exploitation rate ($E_{0.1}$) of *B. latro* in Sayafi Island was 0.671. $E_{0.5}$ and E_{max} values of *B. latro* in Sayafi Island were 0.339 and 0.821, respectively.

Calculation result of exploitation rate (E) using formula E = F/Z showed that exploitation rate of coconut crab recently was 0.455 in Sayafi Island. This value (E_{Sayafi} = 0.455) indicated that coconut crab has exploited in Sayafi Island (E_{Sayafi} value greater than $E_{0.5}$ = 0.339), but exploitation level of coconut crab has not been optimal (E_{Sayafi} value less than $E_{0.1}$ = 0.671).

Birgus latro population in Sayafi Island was dominated by young cohort and non ovigerous female crabs. It indicated that population size of *B. latro* in Sayafi Island has been declining although exploitation rate of crab has not been optimal. Based on research result, resource management that may be applied at this time was a ban on catching crabs for several years to allow young cohorts grew and non ovigerous females developed into adults so that stock of crabs in nature increase. During the no-take season, should be devised rules on catch quota, catchable size and banned fishing season in the spawning season, thereby exploitation resource of *B. latro* can be sustainable.

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