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A Stock Assessment of the Blue Swimming Crab *Portunus pelagicus* (Linnaeus, 1758) for Sustainable Management in Kung Krabaen Bay, Gulf of Thailand

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Abstrak: Satu penilaian stok ketam renjong, *Portunus pelagicus* telah dijalankan menggunakan *crab gill net* dan *collapsible crab trap* di Kung Krabaen Bay, yang terletak di timur Teluk Thailand, dari 2008 hingga 2009. Beberapa indikator penting telah menunjukkan bahawa populasi *P. pelagicus* menghadapi krisis. Mortaliti tangkapan menunjukkan peningkatan kepada 4.14. Kadar eksploitasi ialah 0.71, iaitu lebih tinggi daripada nilai optimum 0.38. Saiz ketam betina matang juga telah berkurangan dari 8.10±0.39 cm kepada 7.52±1.14 cm. Nilai purata fekunditi ialah $0.572\times10^6 \pm 0.261\times10^6$ telur setiap kelompok, dan nisbah jantina (jantan:betina) ialah 1:0.92. Berdasarkan keputusan ini, suatu program pengurusan lestari untuk *P. pelagicus* telah dicadangkan seperti berikut: (i) menutup teluk semasa musim mengawan, (ii) pemulihan semula tapak rumput laut *Enhalus acoroides,* (iii) penstokan semula larva ketam di teluk dan (iv) mendidik dan mewujudkan rangkaian sosial antara kesemua pemegang taruh untuk membina pemahaman yang lebih baik terhadap ekologi ketam dalam menyokong pengurusan perikanan secara lestari di Kung Krabaen Bay.

Kata kunci: Penilaian Stok, Ketam Renjong, Pengurusan Lestari, Teluk Thailand

Abstract: A stock assessment of blue swimming crabs, *Portunus pelagicus* was conducted with crab gill nets and collapsible crab traps at Kung Krabaen Bay, in the eastern Gulf of Thailand, from 2008 to 2009. Several key indicators show that *P. pelagicus* population is in crisis. Fishing mortality shows an increase to 4.14. The exploitation rate is 0.71, higher than the optimal value of 0.38. The size of the mature females has also decreased from 8.10±0.39 cm to 7.52±1.14 cm. The average fecundity is $0.572\times10^6 \pm 0.261\times10^6$ eggs per batch, and the sex ratio (male:female) is 1:0.92. Based on these results, a sustainable management program for *P. pelagicus* was proposed as follows: (i) closing the bay during the spawning season, (ii) restoration of the *Enhalus acoroides* seagrass beds, (iii) restocking crab larvae in the bay and (iv) educating and networking all stakeholders to develop a better understanding of the ecology of the crab to support sustainable fishery management in Kung Krabaen Bay.

Keywords: Stock Assessment, Blue Swimming Crab, Sustainable Management, Gulf of Thailand

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INTRODUCTION

The population decline of the blue swimming crab *Portunus pelagicus* (Linnaeus, 1758) is believed to be the result of problems such as overharvesting by efficient fishing gear, destruction of nursery habitat, harvesting ovigerous females and inefficiency of crab management. These problems are related to the high export of crab meat from Thailand. Since 2000, the annual production of crab meat has been as great as 43871 tonnes, declining to 20000 tonnes in 2011 (Thai Frozen Food Association 2012). In fact, this problem has not only occurred in Thailand but also in Southeast Asian countries such as the Philippines, Vietnam and Indonesia (National Fisheries Institute Crab Council 2013). The high market demand has stimulated increasing harvesting pressure on this common-pool resource, which is a common asset. Many fishermen adapt their harvesting techniques and even seek new techniques to increase their effective harvesting capacity. As a result, the crab stocks in many coastal areas are now in crisis, particularly in Kung Krabaen Bay (eastern Gulf of Thailand), one of the important fishing grounds for *P. pelagicus* in Thailand. A few researchers have assessed the population of *P. pelagicus*: Kunsook (2006), Bhatrasataponkul *et al.* (2008) and Raungprataungsuk (2009). However, they only estimated the stock inside the bay. They used collapsible crab traps in this area. In fact, there are two types of fishing gear, crab gill nets and collapsible crab traps. Generally, the gill net is used outside the bay to harvest larger crabs, whereas the collapsible trap is used inside the bay to harvest smaller crabs. Currently, both groups of fishermen are facing drastic declines in the crab population and decreases in the size of the crabs. This situation has created social conflicts between two groups of fishermen. One of these groups harvests crabs inside the bay, whereas the other group harvests crabs outside the bay. Both groups deny responsibility for these drastic problems. These difficulties may be related to the limited biological and ecological knowledge of *P. pelagicus*. Recommendations by the Bi-State Blue Crab Advisory Committee (BBCAC), USA, have identified indicators that furnish evidence of concern regarding the health of the crab stock. These indicators include the increase in fishing mortality, the near-record levels of fishing effort, the decrease in average crab size and the lack of mature females (Miller 2001). Therefore, it is necessary to conduct research on crab stock assessment to gain additional knowledge with the goal of enhancing the local crab population, which has been shown to be close to its carrying capacity. The results of this research could be shared to educate the local fishermen and other stakeholders who are involved, either directly or indirectly, in the management of the crab population. At present, there is no active crab fishery management strategy or policy plan for Kung Krabaen Bay. The Kung Krabaen Bay Royal Development Study Center is still attempting to establish a population of crabs in aquaculture facilities and to restock juvenile crabs in the bay. Unfortunately, its efforts have not achieved the stated goals. This difficulty can be explained by the lack of concern by the various stakeholders about measures for halting the decline of the crab population.

