LIFE HISTORY AND STOCK STATUS OF SCALLOPED SPINY LOBSTER (*Panulirus homarus)* IN PRIGI BAY, EAST JAVA PROVINCE, INDONESIA: ANALYZING THE POTENTIAL FOR STOCK ENHANCEMENT

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ABSTRACT

Scalloped spiny lobster (*Panulirus homarus*) is one of the dominant lobster species that are captured and traded in Indonesia. Lobster catch in certain fishery areas such as in Southern Java are declining. This can be caused by many factors such as high intensity of fishing or loss of habitat which could limit recruitment. Stock enhancement could be an option to overcome recruitment limitation. Designing effective stock enhancement programmes requires preliminary research into ecological conditions, life history of the species used, status of the wild stock, and the nature and intensity of the fishery. This study attempts to analyse data from a tag-recapture experiment intended to evaluate the potential for lobster stock enhancement in Prigi Bay in southern Java. The objectives of this study were to (1) obtain information about life history and population dynamics of scalloped spiny lobster in Prigi Bay as basic information for potential stock enhancement in the future, (2) gather information about exploitation of the stock and fishing activity and how it may influence a stock enhancement program, and (3) determine how future data collection should be carried out to increase the accuracy of evaluating the potential for lobster stock enhancement. The best-fit Von Bertalanffy growth model of scalloped spiny lobster in Prigi was $Lt = 106[1\text{-}e^{0.3(t+0.392)}]$. The lobster has a long-life span and slow growth. Estimates based on growth parameters (L_∞ and k) for lobsters from catch (untagged) was L_∞= 106 mm CL and k= 0.3 year^{-1} while for tagged lobster was L_∞= 77 mm CL and k=0.98 year^{-1}. Estimated total mortality (Z) of untagged lobster was 1.74 year^{-1}, natural mortality (M) 0.58 year^{-1}, fishing mortality (F) 1.16 year^{-1} and exploitation rate (E) 0.67 year^{-1}. Estimated natural mortality of tagged lobsters was 1.4 year^{-1}, which was higher than untagged lobster. Assessment of stock status was based on the spawning potential ratio (SPR). Different scenarios of growth parameters yielded SPR values of 0.04 (4%), 0.2 (20%) and 0.29 (29%), indicating a risk status as heavily exploited. This study provided initial information for potential stock enhancement; however, further study with complete and comprehensive data is urgently needed since there were some weaknesses in this study, such as incomplete time series of catch data, little detailed length at maturity data, and a short monitoring period of released lobster. In the future, it will be essential to record catch data before stock enhancement is conducted, as well as design a comprehensive experimental stock enhancement programme that includes continued monitoring.

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1 INTRODUCTION

1.1 Background

Lobster is a highly valuable fisheries commodity in Indonesia for both domestic consumption and export markets. There are six tropical spiny lobster species in Indonesia, scalloped spiny lobster (*Panulirus homarus),* ornate spiny lobster (*P. ornatus),* long-legged spiny lobster *(P. longipes),* painted spiny lobster *(P. versicolor),* mud spiny lobster (*P. polyphagus)* and pronghorn spiny lobster (*P. penicillatus)* (Tewfik *et al*., 2009). Scalloped spiny lobster is one of the dominant species that are captured and traded in Indonesia. It has a wide distribution throughout Indonesia, from west coast of Sumatera, south coast of Java, West Nusa Tenggara, South and North Sulawesi, Maluku and Papua (Figure 1) (Sealifebase, 2017).

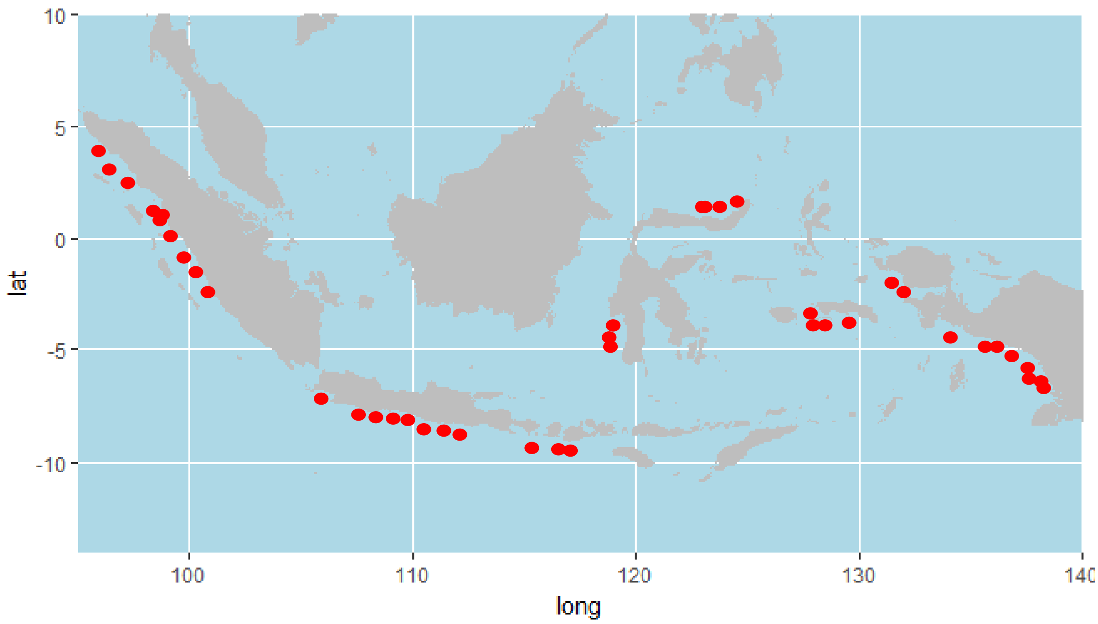

Figure 1. Distribution of scalloped spiny lobster in Indonesia

In some areas, lobster catches have started to decline, as in southern Java; Gunung Kidul, Pacitan, Pangandaran (P4KSI-ACIAR, 2012) and Wonogiri (Sobari *et al*., 2008). Catch decline can be caused by overfishing, habitat destruction and recruitment limitations due to climate change. For example, prior to Regulation of the Minister of Marine Affairs and Fisheries No. 1/ PerMen-KP/ 2016 that set a minimum landing size on lobster, exploitation of lobster seeds (*puerulus*) occurred in West Nusa Tenggara. The seeds were mainly exported to Vietnam and China for aquaculture production. Exploitation of lobster seeds can disrupt the recruitment process and may threaten stock sustainability.

One possible management option to maintain sustainability of lobster fisheries is stock enhancement. Stock enhancement is defined as the release of cultured juveniles into a wild population to augment the natural supply of juveniles and optimize harvest by overcoming recruitment limitations (Bell *et al.*, 2008). Stock enhancement has been viewed as a positive fisheries management tool for over 100 years (Molony *et al.*, 2003) both in freshwater (De Silva & Funge-Smith, 2005) and coastal ecosystems (Leber & Arce, 1996; Bell *et al.*,2008)

Stock enhancement practices have been implemented in some lakes in Indonesia by stocking indigenous species and introducing exotic species such as tilapia (*Oreochromis* spp.) since

1940 (De Silva & Funge-Smith, 2005). There are success stories about fish stock enhancement in lakes and reservoirs in Indonesia, such as stock enhancement of Siammes cat fish (*Pangasiodon hypopthalmus)* in Wonogiri reservoir, freshwater giant prawn (*Macrobrachium rosenbergii)* and bilih fish (*Mystacoleucus padangensis)* into Lake Toba, North Sumatra. According to Kartamihardja (2012), the success of fish stock enhancement programs in some lakes and reservoirs of Indonesia has been supported by certain factors. These factors included that the stocking program was done regularly, or the stocked fish can spawn naturally, the seed was stocked at an optimum level, fishing levels were regulated, a market system was developed, and the management institution was strengthened with the implementation of fisheries co-management.

In Indonesia, lobster stock enhancement has been developed recently as an action to recover lobster resources. The Indonesian Ministry of Marine Affairs and Fisheries through the Agency for Marine Affairs and Fisheries Research and Development recommended stock enhancement or restocking to recovery lobster resources in some areas of Indonesia (Poernomo, 2015). To meet this goal, studies to determine effective patterns of stock enhancement to improve lobster resources in locations such as southern Java are needed.

1.2 Lobster Fishery in Indonesia

The tropical lobster fishery throughout Indonesia is a high-value export-oriented open-access artisanal fishery that occurs throughout the country. Gears used to catch lobster are gill net, *krendet* (a tangle trap), trap and handpicking while the fishermen are diving into the water using compressors as breathing apparatus. The fishery in southern Java has two sectors: one is a tangle trap sector undertaken by part-time artisanal fishers from coastal cliffs, whereas the other is an inshore bottom gillnet sector that operates from small (<10 m) vessels (Milton *et al.*, 2014). Some of lobster fishery areas in Indonesia are southern Java, western coast of Sumatra, Lombok (West Nusa Tenggara), South Sulawesi, North and Central Sulawesi, Maluku, West Papua and the Arafura Sea (Suman *et al.*, 2014). Southern Java is one of the more productive regions, contributing up to 10% of the national catch (Anonymous, 2007).

