Type	Thesis or Dissertation
Title	Behavior of blue swimming crab for improving catch selectivity and efficiency of collapsible pot in Thailand
Author(s)	Boutson, Anukorn
Citation	
Date	2008
URL	http://oacis.lib.kaiyodai.ac.jp/dspace/handle/123456789/845
Rights	

BEHAVIOR OF BLUE SWIMMING CRAB FOR IMPROVING CATCH SELECTIVITY AND EFFICIENCY OF COLLAPSIBLE POT IN THAILAND

September 2008

Graduate School of Marine Science and Technology
Tokyo University of Marine Science and Technology
The Doctoral Course of Applied Marine Biosciences

ANUKORN BOUTSON

BEHAVIOR OF BLUE SWIMMING CRAB
FOR IMPROVING CATCH SELECTIVIY AND
EFFICIENCY OF COLLAPSBILE POT IN THAILAND

Contents

Page

List of Figures……………………………………………………………………………. III

List of Tables…………………………………………………………………………... VII

Abstract……………………………………………………………….….……………. IX

Chapter 1: Introduction………………………………………………………………. 1

1.1 Introduction to blue swimming crab pot fishery in the Gulf of Thailand………... 1

1.2 Fishing gear selectivity…………………………………………………………... 2

1.3 Ghost fishing……………………………………………………………………….. 4

Chapter 2: The analysis of; pot operation, catch, bycatch, discard, and soak time……………………………………………………………….. 5

2.1 Introduction……………………………………………………………………..... 5

2.2 Materials and methods……………………………………………………………… 7

2.3 Results………………………………………………………………………………. 8

2.4 Discussion…………………………………………………………………………... 16

Chapter 3: Use of escape vents to improve size and species selectivity of collapsible pot for blue swimming crab, *Portunus pelagicus* in Thailand…………………………………………………………….. 19

3.1 Introduction………………………………………………………………………… 19

3.2 Materials and methods…………………………………………………………... 21

3.3 Results………………………………………………………………………… 27

3.4 Discussion……………………………………………………………………….. 35

Chapter 4: Study on blue swimming crab behavior for understanding the capture process, and comparison of slope net mesh size for improving the pot catching efficiency……………………………….. 39

4.1 Introduction……………………………………………………………………... 39

4.2 Materials and methods…………………………………………………….. 41

4.3 Results……………………………………………………………………………... 43

4.4 Discussion………………………………………………………..……... 46

Chapter 5: Comparative fishing trials between conventional and modified pots 49

5.1 Introduction……………………………………………………………………… 49

5.2 Materials and methods………………………………………….………………….. 50

5.3 Results……………………………………………………………………………. 53

5.4 Discussion………………………………………………………………………… 60

Chapter 6: Simulated ghost fishing experiment for collapsible crab pot in Thailand………………………………………………………………… 63

6.1 Introduction……………………………………………………………………. 63

6.2 Materials and methods………………………………………………………… 66

6.3 Results……………………………………………………………………………. 69

6.4 Discussion………………………………………………………………………... 79

References…………………………………………………...………………………… 85

Acknowledgements………………………….……………………………………… 101

List of Figures

Page

Fig. 1.1 Blue swimming crab (a), and collapsible crab pot with the size of 36×54×19 cm (b)………………………………………………………………………... 1

Fig. 1.2 Blue swimming crab pot boats in Thailand; small scale (a), 250-350 pots, and commercial scale (b), 1,500-5,000 pots onboard)………………………. 2

Fig. 2.1 The location of study area (⬚ = small scale fishing ground, ◌ = commercial scale fishing ground)……………………………………….……..……. 8

Fig. 2.2 Blue swimming crab size from the small and commercial scale crab pot (n = 400 each)……………………………………………………………….. 14

Fig. 2.3 Pattern of the crab CPUE (crab/pot) according to the soak time of commercial scale pot on 8 Jan 2006 when the hauling started from the last deployed pot (No. of pot = 2,013, CPUE = 0.32)………………………………………... 15

Fig. 2.4 Pattern of the crab CPUE (crab/pot) according to the soak time of commercial scale pot on 5 May 2006 when the hauling started from the first deployed pot (No. of pot = 2,120, CPUE = 0.27)…………………………………………… 16

Fig. 3.1 Collapsible crab pot; box shaped with the size of 36×54×19 cm…………….. 19

Fig. 3.2 Location map of study area (■)……………………………………………… 22

Fig. 3.3 Four different shapes of escape vent (a), located at bottom sides of the lower slope panel (b), to observe the escape behavior of blue swimming crabs from the pot……………………………………………………………….….. 23

Fig. 3.4 Square-shape escape vents were located at 5 pairs of different positions; lower slope panel of corner (1) and center (2), of side panel upper (3) and bottom (4), and of top panel corner (5) to observe the escape behavior of the crabs from the same pot for the vent position experiment……………….. 24

Fig. 3.5 Escape vents (35×45 mm) were located at both sides of the bottom at the side panel for the field fishing trials……………………………………….. 26

Fig. 3.6 The configuration of a deployed pot, individually set and connected with rope to the buoy………………………………………………………………. 26

Fig. 3.7 Frequency of escape through the square vent (a) for shape experiment, and lower side panel vent (b) for vent position experiment………….…………… 28

Fig. 3.8 (a) Size selectivity for blue swimming crab according to escape vent length when vent height was fixed at 35 mm, (b) master curve for crab size (CL) according to vent length (VL)…………………………………….……….. 31

Fig. 3.9 Blue swimming crab size sampled with conventional pots (open columns) and vented pots (shaded columns)……………………………………….…… 32

Fig. 3.10 Size selectivity of 35×45 mm escape vent for blue swimming crab from the field trials with $L_{50\%}$ = 46.9 mm, a = -25.9403, b = 0.5528, and SR = 4.0 mm, in comparison with the result from the laboratory observation………..….…... 35

