

Monsoon cycle influences on catch and size of blue swimming crabs (*Portunus pelagicus*) from crab gillnets in Phetchaburi Province

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ABSTRACT: *Portunus pelagicus* is a crucial resource of Thailand and a large portion of the catch comes from artisanal fisheries. The aims of this study were to elucidate fishing practices and identify the effects of driving factors on catch in terms of quantity and quality of *P. pelagicus* caught by crab gillnets in Phetchaburi Province. Samples were collected from January 2018 to February 2019. In both upper and lower areas of Phetchaburi Province, the lowest catch per unit effort (CPUE) was found in the northeast monsoon season, while the highest was found in the pre-monsoon. The results indicated an interaction between areas, seasons, and mesh sizes on log CPUE, and the log CPUE was generally lower in the northeast monsoon season in both areas and groups of mesh sizes. The size of *P. pelagicus* by carapace width ranged from 5.5 to 17.0 cm with the median \pm interquartile of 11.0 ± 1.0 cm. The crab size in the upper area was smaller than in the lower area in all seasons and the crab size in the southwest monsoon season was larger than in the other seasons for both areas. The median sizes were larger than the first maturity size of 9.5 cm in almost all the months, except October, in the upper area (median carapace width \pm interquartile = 9.0 ± 0.8 cm).

KEYWORDS: blue swimming crab, catch per unit effort, crab gillnet, Gulf of Thailand

INTRODUCTION

Many species of marine resources are highly or overly exploited and impacted by various environmental threats world wide [1]. Throughout history, marine resources were exploited by fisheries which can cause devastating effects on their population, some of which has become threaten, endangered or extinct [2]. The declining of marine catch from unsustainable fisheries not only reflects concerning situation of abundance of species, it also affects economy and food security [3]. In order to cope with the issue of overfishing, understanding local fisheries and their exploited populations are crucial for effective conservation and fisheries management [4].

Crabs are important resources globally, but many populations have been suffered from overfishing and illegal, unreported, and unregulated (IUU) fishing [5]. One of the widely distributed species, *Portunus pelagicus* found in the Indo-Pacific Region, is an important source of food and income in many

developing countries [6]. In Thailand, *P. pelagic* has been the highest wild caught species of crustacean for more than a decade; and the most production (76.5% in 2017) are from the Gulf of Thailand [7]. They have contributed for 90.5% of total crab production by artisanal fisheries and 86.8% of all crab caught by commercial scaled fisheries in the Gulf of Thailand in 2018 [8, 9].

Seasonal variation can have an impact on benthic community abundance and their fisheries [10]. *P. pelagicus* distribution in various regions has been found to be seasonally dynamic. Their migration is driven by food availability and reproduction, which relate to seasonal dynamics of temperature and salinity, and can affect fisheries on their quantity and quality of catch [11]. Weather conditions can also directly affect fisheries, as strong current and wind in monsoon seasons posing a threat to fisher safety, especially smaller vessels and, therefore, affecting catch in the seasons [12].

Demography of the same marine species can be diverse among locations due to the variation of

habitat conditions [13]. The difference life stages of *P. pelagicus* have varied habitat preferences due to their changes in diet as they become mature and, as a result, they move further offshore [14]. Areas with different depth and habitat substrates, which variate crab population, could provide catch differently for fisheries [15].

Artisanal or small-scale fisheries are important as a livelihood which provide food and income for coastal communities and the majority of fishermen in Thailand [16]. More than half of the total *P. pelagicus* catch are from this artisanal fisheries, estimated to be 50.4%, and the majority of the production (75.9% in 2018) are from the Gulf of Thailand caught by crab gillnets [8, 9]. Phetchaburi Province has been recorded to have the second highest number of crab gillnet fishing boats registered in the Inner Gulf of Thailand [17]. Despite their large number and contribution in production and potential impacts on *P. pelagicus* population, artisanal fisheries in Thailand have not been studied comprehensively. The investigation of catch variation by fishermen among areas and periods of time could be beneficial for implementing appropriate fisheries management.

Given the above data, the aims of this study were to elucidate fishing practices and identify key driving factors affecting catch of *P. pelagicus* in terms of quantity and quality. This would be useful for constructing an effective management for sustainability in production of crab gillnet fishery.