Lobsters provide a valuable income for fishermen in some regions, however, it is not the main livelihood for fishermen due to the seasonal nature of the fishery. Lobster catch is strongly seasonal with a peak in October-December in the south coast of Java (Milton *et al.*, 2012), November-March in Aceh (Wahju *et al.*, 2017), and June-December in West Papua (Sururi *et al.*, 2016). Milton *et al.*, (2012) showed that more than 50% of catch in South Java are *Panulirus homarus* and *P. penicillatus*.

The main path of distribution and marketing of lobsters varies in each region. In the south coast of Java, there are two types. The first type is a route from fishers to an auction market and the second type occurs when fishers sell directly to a supplier, then supplier to exporter (Milton *et al.*, 2012). One of the weaknesses in the lobster fishery management is unrecorded catch. Lobsters that pass through to the auction market will be recorded but lobster catches that go directly to the supplier are unrecorded. Therefore, the catch records shown in Figure 2 are a minimum estimate. In general, catches of lobsters have fluctuated over the years. In 2009-2013, they increased significantly, but in 2014 the catches were decreased. In 2009 catch reached 5,892 tons and in 2013 it reached 16,482 tons, but in 2014 it was 10,062 tons (FAO, 2017) (Figure 2). Even though data showed that lobster catch increased, there has been a declining trend of lobster in certain areas such as in southern Java (Milton *et al.*, 2012). In order to overcome declining lobster stocks in some areas, management is needed. One fisheries management option that could be applied to recover stocks is stock enhancement (Molony *et al.*,2003). Therefore, this study addresses the need to evaluate life history and lobster fishing activities to inform whether stock enhancement could be used as a management tool to overcome the problem of declining catch in local Indonesian lobster fisheries.

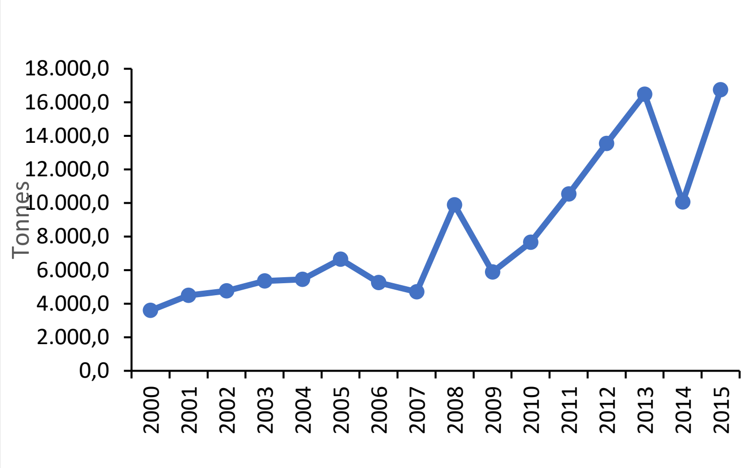

Figure 2. Indonesian lobster production (FAO, 2017)

1.3 Biology and Life History of Spiny Lobster (*Panulirus* spp.)

Panulirus lobster has worldwide distribution, found in the tropical and subtropical regions of the world's oceans. *Panulirus* is variously known as 'rock' or 'spiny' lobster and they provide a valuable source of seafood and exports for a large number of countries. Like other species of lobsters, the spiny lobster has a complex life cycle that consists of several phases in different types of habitat as it grows (Figure 3). The life cycle of the lobster consists of four phases: adults that produce sperm or eggs, phyllosoma (larvae), puerulus (post larvae), juvenile that grow into adult. Spiny lobster eggs hatch as planktonic phyllosoma larvae (about 1–2 mm long) and develop through a series of moults, increasing in size. The phyllosoma phase is planktonic, highly dependent on the current and lasts for 3 - 7 months. Phyllsoma develop in offshore waters and return towards the continental shelf where the final stage larvae metamorphose into the puerulus, a non-feeding stage (about 30 mm in total), which then swims towards the coast. The puerulus phase lasts for 10-14 days. When the puerulus settles, it moults after a few days to weeks into a benthic juvenile stage. Juveniles are usually found in shallow coastal reefs and adults in deeper water offshore. It is in these depths that they reach maturity, that mating takes place, and that the life cycle is completed (Phillip & Smith, 2006).

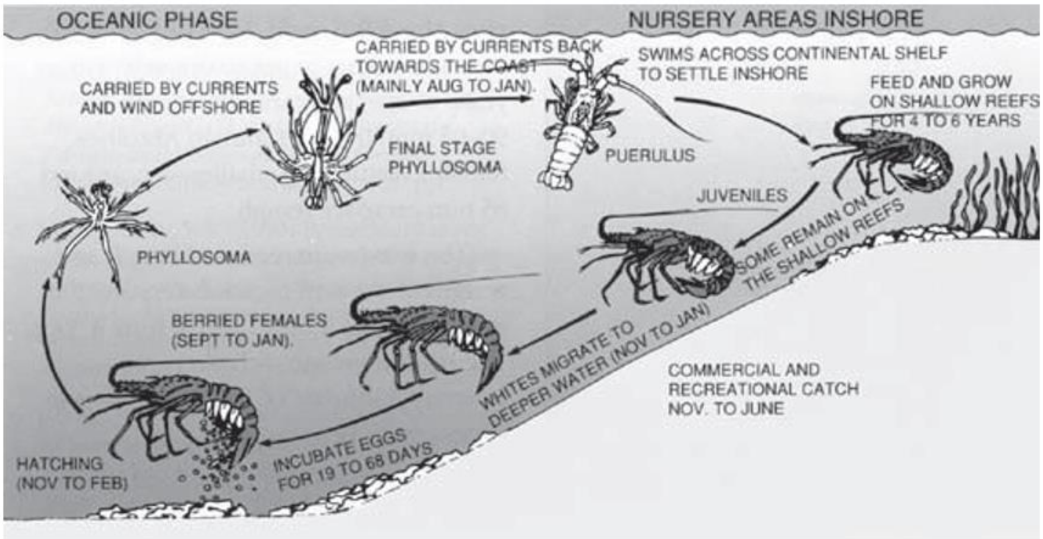

Figure 3. Schematic life history of the western rock lobster, Panulirus cygnus (from Kailola *et al.*, 1993 in Philips & Smith, 2006).

The growth rate and onset of maturity vary widely among spiny and clawed lobsters. In general, the taxa from warmer environments grow faster and mature sooner than those in cooler regions. For example, maturity is reached approximately six to seven years after settlement in *P. cygnus* a temperate species, whereas it is reached after only two years in the tropical species *P. homarus* (Phillip & Smith, 2006). Growth rates and the onset of maturity within taxa are strongly under the influence of the environment (Phillip & Smith, 2006). Scalloped spiny lobster inhabits shallow waters between 1 and 90 m depth, mostly between 1 and 5 m; among rocks, often in the surf zone, sometimes in somewhat turbid water (Holthuis, 1991).

1.4 Stock enhancement

Exploitation of aquatic organisms can cause a decrease in population size in nature and threatening its sustainability. Some issues faced by many exploited stocks of aquatic organisms are recruitment limitation or limitation of juvenile supply and overfishing. To overcome this condition, stock enhancement program can be applied to aim to improve harvests by increasing recruitment to levels approaching the carrying capacity of the habitat.

Stock enhancement is a fisheries management approach involving the release of cultured organisms to increase abundance and yield of natural fish or invertebrate stocks (Lorenzen, 2005). Lorenzen (2005) stated that successful stock enhancement can yield significant production, social and ecological benefits, increase the use of natural aquatic productivity beyond the level achievable by harvesting alone, providing high quality food at relatively low external inputs of energy and protein and with limited effects on aquatic habitats and their competing uses. Furthermore, enhancement can maintain the abundance of exploited stocks above the level supported by natural recruitment. An understanding of the ecological processes in the ecosystem is required to determine which factors define the potential for stocking, such as population dynamics, economic cost-benefits, fisheries management and socio-economic impacts (Støttrup & Sparrevohn, 2007). However, prior to the application of stock enhancement or restocking, there must be a comprehensive understanding of the process involved in stock enhancement and methods for mitigating failures.

A stock enhancement programme needs rigorous design, knowledge of ecological process and life history of the species, and an economic evaluation of the activity through the flow of benefits and costs. Caddy & Defeo (2003) stated that in planning an enhancement or restocking programme, one should consider experimental design at the local scale as well as large-scale, technical and economic feasibility. Stock enhancement programmes have been conducted for various kinds of fish or shellfish and with high cost, however, the extent to which stock enhancement programmes contributed to natural populations of fishes or shellfishes is not easy to assess. Caddy & Defeo (2003) stated that steps when assessing success of enhancement program are to (1) determine the initial number and size structure of seeded organisms, together with the sites of placement; (2) estimate survival and individual growth rates and compare them with those of the wild stock; (3) estimate the number of micro tagged organisms that survived to the harvestable size (biological samplings) and the relative contribution of the enhancement operation to the global landings from the whole area (by sampling landings and markets); (4) perform an economic analysis of the activity through the estimation of the net present value of the intertemporal flow of benefits and costs; (5) estimate uncertainty in the main inputs of the enhancement model, i.e. from growth and survival rates to unit prices and costs; and (6) attempt to reduce uncertainty in input variables by achieving as accurate biological and economic data as possible as a result of a rigorous experimental design.