Fig. 4.1 The shape and bar of diamond mesh (38, 25 and 18 mm) after modified to be square (bar length is a half of mesh size)……………………………………… 42

Fig. 4.2 Slope net length and angle of the pot (a), the pot after was removed the upper net panel (b)………………………………………..………………….. 42

Fig. 4.3 Crawling patterns of the crabs on slope net mesh size of 38 mm (n = 8)….…. 44

Fig. 4.4 Crawling patterns of the crabs on slope net mesh size of 25 mm (n = 8)….…. 44

Fig. 4.5 Crawling patterns of the crabs on slope net mesh size of 18 mm (n = 6)….…. 44

Fig. 4.6 Time spent on the slope net until trapped according to the different mesh size... 45

Fig. 4.7 Crawling pattern of the crabs in case of returning back (un-trapped) (3 crabs returned back on 38 mm, and 1 crab on 18 mm mesh size)………..………….. 45

Fig. 4.8 Average crawling speed on the tank floor (n = 10) and average maximum crawling speed on slope net mesh size of 38 (n = 8), 25 (n = 8), and 18 (n = 6) mm…………………………………………….……………………… 46

Fig. 5.1 Location map of study area (Bang-Pra Beach, Chonburi Province)……….… 51

Fig. 5.2 The vents were cut the mesh size and bound with polyethylene twine at the Both side of bottom side panel of the pot for comparative fishing trials [a = Vent of 1×2 mesh (19×38 mm), b = vent of 1×3 mesh (19×56 mm)]………… 51

Fig. 5.3 Escape vents were located at both sides of the bottom of the side panel for the comparative fishing trials……………………….………………….…... 52

Fig. 5.4 The configuration of a deployed pot, individually set and connected with rope to the buoy………………………………………………………………… 52

Fig. 5.5 Location map of study area (northwest of Si Chang Island, Chonburi Province)………………………………………………………………….. 53

Fig. 5.6 Blue swimming crab size from different pots comparative fishing trials (catch pooled on 19-20 Jan 2008)... 56

Fig. 5.7 Blue swimming crab size from the comparative fishing trials (catch pooled on 6, 8 May 2008)………………………………………………………….… 58

Fig. 5.8 Number of some catch species from conventional and vented pots……….... 59

Fig. 5.9 Number of some catch species from conventional and smaller mesh size at slope net pots…………………………………………………………….… 59

Fig. 6.1 Collapsible pot with the size of 36×54×19 cm (a), and blue swimming crab *Portunus pelagicus* (b)…………………….……………………………….… 65

Fig. 6.2 (a) Study site (■) where the simulated pots were set the deployment, and (b) positions of each pot; No. 1, 3, 5, 7, 10 and 12 set under the edge rafts; No. 2, 6, 8 and 11 set between the rafts, and No. 4 and 9 set beside the huts... 66

Fig. 6.3 CPUE of entrapped animals according to the days (seasons were categorized) after pots deployment…………………………..…………….. 70

Fig. 6.4 CPUE of top ten entire species according to the days after pots deployment… 77

Fig. 6.5 Relationship between mortality rate and the days after initial entrapped (analyzed from the day 1 catches); $y = 0.3133\text{Ln}(x) - 0.2775$, $R^2 = 0.98$…..… 78

Fig. 6.6 Pot conditions and some phenomena after deployment since day 1 until 1 yr approximately, (a) pot and bait by day 1, (b) toadfish and ridged swimming crab inside the pot by day 14, (c) alive wrasse pushed through the mesh to escape out, (d) pot and red soldier fish by day 135 which the CPUE reached the maximum, (e) pot and filefish inside by day 231, and (e) pot with fouling organisms by day 369………………………………………………… 78

List of Tables

Page

Table 2.1 Comparison of crab pot boats and their operations in the upper Gulf of Thailand………………………………………………………………….….….. 9

Table 2.2 Catch composition (by number) from a small scale boat operations (inshore fishing ground)……..………………………………….…..….. 10

Table 2.3 Catch composition (by number) from commercial crab pot boat operations (offshore fishing ground)…………………………..……….…………… 11

Table 2.4 CPUE and discard from small scale (D = Discard No., R = Retention No.)... 13

Table 2.5 CPUE and discard analysis from commercial scale operations…….……... 14

Table 3.1 Frequency comparison of the crabs that escaped through the different shapes of escape vent………………………………………….………………. 27

Table 3.2 Frequency comparison of the crabs that escaped through the different positions of square vent………………….……………………………………. 28

Table 3.3 Size comparison of blue swimming crab catch between conventional and vented pots on 4 and 5 May 2005……………………………..……………. 32

Table 3.4 Catch composition between conventional and vented pots, from the 2 comparative fishing trials……………………………………………….. 34

Table 5.1 The catch according to 4 different types of pot from 2 comparative fishing trails (pooled catch on 19, 20 Jan 2008, n = 30 pots/each)……………….….. 55

Table 5.2 The catch number from comparative fishing trials (pooled catch on 6 and 8 May 2008, n = 90 pots/day/each type)…………………………………… 57

Table 6.1 Newly entire animals of simulated pots at various time intervals from day 1 (26 April 2006) until day 369 after initial deployment (number of pots reduced from 12 to 7 by lost, then further to 5 by damaged), mean catch/pot/year calculated from sum of the total new entry divided by the number of available pots at each interval monitoring………………… 71

Table 6.2 The escape and mortality analysis of the catches by day 1 (27 Apr) after the days passed (examined from the monitoring by day 1, 3, 7, 13, 21 and 34 after initial entrapped)……………………………………………….. 75

Table 6.3 Mortality estimations (per pot/month) of newly catches at various time monitoring intervals based on the derived equation………………………. 76

Abstract

Behavior of blue swimming crab for improving catch selectivity and efficiency of collapsible pot in Thailand

Blue swimming crab *Portunus pelagicus* is an important commercial species both for domestic and export markets in Thailand. Collapsible pot has recently become a major type of fishing gear in the Gulf of Thailand with the increased awareness of the immature sized crab catch. Other finfish and shellfish species are also captured as bycatch which is associated with discard problem. This study aimed to mitigate the impact of the crab pot fishery.