MATERIALS AND METHODS

Study areas

The study areas were classified as upper and lower areas of Phetchaburi Province (Fig. S1). The classification was based on rapid rural appraisal (RRA) on local fishing communities. From the RRA, the differences can be demonstrated as follows. Crab gillnets with larger mesh size (10–11 cm) were more commonly used in the lower area, while smaller mesh sizes (8–9 cm) were more preferred in the upper area. Fishermen in the lower area usually did not operate in the northeast monsoon season, unlike the upper area. Fishermen operated within their respective area and did not cross the area boundary. Samples were collected from 7 sampling sites at fishing ports. The upper area consisted of 3 sampling sites, one in each Sub-districts of Bang Kaeo, Laem Phak Bia, and Hat Chao Samran. The lower area consisted of 4 sampling sites, one each from Nong Khanan, Puek Tian, Bang Kao, and Cha-

am Sub-districts.

Sample collection

Samples were collected monthly from January 2018 to February 2019 covering three seasons. According to the Thai Meteorological Department and the information collected from RRA, two monsoon seasons can be identified, with a gap or pre-monsoon season in-between, in the local scale of Phetchaburi Province. The pre-monsoon season ranged from February to May when the weather was considered the mildest and allowed fishermen to operate most days of the months. The southwest monsoon season was from June to September, while the northeast monsoon season ranged from October to January, when the weather was the most volatile and prevented local fishermen, especially in the lower area, from operating in most days. Quantity of total catch from each sampled fisherman was documented when landed at fishing ports. In cases where fishermen did not classify and separate *P. pelagicus* from other catches, a quarter of total catch would be sampled by cluster sampling. Catch samples were identified by their species, and their size and weight were measured. Stratified random sampling was used in cases where *P. pelagicus* was separated from other catches and, then, sorted by size.

Biological characteristics of *P. pelagicus* samples were collected for size, weight, sex, and stage of external eggs. Size measurement was done using carapace width to the finest scale of 0.5 cm. Weight measurement was done in the scale of gram. Stages of external egg, if existed, were classified by colours, i.e. yellow, orange, brown, and black, in order of maturity.

The details of fishing gears and fishing practices of individual fishermen were collected by interviewing. These included type of fishing gears, number of gears used, size of gears, mesh size, vessel size and engine, distance of fishing areas from shore, operating depth, and time of operation. Crab gillnet mesh sizes were classified into two groups, 8–9 cm and 10–11 cm, which were found to be used by fishermen in the area.

Data analyses

Catch per unit effort (CPUE) was estimated from total weight of *P. pelagicus* divided by fishing effort, which was calculated by standard total crab gillnet length and number of operational days in the areas of study. The total crab gillnet length of each fisher was calculated by multiplying the length of their

gillnet with number of gillnets per pack and number of packs. The number of operational days was the period when crab gillnets were left to catch crabs and recovered. When the distribution of total crab gillnet length and the number of operational days were not normal, the use of median for the estimation of standard total crab gillnet length and standard number of operational days of all fishermen was applied. The medians of number of operational days were the same, at 2 days, across all areas and seasons. Therefore, the same standard number of operational days was used to calculate CPUE for all samples.

The total crab gillnet length was tested through non-parametric analyses to identify if there was a significant difference among areas or seasons, and to clarify if there was a need for utilizing different standard total crab gillnet length and number of operational days to derive CPUE. Mann-Whitney test was used to investigate the differences among upper and lower areas, while Kruskal-Wallis test was used for analysing the variation among seasons.

For the test of the effect of areas, seasons, and mesh sizes on CPUE, the estimated CPUE was transformed through logarithm to satisfy the assumption of homogeneity of variance. Five highest and five lowest values were excluded from the analysis to eliminate an outlier effect. Then ANAOVA was used to test the interaction and main effects of areas, seasons, and mesh sizes on log CPUE at the significant level of 0.05. In the lower area, northeast monsoon season only included samples in December and January for the analysis because there was no crab-gillnet fishermen operating in October and November when the sampling was conducted.

For the study of the effects, of areas, seasons and mesh sizes on *P. pelagicus* size, non-parametric tests were required for statistical analyses due to the size was unable to be transformed to meet assumptions of normality or homogeneity of variance. Wilcoxon signed-rank test was used to compare crab sizes in each month to first maturity size of 9.5 cm [18]. The difference of size among areas and mesh sizes was tested using Mann-Whitney test. The difference of size among seasons was tested by Kruskal-Wallis test with post hoc test of Dunn-Bonferroni's test. The significant level of all tests was 0.05. Samples from the lower area in northeast monsoon season only were those in December and January due to the lack of catch in October and November.

Table 1 Results of NOVA testing effects of areas, mesh sizes, and seasons on log CPUE of *P. pelagicus* caught by crab gillnet in Phetchaburi Province.