Stock enhancement has been conducted in some countries for centuries. Early records of stock enhancement activities include the release of shad (*Alosa sapidissima*) fry from a hatchery in New England in 1867, chum salmon (*Oncorrhynchus keta*) in Japan in 1876 and cod in Norway in (Liao *et al.*, 2003). However, stock enhancement activities at that time were not based on a scientific approach and effectiveness of these activities were not easy to measure. With time, research in stock enhancement developed and many critical questions regarding stock enhancement effectiveness and impact in increasing population and yield came about. Today, various research groups are testing marine stock enhancement impact and effectiveness in many countries, include experimental releases to evaluate survival, optimize release strategies, and determine the contribution of hatchery fish to fisheries (Leber *et al.*, 2004).

Tag-recapture studies are an essential component of evaluating stock enhancement programmes. Results from these studies have varied. In Japan, 8% of 206,000 tagged red seabream were recaptured (Cowan, 1981), and a study showed that the annual catch of red sea bream in Kagoshima Bay increased significantly after the initiation of the stock enhancement program (Kitada & Kishino, 2006). In another stock enhancement program conducted in Kagoshima Bay, Japan 4.8 million flounder juveniles were released between 1974 and 2002. A study showed that the wild and total catch of flounder showed a clear increase after commencement of releases into Kagoshima Bay (Kitada & Kishino, 2006). In Norway, released juvenile cod were established on small scale in the 1970s and on large scale in the mid-1980s. A stock enhancement study revealed recaptured rates from zero to more than 30% and during the 1980s and 1990s, releases of juveniles did not significantly increase the cod production and catches (Svasand *et al.*, 2000). On the other hand, stock enhancement of lobsters in Norway significantly enhanced the depleted lobster population (Agnalt *et al.*, 1998). Stock enhancement of lobster was also conducted in France during 1984 and 1987. The total recaptures of lobsters from 1987-1989 was less than 1% of the 25,480 juvenile lobsters released in the study area (Latrouite, 1998). An experiment to enhance a lobster stock in the UK was conducted from 1983 to 1988 with releasing 50,000 micro-tagged hatchery-reared juvenile into lobster habitat on the English east coast and preliminary monitoring in 1987. Monitoring concluded that the enhancement contributed to the recruitment of the stock (Bannister & Howard, 1991)

1.5 The Stock Enhancement Programme in Indonesia

Stock enhancement programmes, mostly known as "restocking", was conducted in some lakes in Indonesia before 1950 (Sarnita, 1999). The fish species used in the stock enhancement were mostly the cultured species, such as tilapia, common carp, and giant gouramy (Kartamihardja, 2012). Nile tilapia, the most common species introduced in the reservoirs, generally showed good performance, spawned naturally and increased the total fish catch, such as happened in Jatiluhur Reservoir, West Java (Kartamihardja & Hardjamulia,1985).

Stock enhancement in some lakes and reservoirs can increase catch, but in terms of ecosystem balance and improving welfare for fishermen, more evaluation is needed (Kartamihardja, 2012). Introducing fish with no consideration for the precautionary approach or limnological characteristics of the water body could harm indigenous species. To mitigate negative impacts of stock enhancement practice using introduced species, information about the biology and ecology of introduced species and the dynamic of the local ecosystem should be assessed before new species are introduced. Since 1999, stock enhancement of Indonesian lakes and reservoirs have generally been based on scientific data and information about productivity and ecology of the water body, structure of fish community, life cycle and biology of the fish stocked (Kartamihardja, 2007).

Some successful fish stock enhancement programmes in Indonesia are Siamese cat fish *(Pangasionodon hypopthalmus*) in Wonogiri reservoir (Central Java) in 1999-2002, introduced giant freshwater prawn (*Macrobrachium rosernbergii)* in Darma reservoir (West Java) in 2003 and introduced bilih fish (*Mystacoleucus padangensis*) into Lake Toba in North Sumatra. Introduction of Siamese cat fish into Wonogiri reservoir in 1999-2002 has increased yield gradually since 2003. In Lake Toba, the bilih fish yield increased from 653.6 in 2005 to 30,000 tons in 2010 (Kartamihardja & Sarnita, 2010).

There has been recent interest in stock enhancement for lobster in Indonesia due to the reduced catches of lobster in some locations. Scientists are still doing research to obtain the appropriate and effective model of stock enhancement programme in some areas. One example of such research was conducted in 2015-2016 as a tag-recapture experiment of spiny lobster in Prigi Bay and is further analysed in this study.

1.6 Rationale

Declining catches of lobsters in parts of Indonesia could be caused by many factors such as a high intensity of fishing, habitat loss or limitation of recruitment. Milton *et al.* (2014) showed using a larval advection model (1993-2007) that the recruitment of *Panulirus* spp. lobster in Southern Java (Gunung Kidul) was quite high: 50–90% of the recruits were sourced locally compared to a mean of 25% from remote locations (elsewhere). Their study showed that there is the potential for a high level of self-recruitment of lobster *puerulus* to coastal habitats in southern Java (Milton *et al.*,2014). This result implies that there may be a potential benefit of implementing local management of lobster resources. One form of local management of lobster resources could be stock enhancement, with the assumption that releasing juvenile into wild population will augment natural supply of juvenile and overcome recruitment limitation.

Best-practice stock enhancement should include scientific planning and evaluation of a stocking program objectives (Leber, 2002). Preliminary study about status of the stock, life history of wild and released animal, ecological conditions and fishing activity are essential as base information for potential stock enhancement or restocking. This information can be used as an input to evaluate effectiveness of stock enhancement or restocking program in the future. After preliminary studies, experimental stock enhancement is advisable before large-scale commercial stock enhancement is conducted. Best-practice stock enhancement should include scientific planning and evaluation of stocking program objectives (Leber, 2002). Stock enhancement or restocking programme planning should consider experimental design at a local scale as well as a large scale, as well as technical and economic feasibility. An adequate experiment within a well-defined methodological framework should be conducted before stock enhancement is implemented. Finally, growth, survival and production should be monitored in relation to specific environmental and habitat characteristics to identify possible interfering factors and impact on the yield.

1.7 Objective

The overall objective of this study was to evaluate the potential for a lobster stock enhancement programme in Indonesia with case study of Prigi Bay, southern Java. The specific objectives of this study were to (1) obtain information about life history and stock status of scalloped spiny lobster in Prigi Bay as basic information for potential stock enhancement opportunities, (2) gather information about exploitation of the stock and fishing activity and how it influences the stock enhancement program, and (3) determine how effort should be focused in future data collection that would best inform and increase accuracy of evaluating the potential for lobster stock enhancement.

2 MATERIAL AND METHOD

2.1 Area of study

This study was conducted in Prigi Bay which is located in Trenggalek district, East Java province (Figure 4). Prigi was one of the lobster fishing area in southern Java where scalloped spiny lobster was the dominant species of the catches. Lobsters were released in three sites of Prigi which were Karanggongso (08019’17.4” S; 111044’28.2” E), Damas (08019’24.5” S; 111042’27.5” E) and Karangasem (08°20'5.91"S; 111°44'46.58") as shown in Figure 5.

Figure 4. Location of Prigi Bay, Trenggalek District-East Java, Indonesia

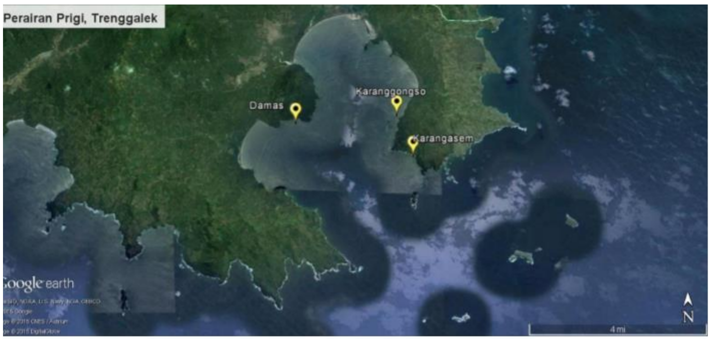

Figure 5. Sites for releasing lobsters in Prigi Bay, Trenggalek District-East Java.