The analysis of; pot operation, catches, bycatch, discard, and soak time

Field surveys were conducted by on-boarding the operations both for small- and commercial-scale boats in the upper Gulf of Thailand in 2006. The small-scale operates inshore (0.5-3.0 km) by one man operation, with individual pot setting of number of 200-350 pots/boat. The commercial-scale operates offshore (>3km) by 5-8 crews with the equipment of hauler machine onboard, with long-line type setting of 1,500-5,000 pots/boat. The catch data collected from both types of fishing were analyzed in order to understand the CPUE, catch size/species composition, bycatch and discard by number. Catch performances of both types were also compared from the view point of operation strategies as fishing ground, operation method, soaking time, etc. Average CPUE for the small-scale operations was 2.81 crabs/pot, which was much higher than the commercial-scale of 0.26 crabs/pot. The composition of blue swimming crab for small-scale accounted for 66-92 % while 39-51% for commercial-scale of the total catch. The average discard ratio for small- and commercial-scale operations were 0.30 and 0.50, whereas the average discard rate were 0.22 and 0.30, respectively. The crab size caught for small-scale was much smaller than commercial scale. The bycatch for commercial-scale consisted of 19-21 species/operation. This was much higher compared with the bycatch for small-scale operation which consisted of 8-10 species/operation. The results showed that the bycatch for both types of operation require the mitigation measures for size and species selectivity improvement.

Use of escape vents to improve size and species selectivity of collapsible pot for blue swimming crab in Thailand

Laboratory experiments were conducted for examining the modification possibility of the collapsible pot for the blue swimming crab by designing appropriate escape vents for shape, position and size to improve the size selectivity by reducing the catch of immature crabs. In laboratory observations, the nearly-square shaped vents of 35 mm height and 45 mm length, located at the lower part of the side panel, showed the best performance to allow

the escape of immature size crabs, by the side-crawling escape behavior through the vents, with the selection carapace length ($L_{50\%}$) as 39.1, 44.4 and 48.7 mm CL for 40, 45 and 50 mm vent length, respectively. Comparative fishing trials between conventional and vented pots with vents of 35×45 mm were conducted to examine the crab size and species selectivity. Use of the vented pots were found to reduce the number of immature crabs in the catch from 70.5% to 11.0% in average, while not affecting the catch efficiency of mature size crabs. The vented pots also showed a selective function for reducing the bycatch species in the comparative fishing trials. Some bycatch from the vented pot were reduced when compared with the conventional pot particularly for the bycatch of other species.

Study on blue swimming crab behavior for understanding the capture process, and comparison of slope net mesh size for improving the pot catching efficiency

For a better understanding of the pot capture process for the blue swimming crab, behavior pattern of the crabs how they were entrapped through the entrance slope net with different mesh sizes was observed with a video camera in an experimental tank. The catching efficiency of the pot with smaller mesh sizes of 18 and 25 mm on slope net was compared with the conventional pot with a mesh size of 38 mm. The crabs (N=12) for the size range of 35.0-45.0 mm carapace length were used for the laboratory experiment. The time taken for the crabs to be entrapped from the first touch at the slope net tended to be reduced as the mesh size became smaller. Crawling patterns on the slope net with smaller mesh size were more likely to be straight forward than the conventional one. Three individuals gave up their attempts to enter the pot trough the slope net mesh size of 38 mm, while no individual gave up for 25 mm, and a single individual gave up for 18 mm. The capture process consisted of 4 stages; bait detection, approach, entry, and escape. The crabs passed through the slope net by crawling, and never returned back if they could reach the ending edge of the slope net. After being entrapped in pot, they fed, and then mostly crawled around the bottom panel and attempted to escape. They sometimes showed territorial behavior for keeping their own space in the pot.

Comparative fishing trials between conventional and modified pots

Comparative fishing trials using 4 different types of pot; conventional, smaller mesh size (25 mm) at the slope net, smaller mesh size at the slope net with vents (19×38 and 19×57 mm), were tested in the fishing ground of small scale pot fishery, 0.5-1.0 km from shore, 4-6 m depth, in the Gulf of Thailand on 19-20 Jan 2008. The vents were made by cutting the meshes at bottom side panel and strengthening the vent edges by binding with polyethylene twine. Thirty pots of each type were used, deployed individually, intervals of 20-30 m, with 13-15 hrs soaking time. Compared with the conventional pot; the smaller mesh size at slope net pots showed the positive results to increase the catch number of blue swimming crab, however including the immature size crab and some bycatch species particularly the crabs, such as smoothshelled swimming crab *Charybdis affinis*, square-shelled crab *Galene bispinosa* were also increased. The smaller mesh size at slope net for vented pots could reduce the number of bycatch while maintained the catch of blue swimming crab, particularly for 19×57 mm vents with the high retention of larger size of crabs.

Simulated ghost fishing experiment for collapsible crab pot in Thailand

The collapsible pots can be accidentally lost at sea, and continue to catch target and non-target species. The ghost fishing study was conducted by quantified number of entrapped animals and estimating the mortality through the simulated experiment. Twelve collapsible pots were set individually on seabed at 4-6 m depths, approximately 0.8 km from coastline of Sriracha Fisheries Research Station, Thailand. Ghost fishing effects were monitored by scuba diving to observe the bait, pot conditions, species, and numbers of entrapped animals for one year from April 2006. The bait originally placed in the pots was consumed within 3 days after deployment. Toad fish *Batrachus grunniens*, black sea urchin *Diadema setosum*, and ridged swimming crab *Charybdis natator* were dominant catch species throughout the monitored period. CPUE of entrapped animals increased as days elapsed and reached the maximum by 135 days after deployment, then decreased as time passed. The simulated pots caught of 7.1 individuals of toad fish, 5.6 sea urchins and 5.5 ridged swimming crabs/pot/year. Other 19 species were also entrapped such as spiral melongena, filefish, catfish, etc. Total number of killed animals was calculated as 20.1 individuals/pot/year. Five pots continued to catch in the second year, which indicated that they have potential to keep the capture function for extended periods until losing the function due to accumulation of bio-fouling at the pot entrances.