Source	SS	d.f.	F	p-value
Area	0.023	1	0.264	0.607
Mesh size	0.380	1	4.296*	0.039
Season	4.990	2	28.186*	<0.001
Area*Mesh size	0.371	1	4.193*	0.041
Area*Season	0.392	2	2.216	0.111
Mesh size*Season	0.664	2	3.751*	0.025
Area*Mesh size*Season	1.793	2	10.129*	<0.001
Residual	27.973	316		

* on *F*-value indicates a statistical significance at the significant level of 0.05.

RESULTS

From the survey along the coast of Phetchaburi Province, 374 catch samples from artisanal crab gillnets were found. Among them, 337 samples were for *P. pelagicus*. The number of fishermen who landed with *P. pelagicus* catch was varied among areas and times. The total number of catch samples in the upper area ($n = 209$) was higher than those in the lower area ($n = 128$). Consistent with the RRA, crab gillnets with 8–9 cm mesh size were more common in the upper area than in the lower area with the percentage of total samples of 68.5% and 55.2%, respectively. The median of depth where crab gillnets were placed was 6 m in both areas.

The landed catch components consisted mainly of *P. pelagicus* with the mean of 90.9% of total catch. The most common landed bycatch was benthic fish with the mean of 6.7% of total catch, followed by other crabs (0.7%), shrimps (0.6%), and pelagic fish (0.5%). All the other bycatches, including bivalves, gastropods, and cephalopods, were about 0.6%.

Catch per unit effort

There was no significant difference of total crab gillnet length among areas ($Z = -1.720$, p -value = 0.086), nor among seasons ($\chi^2 = 0.078$, p -value = 0.962). Therefore, the standard total crab gillnet length of 2880 m was used to calculate CPUE across all areas and seasons. For *P. pelagicus*, the CPUE varied from 0.004 to 0.43 kg/day/100 m. The overall mean of CPUE was 0.10 kg/day/100 m (Fig. 1). The highest mean CPUE in the upper area was found in April 2018, and the lowest was in December 2018. In the lower area, the highest mean CPUE was in March 2018, and the lowest was in December 2018. There was no catch in October and

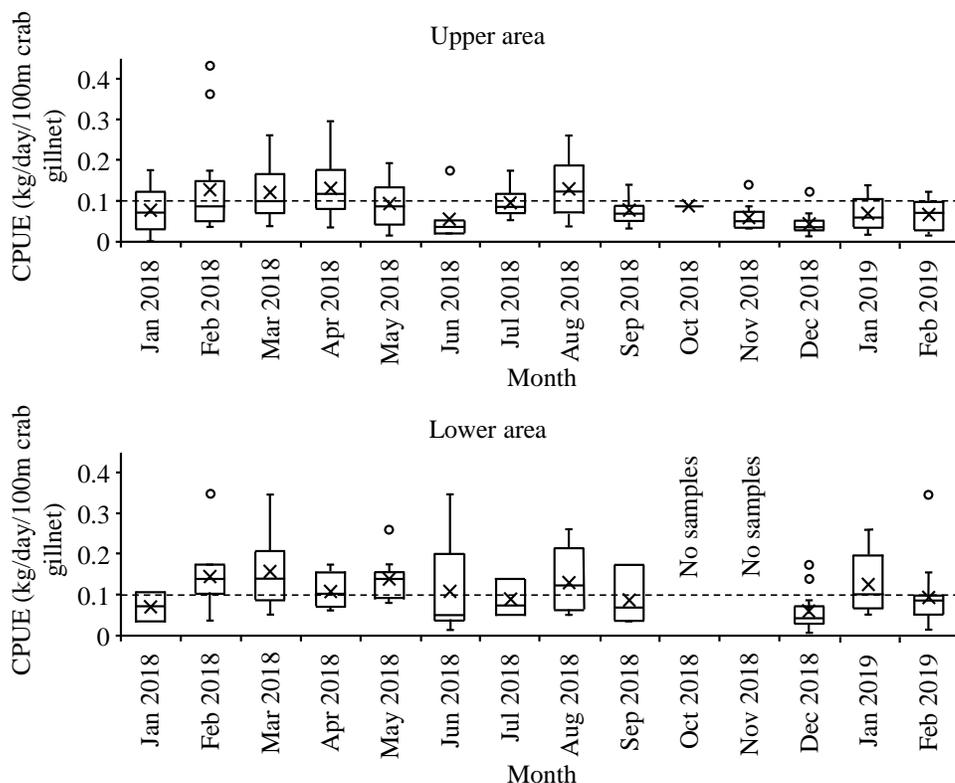


Fig. 1 Monthly catch per unit effort (CPUE) of *P. pelagicus* by crab gillnets in the upper and the lower areas of Phetchaburi Province from January 2018 to February 2019. Box plots represent the median (—) falling between upper and lower quartile (box limits); vertical lines represent extent of the data; circles (o) represent individual outliers; and crosses (×) represent means; dash lines represent overall mean at 0.1 kg/day/100 m. No samples were collected in the lower area in October and November 2018 due to no fishing operated.