2.2 Source of data

Data used in this study were from two sources. First, data were obtained from tagged-recaptured experiment in 2015-2016. A total of 2784 scalloped spiny lobster (*Panulirus homarus)* with 21-63 mm carapace length (CL) and 50-100 grams of body weight were tagged with T-bar (type TBF) using tag applicator (Dennison 10312) (Figure 6). These lobsters used for this experiment originated from wild population instead of aquaculture (hatchery). Lobsters were collected from some location in Prigi and Pacitan (± 130 km from Prigi) (Figure 7) which has higher abundance of lobster and do not have genetically distinct population (Kartamihardja, et al., 2015). Since the latter location has a higher abundance of lobsters, it is being considered as a potential source for obtaining lobster seed with which to enhance Prigi Bay. In this respect, the tagged-recaptured experiment can also be considered a stock enhancement experiment. These lobsters will be referred to as the ‘tagged’ lobsters. Tagging was applied to obtain the growth of restocked or released lobster. Before tagging and after recapture, carapace length and body weight of lobsters were measured. Lobsters were acclimatized for 3 days, two days before tagging and one day after tagging. Water conditions during acclimatization were stable to reduce the risk of stress and death of lobsters. This includes dissolved oxygen (DO), salinity, temperature and pH. Dissolved oxygen required for this step were more than 3 mg/L, salinity 28-32‰ and water temperature 28-30^{o}C. Water conditions were measured four times within 24 hours. One day after tagging, lobsters were released into the bay.

Tagged lobsters were released into sites that has good coral community, cliff contoured with small caves and massive hollow reefs, to provide shelter for lobsters from predators in nature. A total of 90 lobsters were recaptured during January to December 2016. Numbers tagged, percentage recaptured and mean length are reported in Table 1.

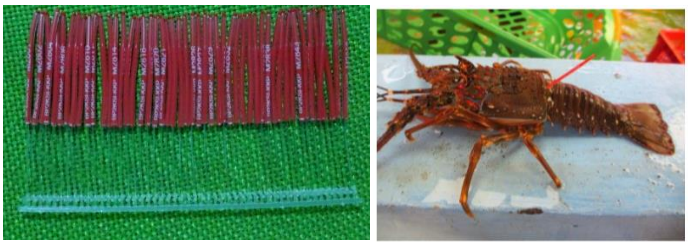

Figure 6. Tag used for tagged lobster.

Figure 7. The origin of lobsters for stock enhancement program in Prigi Bay.

Second, additional data were recorded during monitoring, including length and weight of lobster, catch numbers, and fishing effort associated with lobster catches. Data were gathered by enumerators who recorded information from fishermen. These data were used to represent monthly representations of wild populations from January to December 2016. These lobsters will be referred as 'untagged' lobsters. At the same time, fishermen that captured tagged lobsters (i.e., recaptures) reported them to the enumerators.

Table 1. Numbers tagged, numbers percentage recaptured and mean length of lobster

	Number tagged		Total	Number recaptured		Total
	Male	Female		Male	Female	
2015	1753	1031	2,784	-	-	-
2016	-	-	-	50	40	90
Range of length (mm)	21-63	27-58		43-75	40.9-62	
Mean length (mm)	46.0	45.9		55.9	52.9	

Data set used in this project were:

1. Carapace length, weight and number of tagged lobster that were released in November 2015.
2. Carapace length, weight and number of recaptured tagged lobster.
3. Catch from the study area from February - December 2016, which includes individual lengths and weights and is used to represent the wild population.

2.3 Methods

2.3.1 Length-Weight Relationship

Length-weight relationship can be used to predict weight at a given length (Eq. 1):

$$\mathbf{W = a\,L^b} \qquad \textit{(Eq. 1)}$$

where *W* is the weight in grams, *a* and *b* are parameters of the function and *L* is the carapace length of scalloped spiny lobster. The above equation was fit to lobster length and weight data after linearizing with a logarithmic transformation (Eq. 2):

$$Log\,W = Log\,a + b\,Log\,L \qquad \text{(Eq. 2)}$$

2.3.2 Estimation of length at age

Growth was assumed to follow the von Bertalanffy growth function (equation 3) in which length *L* at time *t* is predicted:

$$\mathbf{Lt = L\infty * (1 - e^{-k(t-t0)})} \qquad \textit{(Eq. 3)}$$

Growth parameters of untagged scalloped spiny lobster (data set 3) that were estimated in this study are asymptotic length (L_∞), growth coefficient (*k*), and initial time (t_0), while only the estimation of $L\infty$ and *k* were done for tagged lobster.

Estimation of growth parameters was done using two data sets. First, growth parameters (L_∞ and *k*) of untagged lobsters were estimated using ELEFAN in *TropfishR* (Mildenberger *et al.*, 2017). The values of L_∞ and *k* are based on the highest *Rn* value (Goodness of Fit) of the ELEFAN method (Gayanilo *et al.*, 2005). Secondly growth parameter (L_∞ and *k*) of tagged-recaptured lobsters were estimated using Fabens method in FSA *R* package. The Fabens method is commonly used to estimate growth parameters *k* and L_∞ model from tagged-recapture data (Wang *et al.*,1995).

The initial time (t_0) for untagged scalloped spiny lobster was estimated based on Pauly (1983) in equation 4 and the predicted life span (longevity (t_{max})) was estimated based on Pauly (1983):

$$\mathbf{Log\,(-t0) = -0.3922 - 0.2752(Log\ L\infty) - 1{,}038(LogK)} \qquad \textit{(Eq. 4)}$$

$$\mathbf{t\,max = 3/K} \qquad \textit{(Eq. 5)}$$

2.3.3 Size structure and recruitment pattern

Length frequency distribution graphs of lobster species were drawn to indicate the size structure of individuals that were released versus recaptured during the experiment. A recruitment pattern was estimated by projecting the length frequency data with time using the growth parameters approach. Estimation of recruitment pattern was conducted using FiSAT II program (Pauly, 1982; Gayalino *et al.*, 2005). The assumption used for this estimation is that there is one month of the year with zero recruitment and all fish sampled grow according to a single set of similar growth parameters.

2.3.4 Mortality

The natural mortality coefficient (M) of untagged scalloped spiny lobster was estimated using the empirical Pauly's formula which describes *M* as a function of L_∞, *k* and *T* (temperature) (Pauly, 1980). The von Bertalanffy curvature parameter *k* is linked to the longevity of the fish and longevity is related to mortality (Sparre & Venema, 1999). Natural mortality is linked to L_∞ or the maximum weight of species. Furthermore, biological processes of fish are influenced by environmental factors such as temperature, whereby biological processes go faster at higher temperatures therefore the natural mortality is related to the environmental temperatures. Pauly's empirical formula for natural mortality is described below:

$$\mathbf{Log\,M = -0.0066 - 0.279\log L\infty + 0.6453\,Log\,k + 0.4634\log T} \qquad \textit{(Eq. 6)}$$

where L_∞ and k are the estimated parameters from the von Bertalanffy growth curve and T is the surface temperature. Because growth parameters were derived from both the untagged lobster data and tagged-recaptured data, M was calculated for each data set.

Second, total mortality (Z) of untagged scalloped spiny lobster was estimated from a length-converted catch curve analysis with input of L_∞ and k value using FISAT II (Pauly, 1983; Gayalino *et al.*, 2005). The length data and growth parameters for these analyses came from the untagged lobsters' data. The fishing mortality rate (F) was estimated from subtraction of total mortality (Z) with natural mortality rate (F=Z-M), then exploitation rate (E) was estimated from fishing mortality divided by total mortality (E= F/Z) (Pauly, 1980).

Estimation of mortality of tagged-recaptured lobster that were released into Prigi Bay only for natural mortality coefficient (M). Natural mortality (M) of tagged lobster was estimated based on Pauly's empirical formula (Eq. 6).

2.3.5 Spawning Potential Ratio

The spawning potential ratio (SPR) of a stock is defined as the proportion of the unfished reproductive potential left at any given level of fishing pressure (Walters & Martell, 2004). Spawning potential ratio (SPR) is an established biological reference point that can be applied to assess the status of stocks in data-limited fisheries (Brooks *et al.*, 2010). Hordyk *et al*. (2014) presented a method for estimating SPR using only length frequency data from catches to support management decisions in data-poor fisheries.

This study determines SPR value using the Length-Based SPR model (LB-SPR) proposed by Hordyk *et al.*, (2014). To use LB-SPR, the first step was determining a variety of population parameters related to growth and natural mortality: M/k, L_∞, and L_m ($L_{50\%}$ & $L_{95\%}$) values. Lengths at maturity (L_m) were determined two ways in this study. First, the estimate of L_∞ obtained from estimation of the Von Bertalanffy growth function (Eq. 3, Section 2.3.2) was used to calculate L_m based on the Beverton & Holt's life history invariants (Jensen, 1996). Second, L_m estimates were gathered from other studies. Based on these results, a variety of L_m values were used as input for the LB-SPR model to represent a variety of potential scenarios, since the true scenario is very uncertain. Using the inputted life history parameters, the LB-SPR model then calculates a null model length-frequency distribution that would be expected under no fishing. By comparing this frequency to the length-frequency distribution observed in the catch, the model estimates fishing pressure and stock status (Hordyk *et al.*, 2014). Computing the model was done using LB-SPR tools Shiny applications from The Barefoot Ecologist Toolbox (Prince, 2003).

3 RESULTS

3.1 Length weight relationship

The length weight relationship of scalloped spiny lobster in Prigi was $W = 0.011\ L^{2.513}$. The value of the slope (b) was 2.513 which is significantly different from 3 ($p < 0.005$) indicating negative allometric growth (Figure 8).