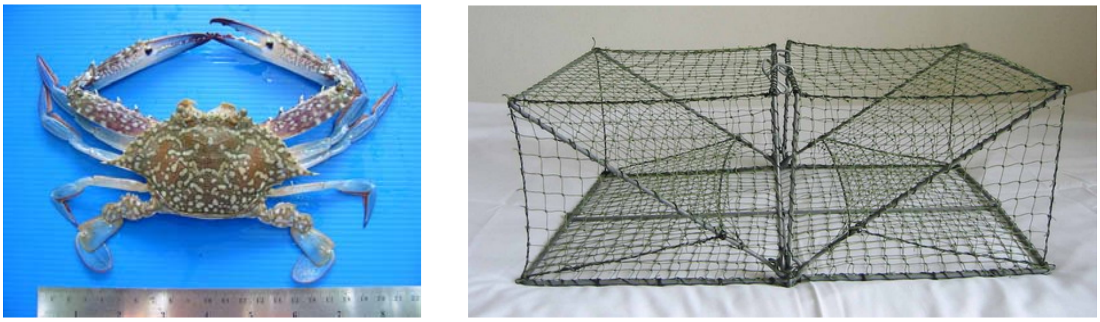
This study revealed that difference of fishing ground between the small- and commercial-scale of the collapsible pot fishery targeting blue swimming in the Gulf of Thailand affected the catch patterns of the crab size and species composition, as well as the bycatch and discard aspects. The results also suggested the significant contribution for improving the crab size selectivity particularly for small-scale, and the species selectivity and catch efficiency particularly for commercial-scale fishery. These aspects can be improved if appropriate combination of escape vents and smaller mesh size at the slope net is used together with the consideration of the fishing ground selection. Ghost fishing is occurred if the pots are lost at sea. The determination of appropriate escape vents can also reduce the negative impacts on the marine ecosystem.

Chapter 1

Introduction

1.1 Introduction to blue swimming crab pot fishery in the Gulf of Thailand

Blue swimming crab *Portunus pelagicus* (Fig. 1.1(a)) is an important coastal species in Thailand both for the domestic and export markets, with an annual production of around 40,000 tons (Fisheries Statistics of Thailand, 2007), worth about US $ 50 million value. Collapsible pot (Fig. 1.1(b)), box shaped, 2 slits entrances with the size of 36×54×19 cm is a major fishing gear type together with the bottom gillnet for catching the crab. The pot made from galvanized frame structure, covered with polyethylene green square shape net (modified from 38 mm diamond shape net). This fishing gear was introduced and transferred from Japan in 1981 (Okawara and Masthawee, 1981) and has been modified from the original design by Thai fisherman (smaller the pot size and changed the covered net from 25 mm red color to 38 mm green color).



(a) (b)

Fig. 1.1 Blue swimming crab (a), and collapsible crab pot with the size of 36×54×19 cm (b).

After the introduction from Japan, the pot was accepted and has been widely used both in the Gulf of Thailand and Andaman Sea. Nowadays there are 2 types of the crab pot fishing boat in the Gulf of Thailand; small scale (Fig. 1.2(a)) and commercial scale (Fig. 1.2(b)). The small scale operates close to the shore (about 0.5-3.0 km) with the number of 200-350 pots/boat, by individual setting and hauling by one man operation. The commercial scale operates far away from shore (>3km) with 5-8 crews onboard, by long-line type setting and hauling the pots by hauler machine with the number of 1,500-5,000 pots/boat or over, which has resulted in a decrease of catch per unit effort, and increased catch of smaller size blue swimming crab (Jindalikit, 2001). This trend requires the urgent mitigation measures for resource conservation together with the renovation of coastal environment, however, no practical success measures have so far been reported for the resource management and stock enhancement.

(a)

(b)

Fig. 1.2 Blue swimming crab pot boats in Thailand; small scale (a), 250-350 pots, and commercial scale (b), 1,500-5,000 pots onboard).

1.2 Fishing gear selectivity

Most fishing gears, for example for trawl gears, are selective for the larger sizes, while some gears (gill nets) are selective for the certain length range only, thus excluding the capture of very small and very large fish. This property is called ‘gear selectivity’. It needs to be taken into account when we want to estimate the real size (or age) composition of the fish in the fishing area. At the same time, it is an important tool for fisheries managements who, by regulating the minimum mesh sizes of the fishing fleet, can more or less determine the minimum sizes of the target species of the certain fisheries (Sparre and Venema, 1998). Fishing gear selectivity relies heavily on the mechanical selection of fish and their behavioral response to the gear during the capture process (Glass and Wardle, 1995).

Sustainable development of fisheries is the crucial strategy to achieve development of marine resources for food security and conservation of the aquatic environment for future generation (FAO, 1995). Size regulations and protection of species are emphasized in contemporary fisheries management. It is primarily important to harvest organisms of the desired species and size, decreasing unwanted bycatch which is currently discarded. These can be achieved by proper separation between retention and exclusion by fishing gear and methods (Matsuoka, 2001).

Selectivity is the function of fishing gear to harvest organisms of limited species and size ranges among populations that are encountered in fishing grounds. Fishing gear selectivity is therefore, composed of two character; 1) size selectivity, and 2) species selectivity (Matsuoka, 2001). A majority of passive fishing gear, such as gillnets, traps, pots, has modal selectivity curves, although sometimes the peaks are not distinctive. Active fishing gear, such as trawl and other seine nets of which selectivity is induced mainly by the function of filtering, has one-tail curves (Matsuoka, 2001).