To resolve the problem of the population decline through appropriate and sustainable crab management, this study aimed to (i) assess the current status of

P. pelagicus stock through the use of the two types of fishing gear employed in Kung Krabaen Bay; (ii) monitor biological indicators such as the sex ratio, fecundity (eggs per batch), stage of ovarian development, size at first maturity and proportion of ovigerous females removed from their habitat; and (iii) propose guidelines for the sustainable management of *P. pelagicus* in the bay.

MATERIALS AND METHODS

Study Area

Kung Krabaen Bay is a small semi-enclosed estuarine system located in the western part (12°34'–12°12'N, 101°53'–101°55'E) of Chanthaburi Province on the eastern Gulf of Thailand. The bay measures 2.5 × 4.0 km and has an average depth of 2.5 m. The bay has an approximate area of 10 km^2 and a total volume of 2.5×10^7 m^3. It is connected to the Gulf of Thailand by a 700 m wide channel in the southeastern corner of the bay [The Kung Krabaen Bay Royal Development Study Center (KKBRDSC) 2003]. The bay is strongly influenced by salinity variations due to the northeast monsoon in the dry season (November to April) and the southwest monsoon in the wet season (May to October). It includes diverse habitat types, e.g., mangrove forests, tidal mudflats, seagrass beds and coral reefs; therefore, the bay is important as not only a natural habitat for *P. pelagicus* but also an invaluable fishing ground.

Data Collection

To examine the abundance and distribution of the stock, samples of *P. pelagicus* were collected monthly for one year from October 2008 to October 2009. Two gear types were used, namely, a collapsible crab trap (2 cm mesh size) and a crab gill net (10 cm mesh size). Twenty seven stations were designed to collect crab samples inside and outside the bay (Table 1 and Fig. 1). Ecological factors, e.g., salinity, were measured with a refractometer (Harikul Science Company, Bangkok), and pH, dissolved oxygen and temperature were measured with a multi-parameter probe (LEGA Engineering Company, Bangkok). Crabs were separated according to sex. The carapace width (CW) was measured to the nearest 0.01 mm, the weight to the nearest 0.01 g. Thirty adult female crabs were collected for gonadosomatic index (GSI) determination and fecundity analysis. All data were analysed with techniques described in the data analysis section.

Data Analysis

Stock assessment and population structure were analysed with the Food and Agriculture Organization International Center for Living Aquatic Resources Management (FAO-ICLARM) Stock Assessment (FiSAT) program (Sparre & Venema 1998). Growth parameters, total mortality (natural and fishing mortality), recruitment pattern and exploitation rate were calculated by this program based on CW and frequency distribution (Sparre & Venema 1998; Pauly 1983). However, before the stock assessment could be analysed by the FiSAT program to obtain the probability of capture (Lc), it was necessary to correct the length-frequency data for the bias caused by the selectivity of the gear used to obtain the samples. This bias can cause the results to deviate from their true values. Accordingly, the size-frequency samples needed to be corrected in terms of the Lc. The unbiased data were then pooled for analysis by the FiSAT program with the Powell and Wetherall method (Spare & Venema 1998). Crab population structure, including the sex ratio and the relationship between CW and weight (W), as well as the size distribution, were also calculated. The CW/W relationship of both sexes was described with an allometric relationship ($Y = aX^b$; Y = weight, x = CW, a and b are the stable value from the linear regression). Seasonal abundance and spatial abundance were calculated from monthly samples from the 27 stations. The differences in crab abundance relative to seasonal and spatial variation were analysed with a one-way ANOVA (Zar 1984). Relationships between crab abundance and ecological factors were determined at a significance level of 0.05 based on a Pearson correlation.

Table 1: Sampling stations for stock assessment of *P. pelagicus* in Kung Krabaen Bay from October 2008 to October 2009.

Group	Number of stations	Stations	Description of habitat and location
1	6	SG11, SG12, SG13, SG31, SG32, SG33	Seagrass bed (*Enhalus acoroides*)
2	3	SG4, SG5, SG6	Seagrass bed (*Halodule pinifolia)*
3	3	M1, M2, M3	Near mangrove reforestation
4	3	U1, U2, U3	Bare ground
5	3	KV1, KV2, KV3	In front of Kung Viman Beach
6	3	KB1, KB2, KB3	In front of Kung Krabaen Bay
7	3	KL1, KL2, KL3	In front of Chao Lao Beach
8	3	P1, P2, P3	In the vicinity of the mouth of the bay

Reproductive Biology

Reproductive biology was studied by examining ovarian development, size at maturity, the GSI and fecundity. The stage of ovarian development was analysed with methods described by Svane and Hooper (2004).

The size at maturity of female *P. pelagicus* was defined by the rule that a female can be classified as mature if the oval abdominal flap can be separated from the carapace (Smith *et al*. 2004). The size at which 50% of the females were mature (L_{50}) was estimated by fitting a logistic regression curve to the proportion of females that were mature in each sequential 1 mm CW size class as described by Oh and Jeong (2003), and King (1995).

$$Proportion\ ovigerous = \frac{1}{1+exp^{(-a+bQCW)}},$$

where, a and b are coefficients and OCW is the outer CW of the female crab.