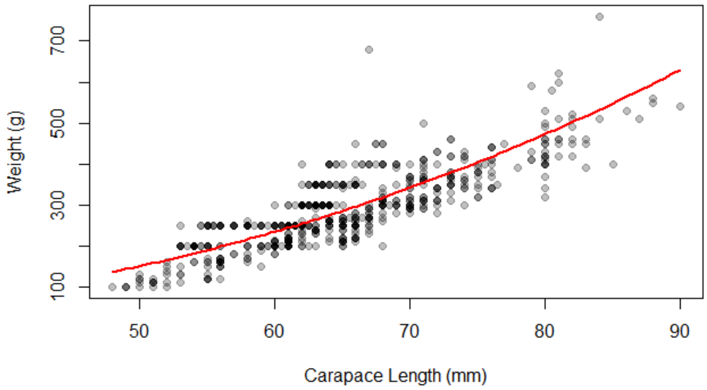

Figure 8. Length weight relationship of scalloped spiny lobster from Prigi Bay 2016.

3.2 Estimation of length at age

Mode progression analysis using ELEFAN showed the general movement of length class toward a larger size, even though the movement was not seen every month (Figure 9). This is probably because the growth rate of the lobster is slow (k<0.5) and because of moulting. The growth occurs in discrete steps, but it is not continuous.

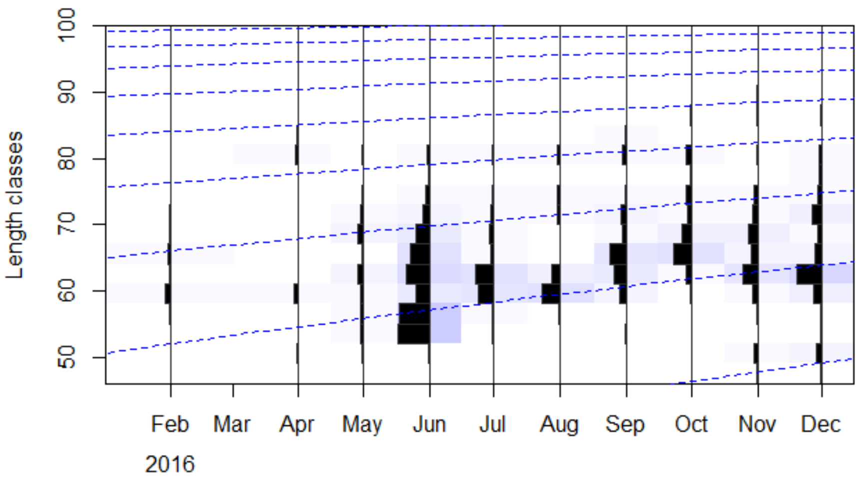

Figure 9. Carapace length modes progression of scalloped spiny lobster in Prigi Bay.

Growth parameters of scalloped spiny lobster were estimated based on carapace length mode progression analysis using ELEFAN with highest Rn value (Goodness of Fit). The estimation of growth parameter ($L\infty$, k, t_0, t_{max}) of scalloped spiny lobster is given in Table 2. The value of growth parameters (L_∞ and k) of untagged lobsters and tagged lobsters were different, L_∞ of untagged lobsters was higher than tagged lobster and k of untagged lobster was lower than tagged lobster. Growth of scalloped spiny lobster in Prigi Bay can be described by formula $Lt = 106[1-e^{0.3(t+0.392)}]$ (Figure 10).

Maximum age (t_{max}) of scalloped spiny lobster in Prigi Bay was estimated to be 10 years. The theoretical length of lobster at age 0 year was estimated to be 11.76 mm CL. Based on the growth curve, lobster growth is relatively fast from 0 to 5 years of age when the growth slows down.

Table 2. Estimation of growth parameters of scalloped spiny lobster

	L∞ (mm)	K ($year^{-1}$)	t0 ($year^{-1}$)
Untagged lobster	106.0	0.3	0.392
Tagged lobster	77.0	0.98	-

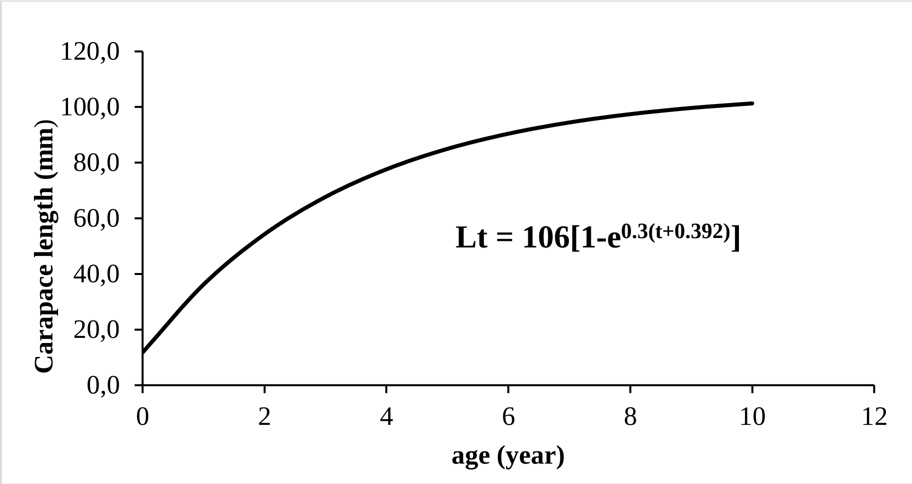

Figure 10. Growth curve of scalloped spiny lobster in Prigi Bay.

3.3 Size structure and recruitment pattern

A total of 2,784 lobsters measure 20-60 mm carapace length (CL), with the majority between 40 and 50 mm were released in stock enhancement experiment at Prigi Bay in November 2015 (Figure 11). Recaptured lobsters were recorded between February and December 2016. A total of 91 lobsters or 3.2 % were recaptured with the carapace length varying from 40 to 75 mm, with majority of lobsters 50-60 mm CL (Figure 12). The tagged- recaptured lobsters represent lobsters mostly originating from a higher abundance location that could potentially be used as a source population for enhancement of Prigi Bay. Sizes of lobster from fishermen catches, which are assumed to represent the wild population, varied 50 -90 mm, with a majority that were 60-70 mm CL (Figure 13).

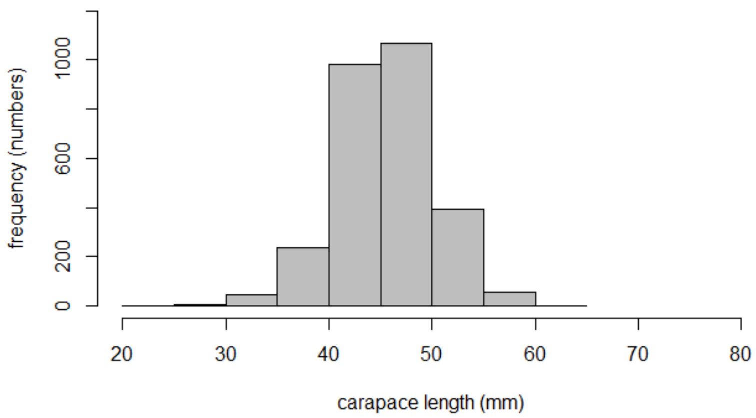

Figure 11. Length distribution of total tagged scalloped spiny lobster.

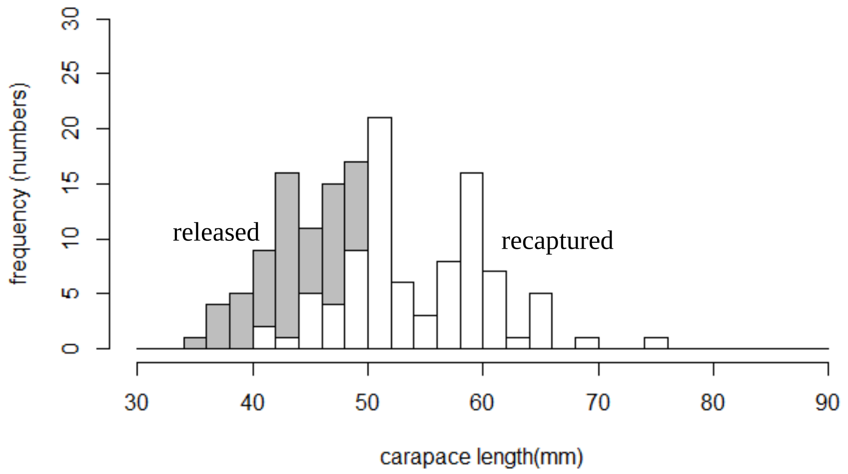

Figure 12. Length distribution of total 91 tagged-recaptured lobster.