Selectivity of the cage trap is complicated. This is attributed to the fact that organisms enter simply through a large opening (the entrance) but evacuate either through an exit (the entrance) or through both an exit and meshes, and that the phenomena for organisms to leave through an exit depends on behavioral differences among species. Selectivity curves of some pots are modal (Koike, 1979), however, it does not seem very sharp. When organisms are dislocated mainly through meshes that are usually much smaller than the entrance, selectivity may have a flat mode, as being saturated. Exclusion of small organisms can be controlled by adding of an escape gap (Brown, 1982)

Escape vents are used in some pot fisheries and the sizes of those vents may be tuned to maximize retention of large fish and escapement of small fish (Shepherd et al., 2002). The information required to maximize efficiency for a pot fishery comprises either comparisons of differing set durations, or continuous data from which the nature of the pot–containment curve can be estimated (Zhou and Shirley, 1997a).

1.3 Ghost fishing

Ghost fishing can be defined as the ability of fishing gear to continue fishing after all control of that gear is lost by the fisherman (Smolowitz, 1978a). It refers to derelict fishing gears either lost or abandoned which remain their capture function in water and continue to induce mortality of aquatic organisms without human control (Matsuoka, 2005). Gear may be lost for a variety of reasons including bad weathers, bottom snags, navigational collisions, faulty fishing methods, abandonment, human error, vandalism, and gear failure (Laist, 1995). Pot ghost fishing can occur through a variety of mechanism; auto-rebaiting, rebaiting by other species, attraction by living conspecifics or by the pot alone (Breen, 1990). The ghost fishing mortality rate is currently an intangible and remains of significant concern to both fishers and fisheries managers (Jennings and Kaiser, 1988). The lack of information relating to this phenomenon results from the incidents and difficulty in undertaking long-term studies in a realistic manner (Bullimore et al., 2001; Matsuoka, 2005). Pots ghost fishing, possibly the best information comes from underwater observations of simulated lost, and the studies short to long term must be carefully considered (Breen, 1990).

This study research aims to reduce the immature size of the blue swimming crab and bycatch from the collapsible crab pot, case study in the upper Gulf of Thailand, including modifications the pot that can improve the catch efficiency by understanding the crab behavioral response, and the impact of the pot ghost fishing also was investigated by simulated lost.

Chapter 2

The analysis of; pot operation, catches, bycatch, discard, and soak time

2.1 Introduction

Pots and traps are widely used to capture crustaceans and fishes (Miller, 1990; Cappo and Brown, 1996). Pots and traps may be baited or unbaited, depending on the target species. The capture process comprises attraction (unbaited traps presumably attract via their structure), approaches, entries, and exits (Fogarty and Addison, 1997). For several pot types, continuous data show that target species often may enter and depart from pots apparently at will (e.g. Jury et al., 2001). The catch rate of pots thus reflects the rate at which the target species enters and exits the pot, in relation to the timing of hauling. The capture process is complicated by the fact that entry and egress may be altered by presence or absence of prior entrants, the appropriate strategy for fishing therefore depends on the costs and benefits of setting and hauling, in relation to stock composition (Frusher and Hoenig, 2001).

Trap can be highly size and species selective and are both efficient and cost effective (Miller, 1990). These devices share with other forms of stationary gear (e.g. long-lines and gillnets), a passive made of capture in which the behavior of the species sought plays a dominant and critical role. Stationary fishing gears are typically sea fixed location and retrieved other variable immersion (soak) intervals. Immersion times can be very greatly in these fisheries and catch is typically not a linear function of the soak interval. These characteristics must be considered in the development of relative abundance indices base on standardize catch and effort series (Forgarty and Addison, 1997).

The fishing effort of a particular vessel is generally accepted as the product of the fishing power and an appropriate measure of fishing activity (Galbraith and Stewart, 1995). The parameters that measure the fishing power are known as ‘capacity parameters’ and result from vessel and fishing gear characteristics. The activity measure may be expressed by the number of fishing trips, fishing time, duration of the trips, number of sets, which in turn depend on the vessel characteristics and fishing method (Parente, 2004). Fishing power is the ability of a fishing unit to catch fish (Galbraith and Stewart, 1995) but since calculating it in absolute terms is not possible, it has been defined as a relative measure. Relative fishing power may be defined as the ratio of the quantity caught by an individual vessel per unit fishing time to that by a vessel selected as a standard reference (Beverton and Holt, 1957).

Catch per pot has been used as an index of abundance during stock assessment studies of crustaceans, but it is greatly affected by many variables (Miller, 1990). Pot design and soaking time are known to influence the pot's capture efficiency because of the different physical parameters of the pot, such as volume, entrance type and number, or mesh size; and because the conditions in the pot change over time. As time elapses, the bait loses its attractiveness, and because of the growing presence of crabs inside the pot intimidating others trying to get in, the pot may become saturated. At this time, depending on retention characteristics of the pot, escape may play an important role (Zhou and Shirley, 1997a).

Over the past three decades, it has been recognized that bycatch and discard is one of the most significant issues effecting fisheries management (Saila, 1983; Alverson et al., 1994). In this study, bycatch and discarded crab pot catches in different fishing area (inshore, offshore) in the Upper Gulf of Thailand were considered using data obtained from joining the operation with the crab pot fishermen for a consecutive year. As the information on the discarding procedure in the area were very limited, the main features of this process was presented, the quantities and qualities of discarded species were reported. Moreover, the CPUE according to the soaking time with the different retrieval method of commercial scale pot was examined.