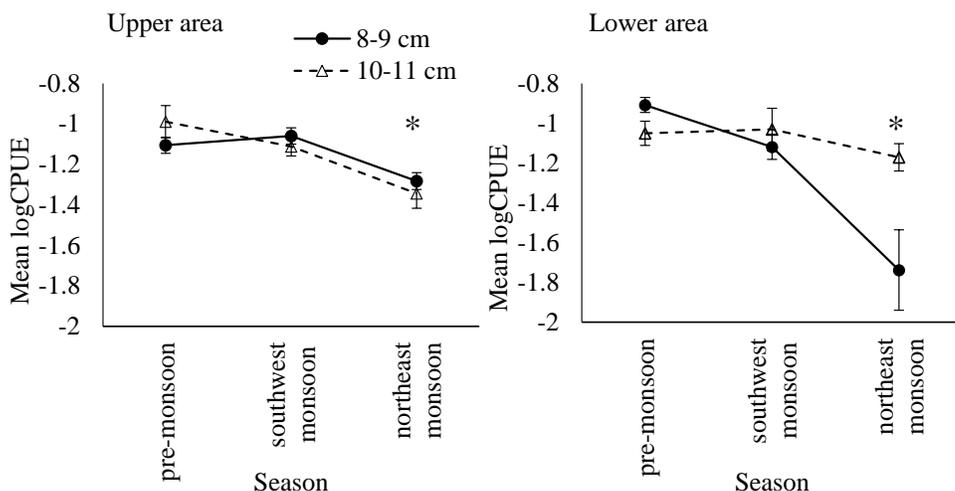


Fig. 2 Log CPUE of *P. pelagicus* caught by crab gillnets with the mesh size of 8–9 cm and 10–11 cm in the upper and lower areas of Phetchaburi Province in three seasons. The CPUE unit is kg/day/100 m. Stars (*) represent statistically significant interactions at the significant level of 0.05.

Table 2 Results of Wilcoxon sign-rank test of *P. pelagicus* carapace width comparing with first maturation size of 9.5 cm.

Month	n	Median (cm)	Z	p-value
January 2018	388	11.5 ± 0.75	15.791*	<0.001
February 2018	655	11 ± 0.75	18.241*	<0.001
March 2018	1256	10.5 ± 1.00	22.259*	<0.001
April 2018	502	10.5 ± 0.75	16.257*	<0.001
May 2018	683	11 ± 1.00	20.539*	<0.001
June 2018	350	12 ± 1.75	14.050*	<0.001
July 2018	358	12 ± 1.25	15.981*	<0.001
August 2018	790	11 ± 1.25	19.925*	<0.001
September 2018	700	12 ± 1.25	20.473*	<0.001
October 2018	142	9 ± 0.75	-2.020*	0.043
November 2018	415	10 ± 0.75	7.866*	<0.001
December 2018	672	11.5 ± 1.00	21.589*	<0.001
January 2019	411	11 ± 1.00	14.865*	<0.001
February 2019	770	11 ± 1.00	20.294*	<0.001

* on Z-value indicates a statistical significance at the significant level of 0.05.

November 2018 in the lower area as fishermen were unable to operate under severe weather of northeast monsoon in less sheltered area.

The ANOVA showed a significant interaction between areas, mesh sizes, and seasons (Table 1). The most noticeable result was that log CPUE from catch in the northeast monsoon season from both areas and groups of mesh sizes was lower than in the other seasons with the one from the lower area by 8–9 cm mesh size being the lowest (Fig. 2). The result from post hoc test confirmed that log CPUE in the northeast monsoon season was significantly lower than the other seasons, apart from the one from the lower area by mesh size of 10–11 cm. The log CPUE from the lower area by 8–9 cm mesh size in pre-monsoon season was significantly higher than all the others. The differentiation of log CPUE from other combinations of area, mesh size and season was not obvious.