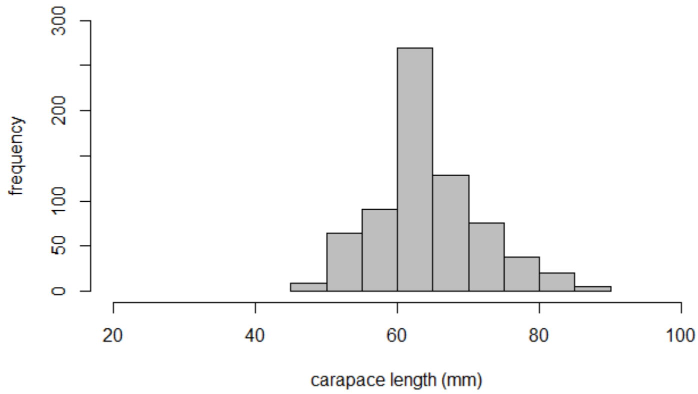

Figure 13. Length frequency distribution of scalloped spiny lobster caught by fishermen in February-December 2016.

Estimate recruitment pattern using FISAT II indicates that recruitment pattern of scalloped spiny lobsters in Prigi Bay occur throughout the year with two peaks in April (8.38%) and August (19.20%). The highest recruitment of scalloped spiny lobster in Prigi occurred in August (Figure 14).

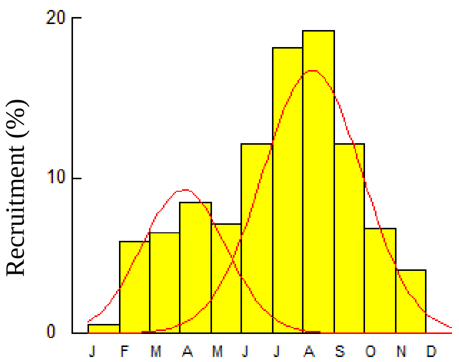

Figure 14. Recruitment pattern of scalloped spiny lobster in Prigi Bay.

3.4 Mortality rate

Estimation of total mortality (Z), natural mortality (M), fishing mortality (F) and exploitation (E) rates was done for untagged lobsters from catch data, whereas for tagged-recaptured lobster, only M was estimated. Length converted catch curve of untagged lobsters yielded estimates of total mortality (Z) as 1.74 $year^{-1}$ (Figure 15), and estimation of M using Pauly formula at temperature 29^{o} C was 0.58 $year^{-1}$, so that a fishing mortality rate (F) of 1.16 $year^{-1}$ and an exploitation rate (E) of 0.67 $year^{-1}$.

The estimated mortality for tagged-recaptured scalloped spiny lobster using the Pauly formula (1980) was 1.4 $year^{-1}$. This value was higher than natural mortality of untagged scalloped spiny lobster (0.58 $year^{-1}$).

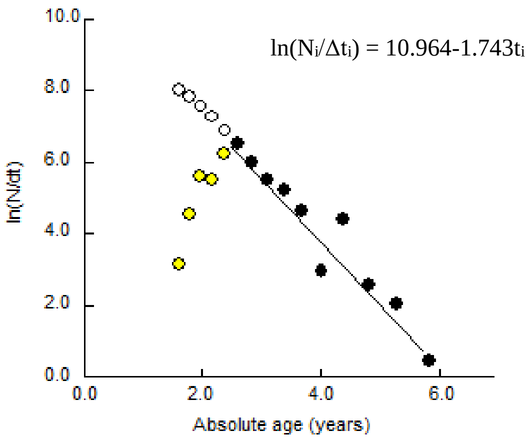

Figure 15. Length-converted catch curve of lobster in Prigi Bay.

3.5 Estimate Spawning Potential Ratio (SPR)

The determination of the SPR value was conducted by using the Length-Based SPR model (LB-SPR) proposed by Hordyk *et al.*, (2014). The estimation of an SPR value LB-SPR needed population parameters *M/k*, L_∞, and L_m as input to run the model.

M/k and L_∞, was estimated from this study whereas a variety of L_m scenarios was tested to represent uncertainty in our current understanding of maturation of scalloped spiny lobsters from Prigi Bay, since there was a lack of recorded lobster maturity data from the study area. Some L_m values were obtained from other studies, and we also obtained an estimate based on life history invariant ratio L_∞/L_∞, proposed by Prince *et al.*, (2015) and Jensen (1996). Prince *et al.*, (2015) conducted meta-analysis of life history invariants from diverse species, including two species of *Panulirus.* Prince's analysis of ratio *M/k* indicated that one *Panulirus* sp. had a ratio of 1.5, while another had a ratio of 1.9, and both belonged to the 'Type I' grouping of species that had a mean of *M/k* of 1.95. In contrast, much of the previous literature on life history invariants was based on Beverton & Holt's life history invariant of *M/k* = 1.5, which according to Jensen (1996) ratio corresponds with L_m/L =0.66.

If we assume that the difference between *M/k* = 1.9 and *M/k* = 1.5 is due entirely to differences in *k* rather than *M*, then *k* must be smaller for *M/k* individuals. A smaller *k* indicates slower growth, which in turn indicates that the length at maturity may be smaller for species with *M/k*

= 1.9 rather than *M/k* = 1.5. Below I calculate L_m/L_∞ that corresponds with *M/k* 1.9 rather than L_m/L_∞=0.66 that corresponds with *M/k* = 1.5.

$$\text{If,}\ \ \mathrm{M/k} = 1.5 \qquad\qquad (Eq.\ 7)$$

or it can be written as $M = 1.5k$

and

$$\mathbf{Lm/L = 0.66} \qquad\qquad \textbf{(Eq. 8)}$$

While, estimated ratio *M/k* from this study was 1.9 (*M/k=1.9*) or it can be written as: $M = 1.9k^*$

If 1.9 k^* = 1.5 k, then $k = \frac{1.9}{1.5}\ k^*$

And according to Jensen (1996), ratio L_m/L_∞ is,

$$\mathbf{L_{(xm)}/L_\infty = 1 - exp(-k_{xm})} \qquad\qquad \textbf{(Eq. 9)}$$

$$\mathbf{x_m = \frac{Log\ (3)}{K}} \qquad\qquad \textbf{(Eq. 10)}$$

Here, substitute k for k^* and x_m for x_m^*

$$\mathrm{L_{(xm)}}/L_\infty = 1 - exp(-\mathrm{K_{xm}})$$

$$L_{(xm)}\Big/L_\infty = 1 - exp\left[-k^*\left(\frac{\log(3)}{\frac{1.9}{1.5}k^*}\right)\right]$$

$$L_{xm}/L_\infty = 1 - exp\left[-\left(\frac{\log(3)}{\frac{1.9}{1.5}}\right)\right]$$

$$Lm/L\infty = 0.58$$

This number is consistent with Prince *et al.* (2015) who empirically estimated L_m/L_∞ as 0.55 for species with a *M/k = 1.9*. Estimation of SPR of scalloped spiny lobster in this paper was scenario with different L_m value. The range of L_m values that were used as input for estimated SPR is given in Table 3 and results from LB-SPR analyses based on these and various L_m values and a ratio *M/k* =1.9 was given in Table 4. Results of the LB-SPR analyses that illustrate length distribution (mm CL) and comparison between length at 50% maturity and length at 50% selectivity are given in Figure 16.

Table 3. L_m used as input for SPR estimation scenario.

L_m (mm CL)	L∞ (mm CL)	Location	Sources
52.07	99.75	Yogyakarta & Pacitan (Southern Java)	Setyanto & West *et al.*, 2017
81.0	103.25	Pelabuhan Ratu (west-Java)	Zairion et al., 2017
61.48	106.0	Prigi	Estimated from this study (L_m/L_∞ =0.58)

Table 4. Different scenario SPR, F/M, Selectivity Length (SL) 50% and 95% and length at 50% and 95% maturity of scalloped spiny lobster.

	M/k=1.9, L_{50} =52.07	M/k=1.9; L_{50} = 81.0	M/k=1.9; L_{50}=61.48
Est SPR	0.29	0.04	0.2
Est F/M	2.33	2.33	2.33
SL_{50} (mm)	58.68	58.68	58.68
SL_{95} (mm)	66.85	66.85	66.85
L_{50} (mm)	52.07	81.0	61.48
L_{95}(mm)	61.9	89.76	70.24

Based on the definition of spawning potential ratio (SPR), unfished stocks have an SPR of 100% ($SPR_{100\%}$). Fishing mortality reduces $SPR_{100\%}$ from the unfished level to $SPR_{X\%}$. Scenarios analysed in this study resulted in SPR values of 0.04 (4%), 0.2 (20%) and 0.29 (29%). $SPR_{4\%}$ indicated that length at 50% selectivity (SL_{50}) of lobsters was much smaller than length at maturity (L_{50}). In case of $SPR_{20\%}$ and $SPR_{29\%}$ also showed that SL_{50} was smaller than L_{50}. Illustration of scenario SPR score with comparison between L_{50} and SL_{50} is given in Figure 16 *(b)*, (*c)* and (*d).*

$SPR_{4\%}$ is bellow *recruitment-overfishing limit* $SPR_{20\%}$ that recommended by Mace & Sissenwine (1993) and below overfishing thresholds for the spiny lobster (*Panulirus* sp.) recommended by Miller & Hannah (2006) in Caribbean and Hawaiian Islands fisheries.