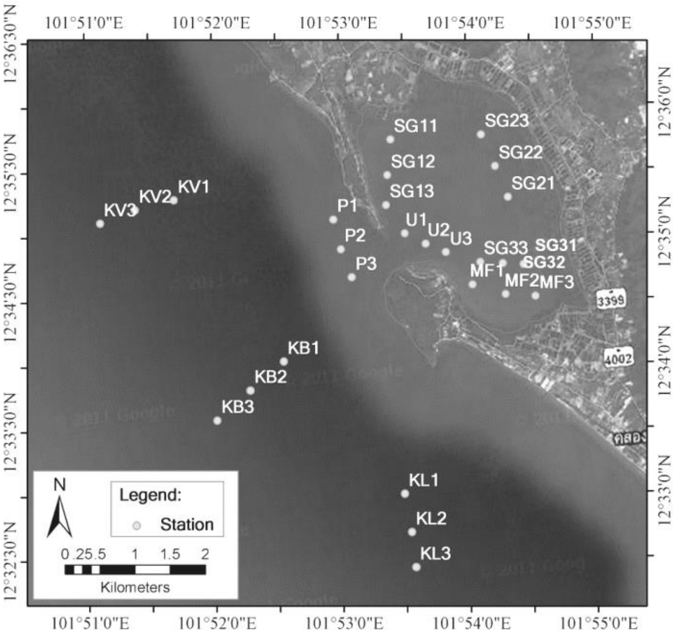

Figure 1: Study area for stock assessment and movement patterns of *P. pelagicus* at Kung Krabaen Bay, Chanthaburi Province, Thailand.
Note: SG = Seagrass bed, KB = Kung Krabaen Bay, MF = Mangrove forest, KV = Kung Viman Beach, U = bare ground, KL = Chao Lao Beach, P = mouth of bay

The GSI was calculated with the formula proposed by Sukumaran and Neelakantan (1997), and Geise and Pearse (1974):

$$GSI = \frac{Wet\ weight\ of\ ovary\ (g)}{Body\ weight\ of\ crab\ (g)} \times 100$$

Fecundity (F) was calculated by counting the number of eggs present on the pleopod in an ovigerous female. The eggs were removed from the pleopod by immersing them in 20% sodium hydroxide solution and freed from the pleopod after 3 hours. They were then filtered and weighted to the nearest 0.1 mg. A sample of the separated egg mass was weighed and counted. The total number of eggs in the entire egg mass was then determined as follows:

$$F = n \times \frac{P}{P^1}$$

where	P	=	the weight of the entire egg mass
	P^1	=	the weight of the subsample
	n	=	the total number of eggs in the subsample.

The average number of eggs per subsample was estimated from three replicate subsamples. The total number of eggs per egg batch was also calculated. The relationship between size of crab (OCW) and F was estimated separately on a monthly basis by fitting a linear regression relating fecundity to CW (Sukumaran & Neelakantan 1997).

RESULTS

The criteria used to determine whether a population was facing a crisis were based on the indicators in Miller (2001).

Growth Parameters

The selectivity of the gear strongly influenced the size distribution and composition of the crab catches. The Lc for the crab trap and crab gill net were calculated (Fig. 2 and 3). In the FiSAT program, Bhattacharya's method was used to distinguish the size frequencies to determine the mean CW of the crab cohort. A modal progression analysis was used to track the mean length of a given cohort through its monthly growth progression (Sparre & Venema 1998) (Fig. 4). The results show that the growth parameters of the male crab were L_∞ = 14.26 cm (L_∞ = CW of *P. pelagicus* in infinity) and K = 2.75 per year (K = carrying capacity value) and that the growth parameters of the female crab were L_∞ = 16.73 cm and K = 1.13 per year.

Mortality and Exploitation Rate

Increasing fishing mortality in crab populations often indicates a declining population. The total mortalities of male and female crabs estimated by the length-converted catch curve (Table 2 and Fig. 5) were 8.15 and 6.95 per year, respectively. The maximum relative yield-per-recruit exploitation rate (E_{max}) was 0.81, whereas the exploitation rate at the optimum level was 0.37 and the present yield was 0.71 (Fig. 6).

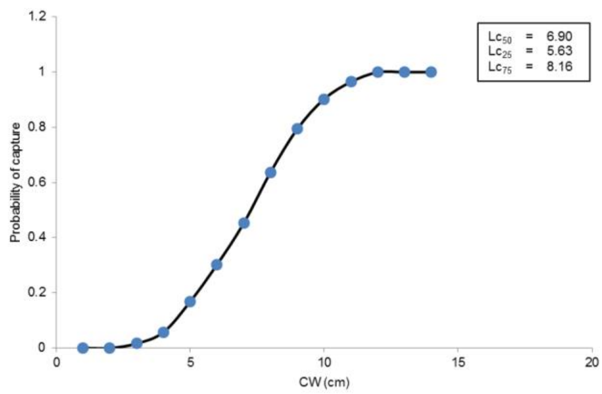

Figure 2: Lc of *P. pelagicus* by crab traps.