2.2 **Materials and Methods**

The studies have been surveyed on board with Thai crab pot fishermen in their fishing grounds both small scale (Bang-pra Beach, Chonburi Province) and commercial scale boat in the upper Gulf of Thailand (Fig. 2.1). The catch data from collapsible pot fishing for the crab were analyzed for better understanding on the size/species composition, in order to improve the capture function of crab pot to reduce the bycatch of immature crab and discard species. Field surveys were conducted by on-boarding operations with the crab pot boats both for small and commercial scales in the upper Gulf of Thailand in 2006. The catch data were analyzed to estimate CPUE and size/species compositions for understanding the discard problem with the results of discard rate and ratio. Discard ratio and discard rate by number were estimated by using these below formulas (Alverson et al., 1994);

$$\text{Discard ratio} = \text{Discards}/\text{Retentions}$$

$$\text{Discard rate} = \text{Discards}/(\text{Discards} + \text{Retentions})$$

Catch performance of small and commercial scale operations were also compared from the view point of operation strategy of fishing effort and setting site difference.

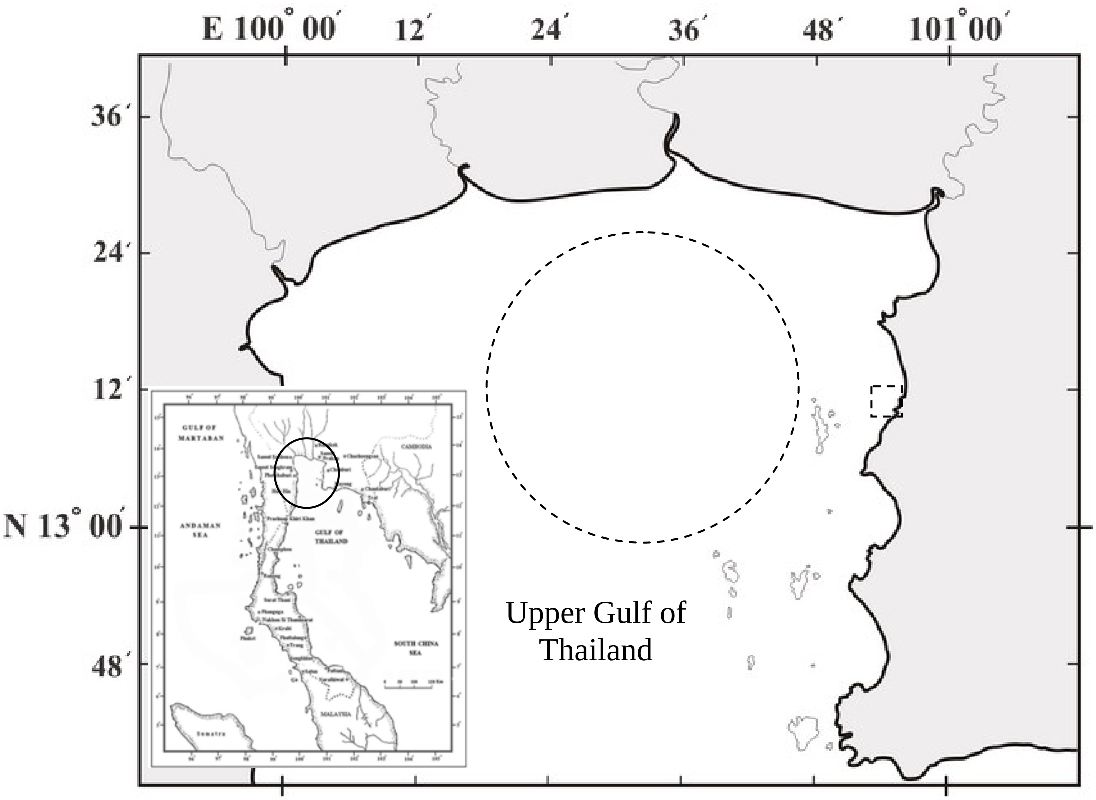


Fig. 2.1 The location of study area (= small scale fishing ground, = commercial scale fishing ground).

2.3 Results

2.3.1 Catch composition

Through out the study, the comparison of crab pot operation between small and commercial scale is shown in Table 2.1. Between both types of the pot fishing, only the pot was same but all others such as; the boat, bait, fishing ground, pot setting, soaking time, etc. were different. The pot numbers onboard had much different, only 200-350 pots/boat in small scale while can reach 5,000 pots/boat or more in commercial scale (Table 2.1)

The catch composition by number from a small scale boat operation (inshore fishing ground) is shown in Table 2.2. The majority catch was blue swimming crab, as 72.4-91.3%. Others species also were caught and being considered as bycatch, both commercial and no commercial value. Ridged swimming crab *Charybdis natator* and smoothshelled crab *Charybdis affinis* were dominant bycatch species through out the study (Table 2.2).

The catch composition (by number) from a commercial scale boat operation (offshore fishing ground) is shown in Table 2.3. The majority catch was still blue swimming crab, but smaller numbers than small scale, as 21.2-51.6%. Others species also were caught and being considered as bycatch both commercial and no commercial value with larger numbers than small scale both in quantity and quality (species). Threadfin bream, mantis shrimp, grunter, filefish and octopus were dominant for commercial valuable species while squared-shelled crab, smoothshelled crab and goby were dominant for low/less valuable species (Table 2.3).