According to Mace & Sissenwine (1993), $SPR_{20\%}$ or $F_{20\%}$ are the points below which a stock is considered at risk of impaired recruitment, which may lead to long term declines. $SPR_{20\%}$ and $SPR_{29\%}$ indicated that the stock at risk and needs to be monitored with concern.

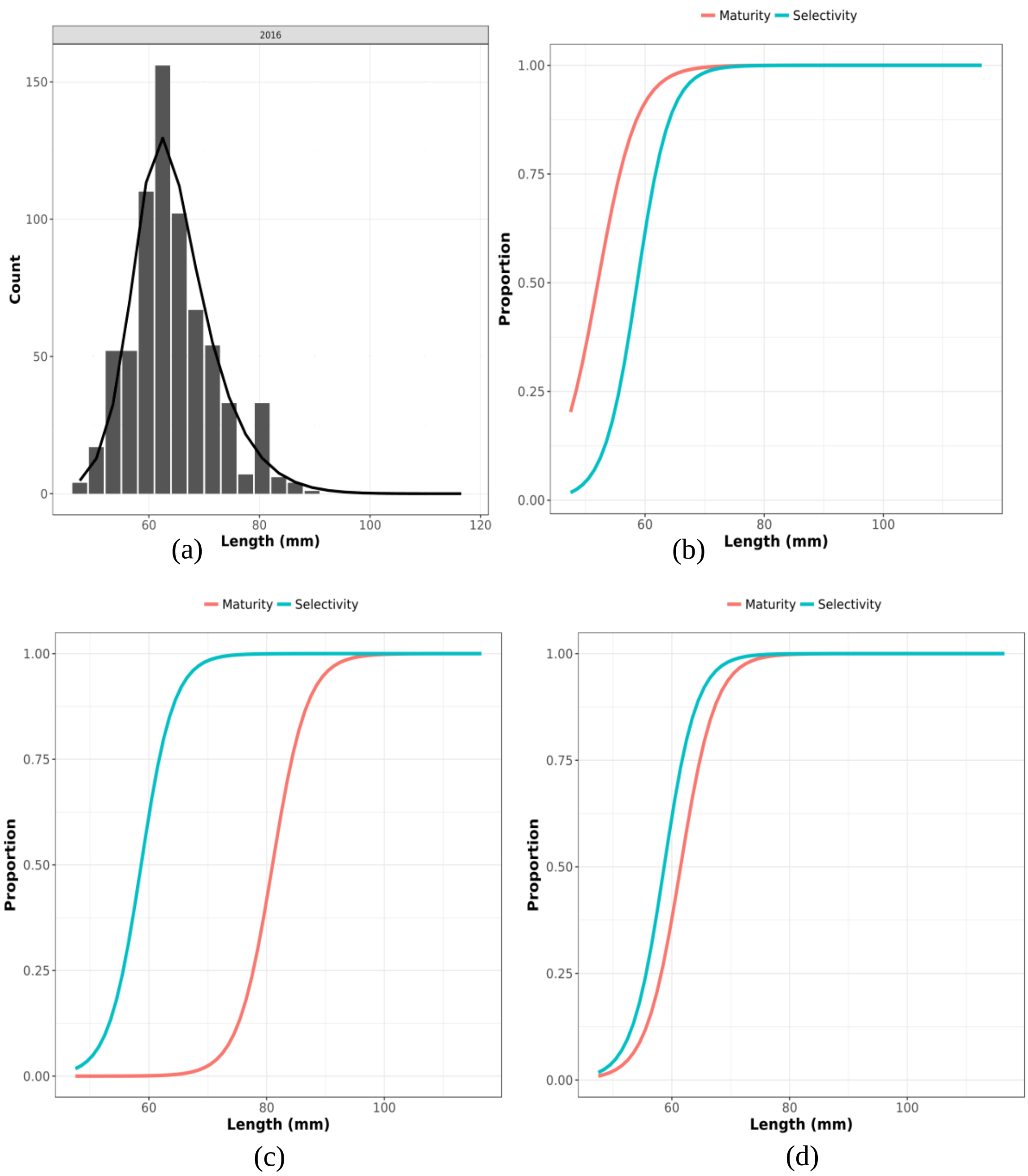

Figure 16. (a) Length distribution (mm CL); (b) scenario of comparison between lengths at 50% maturity to lengths at 50% selectivity of scalloped spiny lobster with L_{50} =52.07 mm CL (c) with L_{50} =81.0 mm CL; (d) with L_{50} = 61.48 mm CL.

4 DISCUSSION

Understanding life history and population dynamics of species is an important starting point for developing a management plan for its population, including the potential for stock enhancement. In addition, assessing the stock status of fish is essential before applying stock enhancement or restocking. Based on the definition of stock enhancement, the aim of stock enhancement is to increase harvest, hence, the status of the stock before enhancement must be determined as a starting point from which to evaluate success of enhancement in the future. This study assessed life history, population dynamics and status of the stock of scalloped spiny lobster as basic information for considering and evaluating stock enhancement programme in the future.

4.1 Length weight relationship

The 'b' value estimated in length-weight relationship indicates that scalloped spiny lobsters in Prigi Bay refer to negative allometric growth pattern. According to Pauly, (1984), the value of 'b' should be between 2.5 to 3.5, and usually close to 3. The 'b' value depends on several factors seasonal and annual effects such as temperature, salinity, food (quantity, quality, and size), sex, time of year, and stage of maturity (Pauly, 1984). The growth pattern of scalloped spiny lobster from Prigi Bay in this study is the same as growth pattern of scalloped spiny lobster in Yogyakarta and Pacitan (Hargiyatno *et al.,* 2013), Pelabuhan Ratu-West Java (Zairion, et al., 2017), Cilacap-Central Java (Bakhtiar *et al.*, 2013), Tabanan-Bali (Kembaren, *et al.,* 2015) and Southern coastal region of Sri Lanka (Senevirathna, *et al.*, 2014),

4.2 Length at age

4.2.1 Length at aged of untagged scalloped spiny lobster

The estimates of growth parameters of untagged scalloped spiny lobster (represent wild population of lobster in Prigi) in this study indicates that this species is a relatively slow growing species ($k < 0.5$). The value of the coefficient of growth (k) can determine how fast the fish will reach its asymptotic length. In addition, the value of k is correlated with longevity (t_{max}) (Pauly, 1980). The estimated longevity of scalloped spiny lobster in Prigi Bay was 10 years. Based on the k value of lobster from many studies, it is known that lobsters are slow growing species which means it also has a long lifespan (Phillip & Smith, 2006). Based on the estimated k, $L\infty$ and t_0 that were plotted on Von Bertalanffy growth model, scalloped spiny lobster in Prigi Bay reaches the minimum landing size regulated by Ministry of Marine Affairs and Fisheries No 56/ 2016 (>80 mm CL) within 5 years. This information can be taken into consideration in managing stock enhancement as it corresponds with the ages of harvesting.

Growth parameter values of the same species can vary among different regions. However, the estimate of asymptotic length of the scalloped spiny lobster in Prigi is close to that of the same species from another part of south coast Java (Milton *et al.*, 2012) as seen in Table 5. Larger differences were observed when compared with studies conducted further away, and could be caused by structure of sample, maximum length of sample, fishing pressure and habitat degradation. Growth of lobster is influenced by various factors such as temperature, food limitation, density, space and shelter (Phillip & Smith, 2006).

Table 5. Growth rate (k), asymptotic length (L∞) of scalloped spiny lobster in some locations.

Location	L_∞ (mm CL)	k (year^{-1})	References
Prigi (Southern Java)	106.0	0.3	This study
Pelabuhan Ratu (West Java)	103.25 (female)	0.4 (Female)	Zairion, et al., 2017
	110,50 (male)	0.29 (male)	
Yogyakarta&Pacitan (Southern Java)	99.75	0.51	Setyanto & West *et al.,* 2017
West Aceh (Sumatra)	119.5	0.39	Kembaren & Nurdin, 2015
South coast Java	105.6	0.93	Milton, Proctor, Satria, & West, 2012
Cilacap (Southern Java)	110(male)	0.26 (male)	Bakhtiar *et al.,*2013
	95.62 (female)	0.31 (female)	
Sri Lanka	127 (male)	0.41(male)	Jayakody, 1993
	121(female)	0.39 (female)	
Sri Lanka	287	0.43	Jayawickrema, 1991
Oman	144.5 (male)	0.75 (male)	Al- Marzouqi *et al.*, 2007
	134.7 (female)	0.81 (female)	
Oman	144.8	0.72	Mehanna, 2012

4.2.2 Length at age of tagged lobster

Estimation of growth parameter from tagged lobsters were not similar with untagged lobster, where asymptotic length was very low (L_∞ = 77.7) and coefficient growth was high (k = 0.98). This might occur because the lobsters sampled were not random and were instead dominated by small sizes. After releasing lobsters in November 2015, monitoring of recaptured tagged lobsters from fishermen catches were conducted only from January to December 2016, which means that the lobsters were still small and likely at a young age that exhibits fast growth. Moreover, the possibility of tag loss is a common problem in tagged-recaptured studies that can affect the estimation of growth.