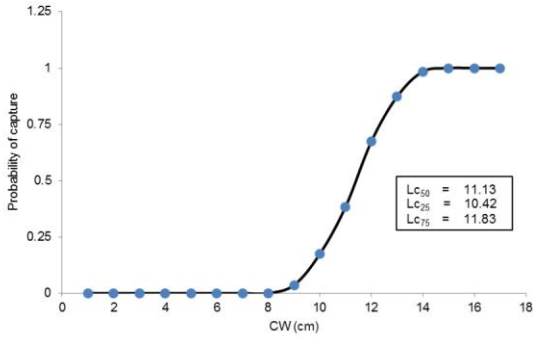

Figure 3: Lc of *P. pelagicus* by crab gill nets.

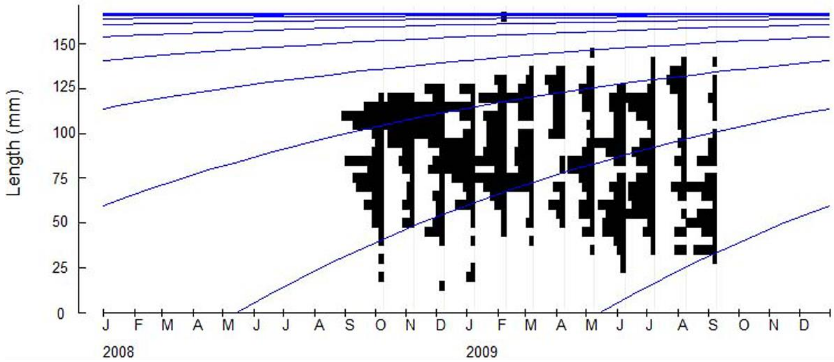

Figure 4: Size-frequency distribution of CW of *P. pelagicus* at Kung Krabaen Bay, Chanthaburi Province.

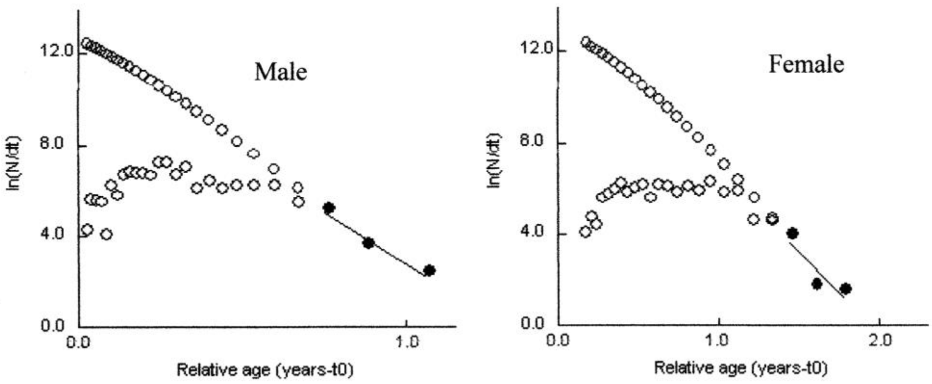

Figure 5: Length-converted catch curves of male and female *P. pelagicus* at Kung Krabaen Bay, Chanthaburi Province.

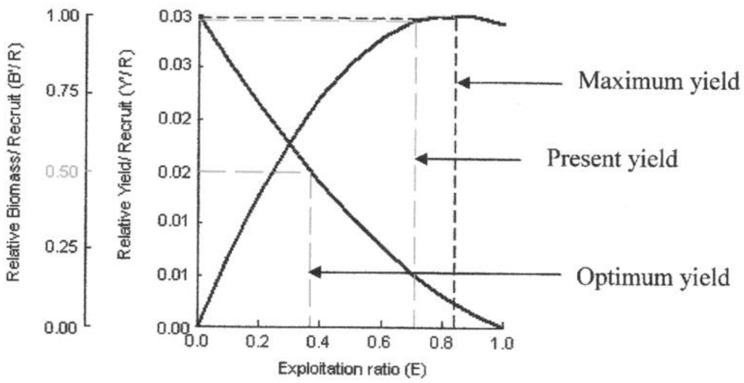

Figure 6: Exploitation rate of *P. pelagicus* at Kung Krabaen Bay, Chanthaburi Province.

Table 2: Estimated mortality parameters of *P. pelagicus* in Kung Krabaen Bay, Chanthaburi Province.

Crabs	Total mortality (Z)	Natural mortality (M)	Fishing mortality (F)
Total	5.83	1.69	4.14
Male	8.15	3.98	4.53
Female	6.95	2.07	4.88

Recruitment Pattern

Recruitment showed two prominent peaks during the years of the study. The first peak occurred between October 2008 and April 2009, and the second peak occurred between May 2009 and September 2009 (Fig. 7).

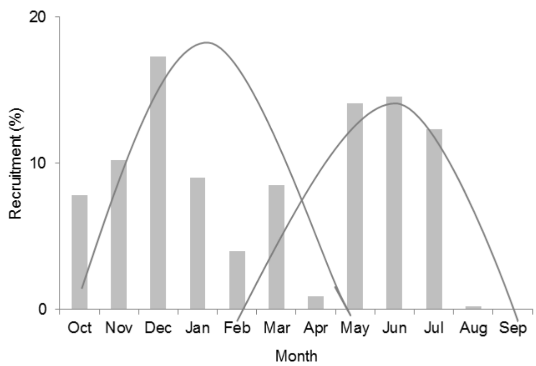

Figure 7: Recruitment pattern of *P. pelagicus* at Kung Krabaen Bay, Chanthaburi Province.