Size

A total of 8092 *P. pelagicus* individuals were sampled with 58.34% male, 40.84% female, and 0.82% unidentified sex. Crab size was commonly larger than 9.5 cm from monthly survey except in October 2018 where it was significantly smaller (Table 2). Larger crabs were generally found in the southwest monsoon season. The proportion of crabs over 9 cm size class was higher in the lower area in every month excepts in October and November when there was no sample in the lower area for

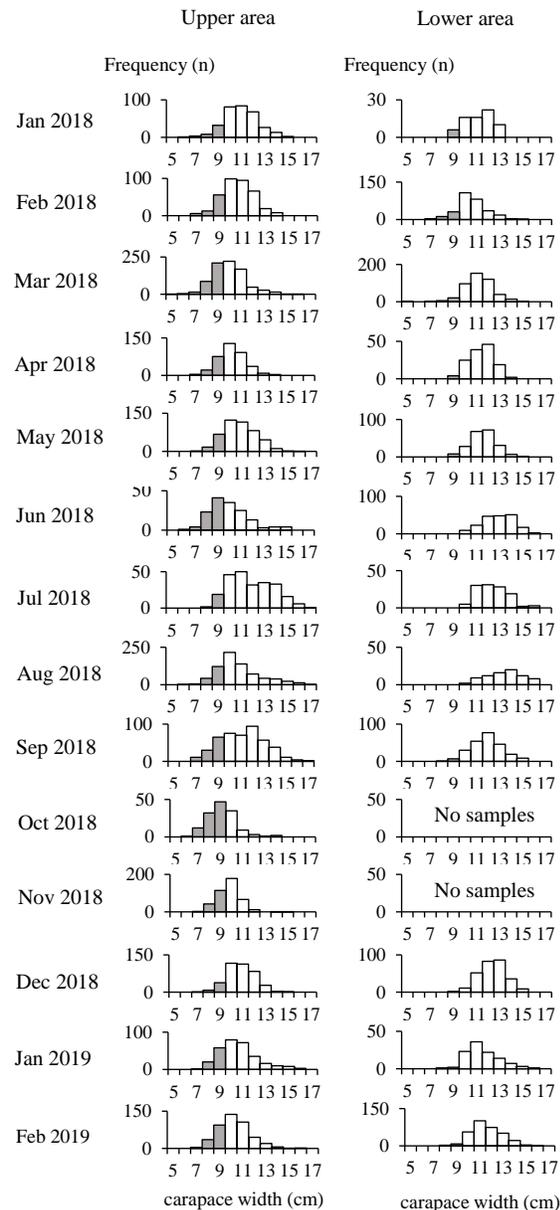


Fig. 3 Histogram plots of *P. pelagicus* sizes from the upper and lower areas of Phetchaburi Province from January 2018 to February 2019. Grey bars indicate the carapace width within the size class of 9 cm and smaller. White bars indicate size classes larger than 9 cm. No samples were collected in the lower area in October and November 2018 due to no fishing operated. Frequency scales are varied by months.

the comparison (Fig. 3). More than half of the upper area crabs in October were within 9 cm size class and under. Females with external eggs were

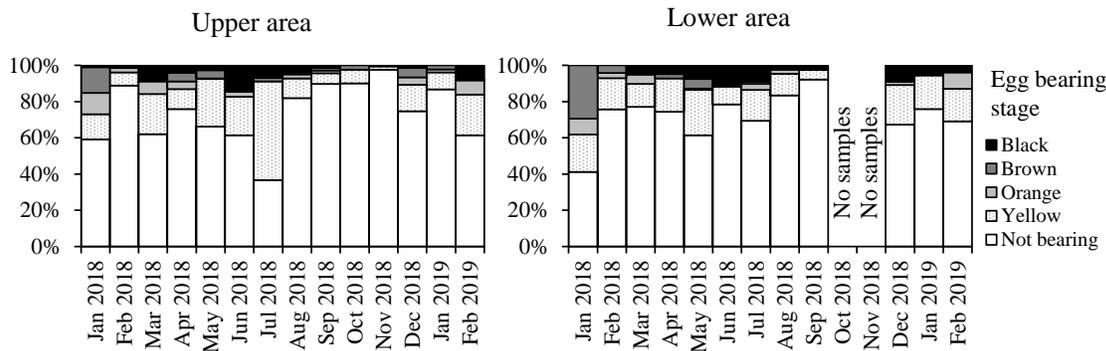


Fig. 4 Proportion of egg bearing crabs of female *P. pelagicus* from the upper and the lower areas of Phetchaburi Province sampled from January 2018 to February 2019. The maturity of external eggs was classified by egg colours into four stages.