As mentioned before, the lobster population under study has a long-life span and is a slow growing species. This can be one of the considerations in designing framework of stock enhancement /restocking pilot study, which determines the time duration for monitoring in order to obtain sufficient samples for proper scientific analysis of growth. Monitoring for released lobster must be set up more than five years to get large enough sized individuals to more accurately estimate growth parameters.

4.3 Size structure and recruitment pattern

The dominant size of lobsters in commercial catches in Prigi were 60.0-70.0 mm CL, which is smaller than legal size regulated by Ministry of Marine Affairs and Fisheries No 56/year 2015 (>80 mm CL). This condition indicated that fishermen have not abided by the regulation of legal size. Noncompliance might occur because fishermen are still not aware of the regulation that was issued in 2015. Alternatively, they may be aware but not understand the importance of the regulation. Therefore, increasing fishermen's awareness and education regarding the regulation is necessary, as well as continued monitoring of catch.

This study indicated a biannual recruitment pattern for scalloped spiny lobster, including a smaller peak in April (8.38%) and and a larger peak in August (19.20%). Another study conducted by Zairion *et al.*, (2017) in Pelabuhan Ratu-West Java, showed two annual recruitments with peaks in February and September. Study conducted by Bakhtiar *et al.*, (2013) found that scalloped spiny lobster in Cilacap (Southern Java) has two annual recruitment patterns with peak in June and October while study conducted by Suman (1994) in Pangandaran (Southern West Java) showed that recruitment pattern of scalloped spiny lobster has two peaks in April and October. Recruitment pattern of scalloped spiny lobster in southern coast of India also showed two cohorts per year, which was represented by two recruitment peaks in May and September (Thangaraja *et al.*,2015).

Recruitment is generally determined by the number of spawners, fecundity, and the mortality rate of new recruits before they can reach fishable size. The success of recruitment is also determined by the environmental conditions when a juvenile cohort settles onto the nursery ground. Recruitment pattern can be important information for the management of lobster. Based on recruitment pattern, limiting fishing during the peak of recruitment may be an option to consider in management.

4.4 Mortality

Estimated natural mortality of scalloped spiny lobster in Prigi is 0.58 $year^{-1}$. This value is similar to natural mortality of species in West Java (Zairion *et al.*, 2017) as seen in Table 6. The fishing mortality rate of the species in Prigi is similar in other places in Indonesia like in West Java but lower compared to another part of Southern Java (Yogyakarta and Pacitan) in 2010 (Table 6). Fishing mortality indicated that exploitation is quite high in Prigi. The exploitation rate was similar with exploitation rates found in Pelabuhan ratu-West Java (Zairion *et al.*, 2017) and in southern Java (Setyanto & West, 2017).

Table 6.Total, natural and fishing mortality of scalloped spiny lobster in some locations.

Location	Z ($year^{-1}$)	M ($year^{-1}$)	F ($year^{-1}$)	E ($year^{-1}$)	References
Prigi (Southern Java)	1.74	0.58	1.16	0.67	In this study
Pelabuhan Ratu (West Java)	1.6 (m) 2.27(f)	0.56 (m) 0.71 (f)	1.07	0.66 (m)	Zairion, et al., 2017
Yogyakarta &Pacitan (Southern Java)	3.462	0.84	2.63	0.69(f)	Setyanto & West, 2017
Southern Java	2.93	1.19	1.74	0.59	Milton, Proctor, Satria, & West, 2012
West Aceh (Sumatra)	1.44	0.67	0.77	0.54	Kembaren & Nurdin, (2015
Cilacap (Southern Java)	1.6	0.69	0.91	0.57	Bakhtiar, *et al*, (2013)
Sri Lanka	2.1 (m) 1.6 (f)	0.98 (m) 0.92 (f)	1.02 (m) 0.68 (f)		Jayakody, 1989
Oman	4.1 (m) 4.76 (f)	0.95 (m) 0.95 (f)	3.16 0.86		Mehanna *et al.*, 2012

Explanation: (m) male, (f) female

Natural mortality rate (*M*) of the tagged lobster was higher than untagged lobster. Higher mortality might occur because of the handling and tagging activity. Some studies showed that tagging also causes risks associated with mortality (Wahle & Fogarty, 2006). Natural mortality is also affected by some factors such as environmental condition (temperature, salinity, pH), food source and predation. Therefore, higher mortality could additionally occur because many of the tagged lobsters that were released into the bay were transplanted from another location and needed to adjust to the new conditions that might be dissimilar as the place of origin.

4.5 Stock Status

Stock status of the scalloped spiny lobster in this study was assessed from spawning potential ratio (SPR). SPR is a reproductive relative index used to assess stock status in exploited stock (Mace & Sissenwine, 1993). SPR is defined as a proportion of the unfished reproductive population left in the population after exploitation by a fishery and is usually used to set target and limit reference points for fisheries management in data-poor fisheries (Hordyk *et al.*, 2014). For example, Mace and Sissenswine (1993) recommended SPR20% as a recruitment-overfishing limit for stocks with average resilience or productivity.

Scenarios that estimated SPR showed that the Prigi lobster stock ranged from a heavily exploited (SPR 4%) status to an at-risk status (SPR 20%). Although the scenario that yielded an SPR of 29% was still slightly above the recruitment-overfishing limit recommended by Mace and Sissenswine (1993), caution is needed in management of the lobster stock to prevent population decline. The low value of SPR (SPR = 4%) indicated that the potential lobsters remaining that were able to continue spawning were very few, because lobsters were captured before becoming mature. This is as illustrated with an SL_{50} much smaller than L_{50} in Figure 16. The scenario with SPR = 20% also indicated that status of stock is at risk of recruitment overfishing since most lobsters were captured before maturing, as illustrated with SL_{50} smaller than L_{50} (Figure 16).

As the status of the lobster stock was at-risk, stock enhancement or restocking could be an option in fisheries management alongside controlling capture activity, for example by increasing the length captured to a size bigger than the length at maturation. Stock enhancement could be effective if harvesting behaviour of fishers were in accordance with the provisions of sustainability, for instance by not capturing immature lobsters. However, if harvesting behaviour of fishermen remains the same, resulting in a length of capture that was smaller than length at maturity, sustainability of the stock is threatened. The enhancement program would not be effective if fishermen behaviour in harvesting is still the same.

5 CONCLUSION AND RECOMMENDATION

Prior to applying a stock enhancement programme, it is essential to design a framework to mitigate failures and gain knowledge in achieving the objective. Blankenship & Leber (1995), recommended ten principles of a responsible approach for marine stock enhancement. Among others, these included (1) prioritize target species for enhancement and assess reasons for decline of the wild population; (2) consider biological, life history and ecological traits of released and wild fish; and (3) educate stakeholders to develop a successful enhancement program.

This study attempted to gather life history parameters that affects population dynamics (i.e., growth, maturity, and mortality), to assess the status stock of the wild scalloped spiny lobster prior to enhancement activities and to collect information about lobster fishing activity in Prigi as basic information for evaluating the potential for stock enhancement. In support of the first principle, the LB-SPR analysis provided an indication that the stock is at a relatively high risk of recruitment overfishing. Providing information on stock status before stock enhancement is applied is essential as one of parameter to evaluate successful of stock enhancement in the future.

In support of the second principle, this study has been started to assess life history and dynamic population of wild scalloped spiny lobster as well as growth of released lobster. However, more advanced study about biology and ecology of wild and released lobster are still needed.

In support of the third principle, based on analysis from this study it was found that lobster catch was dominated by small size (smaller than legal size). Continued exploitation of immature lobsters, even after implementation of a minimum landing size by the Ministry of Fisheries, might occur because fishermen are not aware of the regulation. Therefore, educating fishermen about minimum size of lobster that can be captured and how it maintains sustainability of stock is recommended as a necessary starting point.

However, although this study has provided initial essential information for potential stock enhancement, further study with complete and comprehensive data are urgently needed since some weakness in this study exist, such as poor time series data of catch, detailed length at maturity data, and short-term monitoring after the release of lobsters in the tagged-recapture experiment (12 months). Moreover, study related to tagging induced mortality or tagging-induced slower growth should be conducted as a part of stock enhancement experiment. More information regarding tagging loss in relation to moulting is also needed for this study.

More completely tagging study that compare growth and mortality rates between lobsters obtained within local area versus outside local area are also needed in the future to determine whether the lobsters from other location grow slower or die quicker after transport. In addition, research in aquaculture related seed producing should be conducted since aquaculture has important role in supporting seed or juvenile for stock enhancement programme.

In the future, recording catch data before stock enhancement is conducted is essential. Furthermore, monitoring both catch and released lobster through tagging experiments within the restocking/stock enhancement programme is required. Designing experimental stock enhancement that includes continued monitoring is crucial to evaluate effectiveness of stock enhancement. Further studies with complete and comprehensive data must be conducted to improve the result of this study, since there are some weaknesses that can generate bias in parameter estimates on which our recommendations are based.

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