Table 2.1 Comparison of crab pot boats and their operations in the upper Gulf of Thailand

	Small Scale	Commercial Scale
Boat size	1.7 × 5 m	3 × 10 m
Engine	5 HP	168 HP
No. of crews	1	5-10
No. of pot	200-350	1,500-5,000
Bait	trevally, croaker, others	tilapia
Fishing ground (from shore)	0.5-3 km	>3 km
Fishing depth	3-8 m	15-30 m
Pot setting	Individual	long-line (set)
Pot interval	20-25 m	12-15 m
Soak time	12-24 hrs (over night)	3.5-12 hrs (day)
Time used for shooting	1 hr/300 pots	1 hr/2,000 pots
Time used for retrieving	3 hrs/300 pots	4.5 hrs/2,000 pots

Table 2.2 Catch composition (by number) from a small scale boat operations (inshore fishing ground)

Species	Scientific name	Number of pot											
		295		299		366		366		367		367	
		17 May 2006		18 May 2006		8 Dec 2006		9 Dec 2006		18 May 2007		19 May 2007	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Blue swimming crab**	*Portunus pelagicus*	1,135*	91.3	1,199*	85.9	1,109*	72.4	870*	65.5	734*	76.1	583*	75.0
Ridged swimming crab**	*Charybdis natator*	89	7.2	166	11.9	6	0.4	4	0.3	141	14.6	137	17.6
Smoothshelled crab	*Charybdis affinis*	3	0.2	9	0.6	389	25.4	428	32.2	44	4.6	35	4.5
Flower moon crab	*Matuta planipes*	3	0.2	5	0.4	4	0.3	1	0.1	1	0.1	1	0.1
Filefish**	*Monacanthus chinensis*	4	0.3	4	0.3			1	0.1	10	1.0	4	0.5
Tripodfish	*Pseudotriacanthus strigilifer*	1	0.1	1	0.1								
Spiral melongena**	*Pugilina cochlidium*	6	0.5	4	0.3	5	0.3	7	0.5	11	1.1	2	0.3
Star fish	*Astropecten* sp.	1	0.1	3	0.2	14	0.9	14	1.1	5	0.5	2	0.3
Hermit crab	*Calibanarius longitarsus*	1	0.1	1	0.1				0.0	12	1.2	8	1.0
Mangrove stone crab**	*Myomenippe hardwickii*			2	0.1					2	0.2	3	0.4
Cuttlefish*	*Sepia pharaonis*			1	0.1					1	0.1		
Toad fish	*Batrachus grunniens*					1	0.1					1	0.1
Octopus*	*Octopus* sp.					1	0.1	2	0.2				
Spinefoot*	*Siganus oramin*					1	0.1	2	0.2				
Grunter*	*Terapon* sp.									3	0.3	1	0.1
Striped catfish*	*Plotosus lineatus*					1*	0.1						
	Total	1,243	100	1,395	100	1,531	100	1,329	100	964	100	777	100

* Indicate the number retained of species from each operation, ** Indicate those species that have marketable value.

Table 2.3 Catch composition (by number) from commercial crab pot boat operations (offshore fishing ground)

		Number of pot	2,013		2,117		2,120		1,687		1,698	
			8-Jan-2006		29-Apr-2006		5-May-2006		21-Sep-2006		26-May-2007	
			Catch		Catch		Catch		Catch		Catch	
No.	Species	Sci. Name	No.	%	No.	%	No.	%	No.	%	No.	%
1	Blue swimming crab**	*Portunus pelagicus*	647*	42.0	688*	51.6	569*	41.1	319*	38.4	337*	21.2
2	Square-shelled crab	*Galene bispinosa*	500	32.4	58	4.3	38	2.7	419	50.5	124	7.8
3	Crab (ปูแกละ)	Grapsidae	27	1.8					1	0.1		
4	Crabs	Leucosidae	13	0.8	2	0.1	1	0.1				
5	Smoothshelled crab	*Charybdis affinis*	7	0.5	44	3.3	141	10.2	2	0.2	103	6.5
6	Spider crab	Majidae	6	0.4	9	0.7	7	0.5	3	0.4	4	0.3
7	Crucifix crab**	*Charybdis feriatus*	1	0.1			2	0.1	1	0.1		
8	Ridged swimming crab**	*Charybis natator*			2	0.1	11	0.8			3	0.2
9	Mud crab**	*Scylla serrata*							1*	0.1	1*	0.1
10	Mangrove stone crab**	*Myomenippe hardwickii*					8	0.6				
11	Threadfin-bream**	*Nemipterus* sp.	240*	15.6	85*	6.4	209*	15.1	25*	3.0	417*	26.3
12	Threadtail tickletail**	*Pentapus setosus*	47*	3.0								
13	Grunter**	*Terapon* sp.	25*	1.6	66*	4.9	104*	7.5	7	0.8	19*	1.2
14	Filefish**	*Monacanthus chinensis*	9	0.6	23*	1.7	5	0.4	10*	1.2	252*	15.9
15	Croaker**	*Johnius* sp.	5	0.3	24*	1.8	15*	1.1	3	0.4	2	0.1
16	Ponyfish**	*Leioganathus sp.*	4	0.3								
17	Flathead**	*Platycephalus indicus*	1	0.1								

Table 2.3 (Cont.)

No.	Species	Sci. Name	8-Jan-2006		29-Apr-2006		5-May-2006		21-Sep-2006		26-May-2007	
			Catch		Catch		Catch		Catch		Catch	
			No.	%	No.	%	No.	%	No.	%	No.	%
18	Goby	Gobiidae	1	0.1	18	1.3	57	4.1	7	0.8	25	1.6
19	Toad fish	*Batrachus grunniens*	1	0.1								
20	Cardinalfish	*Apogon* sp.	1	0.1					5	0.6	7	0.4
21	Spinefoot**	*Siganus* sp.			20*	1.5	8	0.6	10*	1.2	13	0.8
22	Puffer** (ปลาปักเป้า)	*(Lagocephalus sp.)*			4	0.3	3	0.2				
23	Trevally**	*Selaroides leptolepis*							1	0.1		
24	Sole** (Soleidae)	*Paraplagusia bilineata*							2	0.2	1	0.1
25	Flounder**	Bothidae							1	0.1		
26	Striped catfish**	*Plotosus lineatus*							1	0.1		
27	Seahorse	*Hippocampus hystrix*									2	0.1
28	Cuttlefish**	*Sepia* sp.			8*	0.6	8*	0.6	9*	1.1	19*	1.2
29	Octopus**	*Octopus* sp.	4*	0.3	46*	3.4	38*	2.7	1	0.1	53*	3.3
30	Mantis shrimp**	*Miyakea neap* & Squilidae	2	0.1	206*	15.4	97*	7.0	1	0.1	191*	12.0
31	Shrimp**	*Matapenaeus* sp.	1	0.1	4	0.3	1	0.1			1	0.1
32	Ark**	*Scapharca indica*			20	1.5	45	3.3				
33	Asian Moon scallop**	*Amusium pleuronectes*					5	0.4				
34	Murex	*Murex* sp.			7	0.5	12	0.9	1	0.1	13	0.8
		Total	1,542	100	1,334	100	1384	100	830	100	1587	100

* Indicate the number retained of species from each operation, ** Indicate those species that have marketable value.