Sex Ratio

Monthly variation was observed in the sex ratio. The overall ratio of males to females was 1:0.92 (Table 3). Male crabs were captured more frequently than female crabs except in November 2008 and April, June and October 2009.

Table 3: Sex ratio of *P. pelagicus* at Kung Krabaen Bay, Chanthaburi Province from October 2008 to October 2009.

Month	Male	Female	Total	Expected	$\chi 2$	Ratio
Oct-08	46	31	77	39	1.47	1:0.67
Nov-08	38	46	84	42	0.38	1:1.21
Dec-08	52	51	103	52	0.01	1:0.98
Jan-09	58	42	100	50	1.28	1:0.72
Feb-09	52	45	97	49	0.00	1:0.87
Mar-09	56	30	86	43	0.37	1:0.54
Apr-09	13	28	41	21	0.81	1:2.15
May-09	29	29	58	29	0.14	1:1
Jun-09	35	45	80	40	0.02	1:1.29
Jul-09	46	38	84	42	0.15	1:0.83
Aug-09	28	20	48	24	0.57	1:0.71
Sep-09	35	27	62	31	2.1	1:0.77
Oct-09	15	33	48	24	1.11	1:2.2
Total	503	465	968	486	0.23	1:0.92

Length-weight Relationship

The relationship between OCW and W was $W = 0.0002CW^{2.9211}$ and $W = 0.0002CW^{2.8944}$ in male and female crabs, respectively (Fig. 8 and 9). The result showed that the W of the male crab was greater than that of a female crab with the same OCW. This result was consistent with prior findings by Sukumaran and Neelakantan (1997). The differences in growth rate between males and females resulted from the earlier age at first reproduction of the females. When a crab becomes sexually mature, growth often decreases (Hartnoll 1982) due to the significant amount of energy used for reproduction. The values of the regression coefficient b for males and females were both less than 3, indicating that crabs of both sexes exhibited allometric growth (t-test). The correlation coefficient r between CW and W for males and females was 0.961 and 0.9346, respectively. These results clearly indicated that the correlation between CW and W is strongly positive in this species.

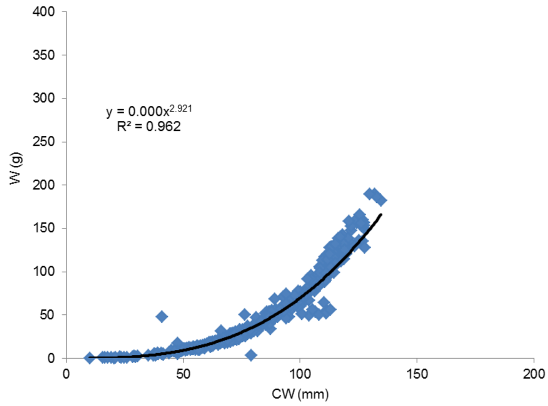

Figure 8: Relationship between CW and W of male *P. pelagicus* at Kung Krabaen Bay, Chanthaburi Province.

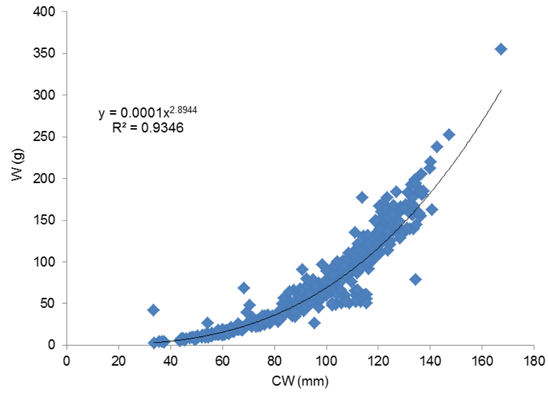

Figure 9: Relationship between CW and W of female *P. pelagicus* at Kung Krabaen Bay, Chanthaburi Province.

Seasonal Abundance and Distribution

P. pelagicus occurred throughout the period October 2008 – September 2009 in Kung Krabaen Bay. Males and females represented 51.96% and 48.04% of the total population, respectively. The crabs collected at the 27 sampling stations were primarily collected at stations KL (outside the bay), SG (inside the bay) and U (bay mouth). The highest crab abundance was recorded at stations KL and SG2 (deep within the bay). The abundance of the crabs differed significantly among stations ($p<0.05$) but not between seasons ($p>0.05$). However, the abundance of crabs in the dry season tended to be higher than that in the wet season. Thus, the peaks of the crab fishing season occurred from December to January and June to July. In the dry season, under the influence of the northeast monsoon, a high density of crabs was observed at Chao Lao Beach (zone KL3 and zone KL2, the most southerly station outside the bay) and at stations at the mouth of the bay without vegetation covering the substrate (zones U1 and U2). In the wet season, under the influence of the southwest monsoon, a high density of crabs was observed in beds of the seagrass *Halodule pinifolia* (zone SG22, SG23), at stations at the mouth of the bay without vegetation covering the substrate [zones U1 and U3 and Chao Lao Beach (zone KL3)] (Fig. 10).