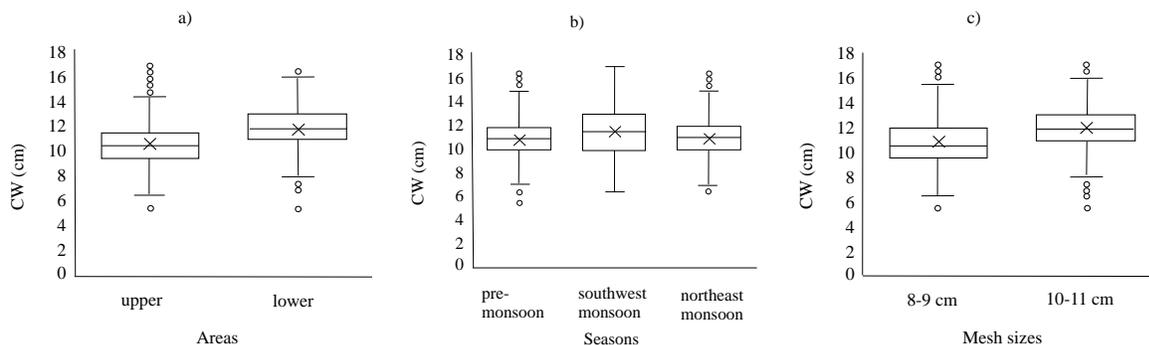


Fig. 5 Sizes of *P. pelagicus* caught by areas (a), seasons (b), and mesh sizes (c). Box plots represent the median (—) falling between upper and lower quartile (box limits); vertical lines represent extent of the data; circles (o) represent individual outliers; and crosses (x) represent means.

found in every month, but did not exceed 50% of all females except in July 2018 in the upper area and in January 2018 in the lower area (Fig. 4). This result indicated possible multiple reproductive peaks in the southwest and northeast monsoon seasons.

The size of crabs was significantly different among areas ($Z = -32.211$, p -value < 0.001), seasons ($\chi^2 = 221.584$, p -value < 0.001), and mesh sizes ($Z = -28.378$, p -value < 0.001). The crabs in the lower area, with the median of 12.0 ± 1.0 cm, were larger than those in the upper area (10.5 ± 1.0 cm) (Fig. 5). For the differences among seasons, the post hoc test showed that the size of crabs in the southwest monsoon season (11.5 ± 1.5 cm) was significantly larger than in the pre-monsoon season (11.00 ± 1.00 cm) ($Z = -14.485$, p -value < 0.001) and in the northeast monsoon season (11.00 ± 1.00 cm) ($Z = 10.871$, p -value < 0.001). The sizes of catch in the pre-monsoon and the northeast monsoon seasons were

not significantly different ($Z = -1.905$, p -value = 0.057). The size of crabs caught by crab gillnet with the mesh size of 10–11 cm (11.8 ± 1.0 cm) was larger than those from the 8–9 cm mesh size (10.5 ± 1.3 cm).

DISCUSSION

The overall size of *P. pelagicus* was larger than the first maturity size of 9.5 cm from a study in the Upper Gulf of Thailand [18]. When compared the size of *P. pelagicus* and the average CPUE in this study with the results in another study on crab gillnets in Phetchaburi Province in 2005, the size in this study was close to the 2005 result, which was 10.93 cm on average, and the average CPUE in this study was lower than half of the 2005, which was 0.21 kg/day/100 m crab gillnet [19]. This could be a sign of a decline in abundance of population, which is consistent with the drastically decline on the annual total catch of *P. pelagicus* in the Gulf

of Thailand during the past two decades [7]. The number of crab gillnet vessels in the area has also increased from 1281 in 2007 to 4792 in 2015 [17]. The increase in number of fishing vessels could introduce higher fishing effort, resulting in lower CPUE.

The size and catch variation between the upper and the lower areas could occur due to differences in local physical habitat conditions and nutrients. The upper area is located near the mouth of Mae Klong River, Bang-tabun River, and Phetchaburi River which discharge sediment to the coast and create a shallower seabed with higher composition of silt compared with the lower area [20]. Moreover, topography of the area shows a greater depth in the lower area than the upper area [21]. The depth and substrates could affect the abundance and the size of invertebrates in benthic community, including crabs and their sources of diet such as polychaetes residing in the area [22]. The higher concentration of nutrients from runoff discharge in the upper area could generate higher productivity and food abundance, which could be a suitable nursery ground for juvenile crabs [23]. *P. pelagicus* commonly move into deeper sea as they age [24]. In other parts of Thailand, they have been found to be larger in deeper areas of the sea due to their differences of feeding ecology in life stages, which makes larger crabs move to the deeper areas for their suitable diet [25].