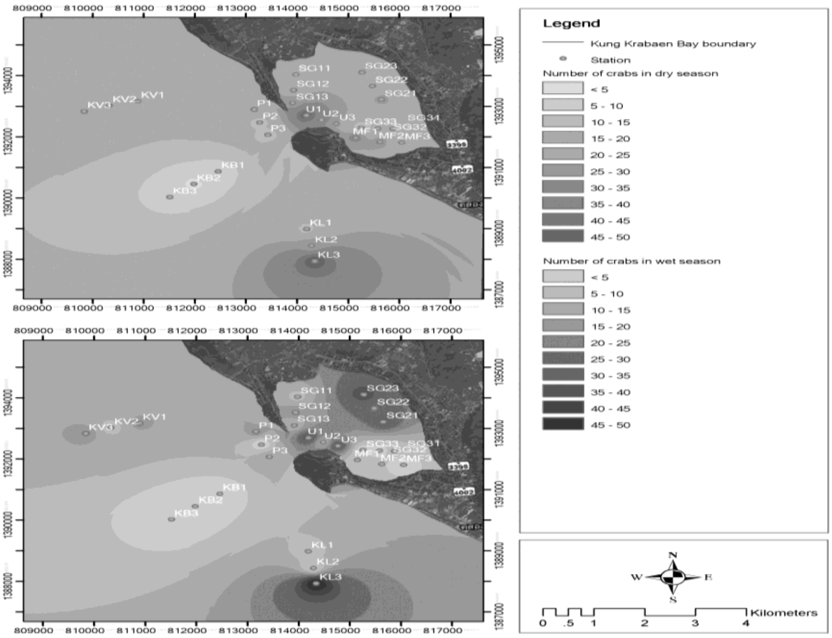

Figure 10: Seasonal distribution of *P. pelagicus* in dry and wet season at Kung Krabaen Bay, Chanthaburi Province.

An analysis of the relationship between crab abundance and ecological factors showed that salinity and temperature were the major ecological factors controlling the distribution of the crab (Pearson correlation, p<0.05). In the dry season, the average salinity was 32.21±0.89 PSU, the average temperature 29.5±1.72°C. In the wet season, the average salinity was 29.5±1.88 PSU, the average temperature 29.51±1.55°C due to the influence of the wet monsoon season with its high rainfall.

Reproductive Biology of *P. pelagicus* Gonad and ovarian development

Gonad and ovarian development were determined from 30 mature females with an average CW of 8.25 cm. The proportion of berried (externally egg-bearing) females and fecundity were also investigated. The ovaries of the crabs increased in size and showed colour changes during development. A morphological study of ovarian development in *P. pelagicus* detailed the 6 stages of development (modified from Svane & Hooper 2004) (Fig. 11):

Stage 1	Gonad immature, white and translucent;
Stage 2	Gonad maturing, light yellow, H-shaped eggs present, not extending into hepatic region;
Stage 3	Gonad maturing, dark yellow and extending into hepatic region;
Stage 4	Gonad matured, orange and extending into hepatic region;
Stage 5	Ovigerous, female bearing fully matured eggs (orange eggs) externally;
Stage 6	Ovigerous, female bearing fully matured eggs (black eggs) externally; the female will spawn within 24 hours.

The monthly proportions of each developmental stage are shown in Figure 12. It is clear that *P. pelagicus* are able to breed throughout the year, as ovigerous females were found in every month. The maximum abundance of berried females (45.71%) was recorded in March 2009 (Fig. 13).

Gonadosomatic index (GSI)

The monthly variation in the GSI in females is shown in Figure 14. The GSI values for the 369 specimens of *P. pelagicus* ranged from 0.54% to 6.3%. These results indicated that 3 peaks of active spawning occurred in *P. pelagicus*, in December, March and August.

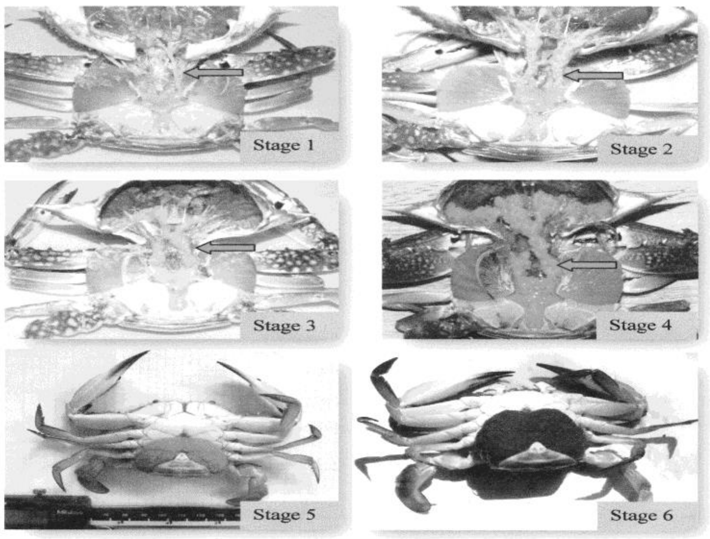

Figure 11: Stages of ovarian development of *P. pelagicus* at Kung Krabaen Bay, Chanthaburi Province.

Note: Stage 1: gonad immature; Stage 2: gonad maturing, light yellow; Stage 3: gonad maturing, dark yellow; Stage 4: gonad matured; Stage 5: ovigerous female (bearing orange eggs); Stage 6: ovigerous female (bearing black eggs)

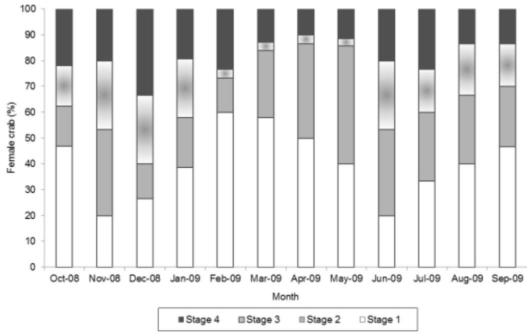

Figure 12: Seasonal changes in the proportion of four ovarian development stages of female *P. pelagicus* at Kung Krabaen Bay, Chanthaburi Province.
Note: Ovigerous females were studied only in Stages 1–4 by weighing the entire crab and the ovary

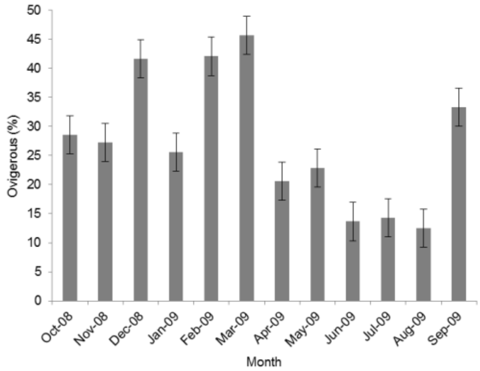

Figure 13: Proportions of ovigerous female *P. pelagicus* at Kung Krabaen Bay, Chanthaburi Province observed in collapsible crab traps and crab gill nets.

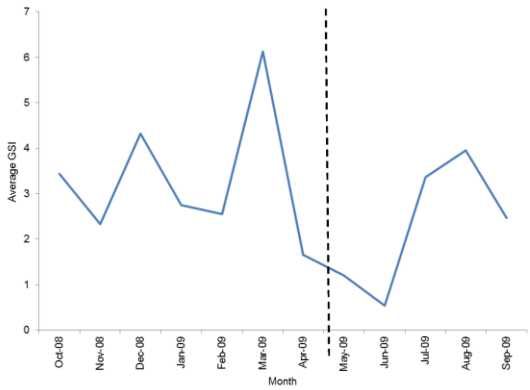

Figure 14: GSI in female *P. pelagicus* at Kung Krabaen Bay, Chanthaburi Province indicating 3 spawning periods: November-December, February-March and June-August.

Fecundity

The estimated fecundity for individual crabs varied from 0.148×10^6 to 1.448×10^6 eggs per batch from October 2008 to September 2009. The minimum fecundity was found in a berried female crab having a CW of 8.58 cm and a body weight (BW) of 62.06 g. The maximum fecundity was found in a berried female crab having a CW of 13.60 cm and a BW of 186.86 g. The average fecundity was $0.572 \times 10^6 \pm 0.261 \times 10^6$ eggs for a berried female crab with a mean CW of 11.88±11.57 mm and a BW of 129.46±27.19 g. The results showed two peaks of high fecundity, in December 2008 and June 2009. The fecundity results were correlated with the peaks of recruitment of crab larvae (Fig. 15).

First sexual maturity

Size at maturity is important in terms of stock reproductive strategy and output. A large size at maturity facilitates a high reproductive potential and is generally related to fecundity (Stearns 1992). It has been suggested that high fishing pressure may reduce the size at maturity (Pollock 1995; Stearns 1976). The size at which 50% of the female *P. pelagicus* were sexually mature was estimated to be 10.62 cm CW (Fig. 16). The results of the gonad study also indicated that the smallest mature female recorded was 5.82 cm CW and that the average size of matured females was 7.52±1.14 cm CW.

DISCUSSION

Scientific Findings from Stock Assessment and Reproductive Biology of *P. pelagicus* In Kung Krabaen Bay, Chanthaburi Province, Eastern Gulf of Thailand

Several indicators clearly indicated that the *P. pelagicus* population was in crisis. The fishing mortality and percentage of ovigerous females removed from the habitat showed increases compared with previous studies, a result of overharvesting. It is clear that increasing fishing mortality in the crab population often indicated a population decline. The exploitation rate, 0.71, greatly exceeded 0.38, the optimum rate. Moreover, according to Bhatrasataponkul *et al.* (2008) and Jindalikhit (2002), the average size and average fecundity decreased, with peak recruitment in December and June. The analysis of the relationship between crab abundance and ecological factors showed that salinity and temperature are suitable for growth and moulting during this period (Kangas 2000). The results of this study are also related to the findings of Romano and Zeng (2006), which indicated that salinity affects survival, growth and the osmolality of the haemolymph in early juvenile *P. pelagicus*. Furthermore, the results of that study demonstrated that a salinity range of 20–35 PSU is suitable for the culture of early juvenile *P. pelagicus*.

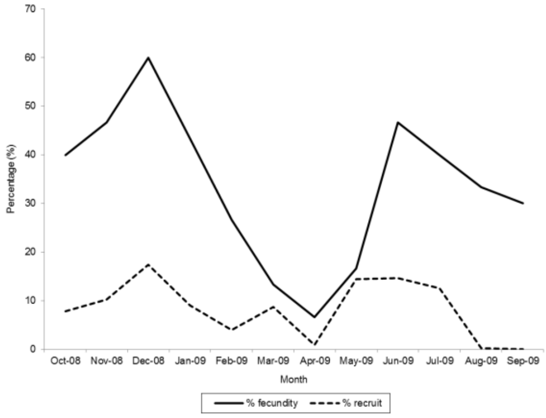

Figure 15: High-fecundity period of female *P. pelagicus* relative to larval recruitment at Kung Krabaen Bay, Chanthaburi Province.