Environmental conditions, such as nutrient concentration and changes from seasonal variation, were known to affect population of marine species including invertebrate via food availability [26]. In other areas within the Gulf of Thailand, the diet composition of *P. pelagicus* was different between seasons and consisted with teleost fish and crustaceans from the middle of pre-monsoon to the beginning of northeast monsoon seasons due to the higher abundance of preys [27]. The concentration of nitrogen and phosphorus in the area during the southwest monsoon season was observed to be higher than in other seasons, which could result in higher productivity and food availability for crab growth. Larger *P. pelagicus* in Phetchaburi Province could be foraging in the greater depth for their preferable diet in the seasons when the abundance of food in the shallow area was scarce and moved closer to the coast in the late pre-monsoon season where nutrient and productivity started to increase [28].

Portunus spp. commonly breed all year round in tropical environment with seasonal peaks [29]. This

is consistent with the finding in this study where females bearing external eggs were found all year with higher numbers in some months. *P. pelagicus* was found to move offshore to their spawning grounds in many areas including other parts of the Gulf of Thailand [30]. The salinity in the area of Phetchaburi Province, especially in the upper area located closer to Phetchaburi, Bang-tabun, and Mae Klong Rivers, was found to decrease by the effect of runoff in the late southwest monsoon season [31]. This could cause adult *P. pelagicus* to migrate offshore to their spawning ground until they relocated back closer to the coast in the pre-monsoon season where salinity and temperature increased to a preferable condition [28]. The movement into the deeper area, further from the coast, could raise difficulty for harvesting especially for artisanal fisheries with their limitation to pursue the crabs [32]. This could explain the lower CPUE in the late southwest and the northeast monsoon seasons. However, *P. pelagicus* spawning movements cannot be concluded by this study as samples were obtained from artisanal fishing with limitation in accessibility to deeper part of the sea.

Other than the obstacle of going further to catch crabs in their spawning area in the spawning season, the northeast monsoon season could also pose a threat to safety of fishermen and their fishing gears [33]. Harsh weather condition and entanglement with other fishing gears in the area could result in damages or losses of gillnets [34]. However, the effect of seasonal changes varied among places [35]. In this case, fishermen in the upper area did not need to apply as much caution with the weather compared with the lower area due to the less severe effects of the monsoon in their natural bay structure. This clearly reflected in the number of fishermen found operating in October and November in the upper area, while there was none encountered in the lower area [36]. The CPUE in this period of the year was lower than the overall average value, which could be due to the absence of larger crabs in the accessible fishing grounds. The movement of spawning crabs could also be responsible for the smaller size of catch in the northeast monsoon season where it was still viable, resulting in more than half of crabs caught in the upper area in October being smaller than the first maturity size of 9.5 cm from a study in the nearby area [18].

Smaller mesh sizes generally have higher selectivity for smaller individuals [37]. In this study, the smaller mesh sizes were more dominant in the upper area, because they allowed fishermen to catch

smaller crabs and gain similar CPUE to the lower area. The size selectivity of fishing gears should be considered for the benefit in both biological and socioeconomic aspects [38]. The appropriate size of catch should be considered along with the first maturity size of *P. pelagicus*, which could be varied among locations [39]. In the nearby area of the Upper Gulf of Thailand, maturity size was estimated at 9.5 cm [18], while it was 7.5 cm in the Eastern Gulf of Thailand in Chanthaburi Province [40]. In this study, the majority of crabs caught by both groups of mesh size were larger than the aforementioned first maturity sizes. On economic aspect, the larger mesh size provides larger crabs, which are more valuable and could potentially provide fishermen with more income while having no drastic decline in total CPUE [41].

CONCLUSION

In conclusion, quantity of catch and crab size can be varied by habitat conditions, seasons, and mesh sizes. The main driving factor effecting CPUE and size of *P. pelagicus* was seasonality because it could majorly affect the ecosystem surrounding crabs and their behaviours. As there is no robust information of population dynamics and fishing impacts in the area, fishery management should be proceeded cautiously. The maturity size of *P. pelagicus* in the area of Phetchaburi Province should be investigated to verify if the common size of crabs caught using crab gillnets is sustainable. Then, minimum crab size should be established in the regulation accordingly to ensure a reproduction opportunity before being caught. This measure could particularly work well with this type of fishing as crabs would normally be alive after taking out from the gillnet, making it possible to release the undersized individuals back to the water and discard issues is also mitigated. Moreover, a possibility of setting up a nursery ground in the upper area of Phetchaburi Province where smaller crabs were more common should be investigated. During the northeast monsoon season, especially in October, a seasonal closure in the upper area should be considered with the reason that the majority of crabs caught in this period were smaller than 9.5 cm with low CPUE. Moreover, the spawning season along with the spawning grounds should be validated for a precise implementation of seasonal and area closures. This will minimize the impact of regulation on fishermen while still allow crabs to reproduce without disturbances and provide higher recruitment to ensure a sustainable production.