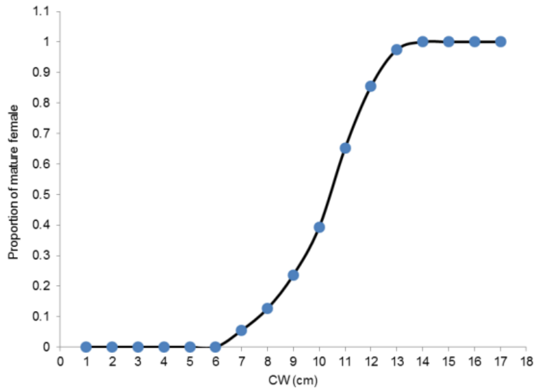

Figure 16: Logistic curve showing the proportion of mature *P. pelagicus* in each size category at Kung Krabaen Bay, Chanthaburi Province.

Key parameters, including fishing mortality, the percentage of ovigerous females, the exploitation rate, the average size and the average fecundity clearly indicated that *P. pelagicus* population in Kung Krabaen Bay was in crisis. The size of mature females decreased, and fecundity was also lower than the recruitment rate. As shown by several studies in many coastal areas, Thailand has been facing the same crisis involving the decline of larval and juvenile crab populations. This study clearly indicated the occurrence of the crisis, as ovigerous females are harvested during the spawning season (Raungprataungsuk 2009; Bhatrasataponkul *et al*. 2008). Apparently, the recruitment of juvenile crabs to the fishery will be low because recruitment is related to the amount of reproductive biomass (Zheng & Kruse 1999), the rate of density-dependent mortality (Lipcius & Van Engel 1990) and the rate of emigration (Pile *et al*. 1996). This study clearly indicated that the recruitment of larvae and juveniles was related to the fecundity and size at maturity of female crabs. Thus, restrictions on the catch of gravid females or berried females during the spawning season should be enforced by the management of the fishery. The results found for the measurement indicators are summarised in Table 4.

Table 4: Measurement indicators at Kung Krabaen Bay, Chanthaburi Province.

Indicators	Criteria indicating declining population
Fishing mortality	Increased (88.16%)
Exploitation rate	0.71 (optimum exploitation rate = 0.38)
Size of mature females	Decreased (6%)
Number of ovigerous females removed from population	Increased (lost 45.7% per year)
Average fecundity	Decreased (19.72%)

Sustainable Management of *P. pelagicus* in Kung Krabaen Bay

The information gathered by this study indicates that crab stock assessment in terms of biological indicators justifies the need for the sustainable management of *P. pelagicus* in Kung Krabaen Bay. Therefore, the study proposes some key mechanisms for the sustainable management of *P. pelagicus* based on key biological indicators (Table 5).

Table 5: Biological indicators and criteria for proposing sustainable management of *P. pelagicus* in Kung Krabaen Bay, The Gulf of Thailand.

No.	Biological indicators	Proposed criteria for sustainable management
1.	Fishing mortality (increased 88.16%)	a. Closing crabbing inside and outside the bay during spawning season
2.	Exploitation rate (0.71 > optimum = 0.38)	
3.	Size of mature females (decreased 6%)	b. Setting minimum mesh size of fishing gear at 6.35 cm
4.	Number of ovigerous females lost (45.7% annually)	c. Promoting active participation in a crab bank project to restock crab in the bay
5.	Average fecundity (decreased 19.72%)	d. Providing all biological knowledge to all stakeholders to facilitate the understanding the life history and migration of the crab population
6.	High density of crabs in seagrass beds	e. Establishing protection for zones covered with seagrass beds inside the bay and spawning grounds outside the bay
		f. Restoring seagrass beds as productive feeding and nursery grounds for *P. pelagicus*
		g. Promoting public participation or networking by relevant stakeholders in sustainable management of crab to create a sense of ownership of crab population

CONCLUSION

This study showed that *P. pelagicus* population in Kung Krabaen Bay is currently in crisis due to overharvesting. Apparently, the reproductive status of the crabs is directly affecting larval recruitment. Several biological indicators, such as fishing mortality and the percentage of ovigerous females removed from the habitat, have increased compared with previous studies. The exploitation rate was 0.71, far exceeding the optimal exploitation rate of 0.38. The size at first maturity, the size of mature females and the average fecundity have also decreased due to the overharvesting of adult crabs. This situation of population decline is comparable to that affecting the crab stocks at other coastal sites in Thailand and Southeast Asia. Accordingly, this study proposes the following measures for the sustainable management of *P. pelagicus*: (1) establish a closed season inside the bay during spawning season, (2) limit the mesh size of fishing gear, (3) restock crab larvae in the bay, (4) set up a protected seagrass bed zone inside the bay and a protected spawning ground outside the bay, and (5) promote networking with all stakeholders to facilitate a better understanding of the ecology of the crab to support sustainable fishery management in Kung Krabaen Bay. The study also suggests that the success of sustainable management depends on the acquisition of concrete scientific knowledge.

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