Appendix A. Supplementary data

Supplementary data associated with this article can be found at <http://dx.doi.org/10.2306/scienceasia1513-1874.2021.060>.

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Appendix A. Supplementary data

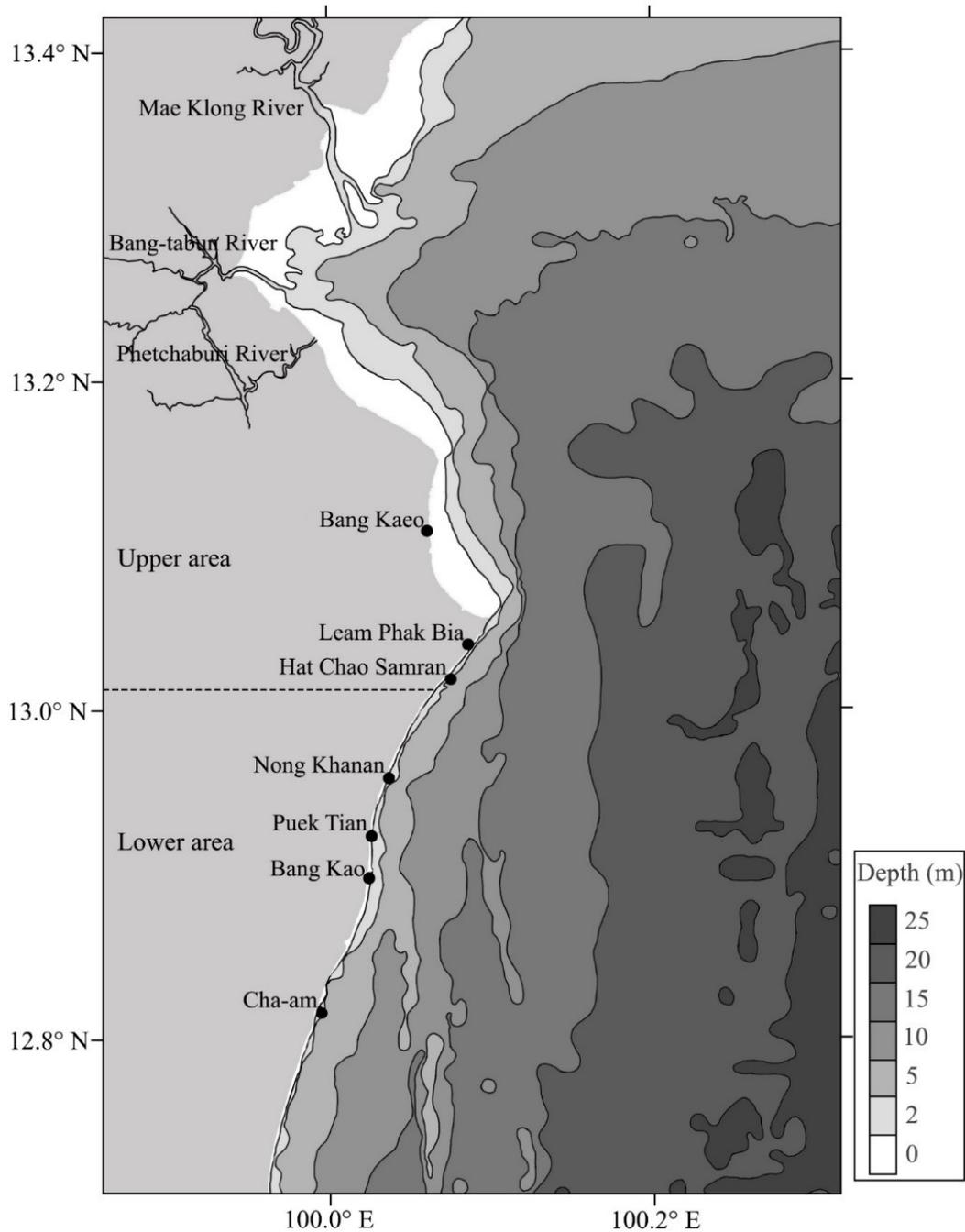


Fig. S1 The coastline of Phetchaburi Province in the Inner Gulf of Thailand showing the seven sampling sites along the coast in the upper and the lower areas. Major rivers close to the area are presented. The contour of sea depth is also provided in the map.