2.3.1 CPUE and discard analysis

Catch Per Unit Effort (CPUE) and discards from small scale pot were analyzed and shown in Table 2.4. Average CPUE of the blue swimming crab from 6 operations was 2.81 crabs/pot. Fishermen retained only the blue swimming crab and discarded all the others. Average discard ratio and discard rate were 0.30 and 0.22 respectively. The average discard/pot was 0.76.

Table 2.4 CPUE and discard from small scale (D = Discard No., R = Retention No.)

Date	No. of Pot	No. of total catch	No. Retained	Crab CPUE	Discard		
					Ratio (=D/R)	Rate (=D/((D+R))	Per pot
17-May-06	255	1,243	1,135	3.8	0.10	0.09	0.37
18-May-06	299	1,395	1,199	4.0	0.16	0.14	0.66
08-Dec-06	366	1,531	1,109	3.0	0.38	0.28	1.15
09-Dec-06	366	1,329	870	2.4	0.53	0.35	1.25
18-May-07	367	964	734	2.0	0.31	0.24	0.63
19-May-07	367	777	583	1.6	0.33	0.25	0.53
			Mean	2.81	0.30	0.22	0.76

CPUE and discards from commercial scale pot were analyzed and shown in Table 2.5. Average CPUE of the blue swimming crab from 5 operations was much smaller than small scale as 0.26 crabs/pot. The fishermen were not only retained blue swimming crab but also some economic value species such as threadfin bream, mantis shrimp, filefish, grunter and octopus. Average discard ratio and discard rate were 0.50 and 0.3 respectively slightly larger than small scale. The discard/pot was smaller, average as 0.19 individual.

Table 2.5 CPUE and discard analysis from commercial scale operations

Date	No. of pot.	No. of total catch	Crab CPUE	No. total retained	CPUE (total retained)	Discarded No.	Discard by No.		
							Ratio	Rate	Per pot
8-Jan-06	2,013	1,542	0.32	964	0.48	578	0.60	0.37	0.29
29-Apr-06	2,117	1,334	0.32	1166	0.55	168	0.14	0.13	0.08
5-May-06	2,120	1,384	0.27	1040	0.49	344	0.33	0.25	0.16
21-Sep-06	1,687	830	0.19	374	0.22	456	1.22	0.55	0.27
26-May-06	1,698	1,587	0.20	1289	0.76	298	0.23	0.19	0.18
	Mean	1,335	0.26	967	0.50	369	0.50	0.30	0.19

The size of blue swimming crab from each fishing type is shown the comparison in Fig. 2.2. It shows clearly that small scale fishermen (inshore fishing ground) catch the big amount of the small size crab while commercial scale (offshore fishing ground) catch the larger size from their operations due to the different of fishing ground.

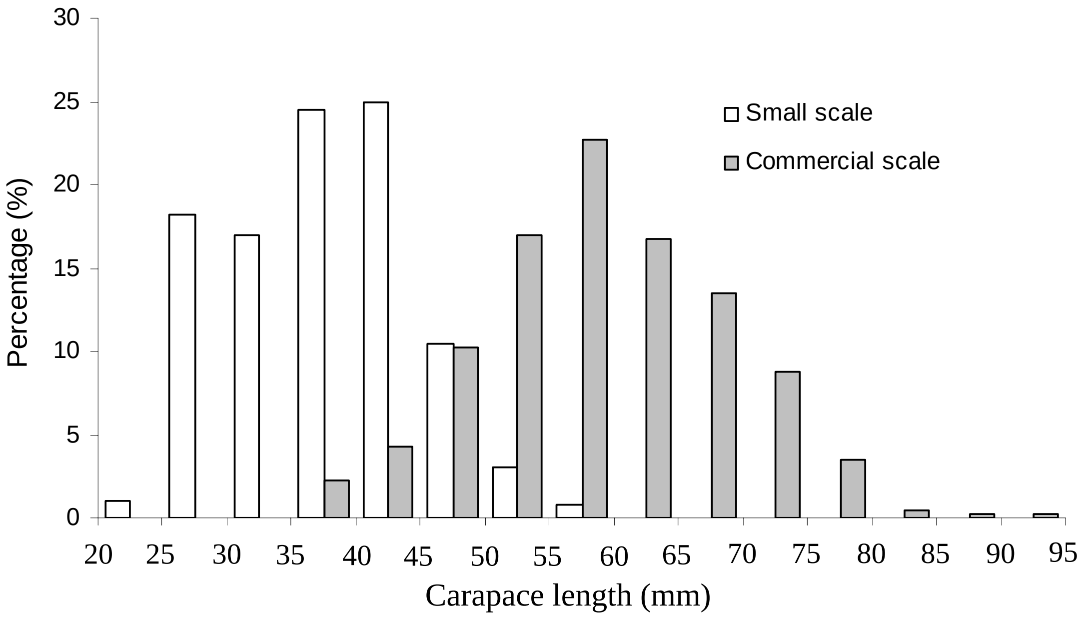


Fig. 2.2 Blue swimming crab size from the small and commercial scale crab pot (n = 400 each).

2.3.2 Soak time

The soak time of small scale is 13-15 hrs (over night). Small scale fishermen start their pot deployment in the evening (about 4 pm) and start retrieving in the next early morning (about 5 am). The soak time from commercial scales was much shorter than small scale, only 3-11 hrs (for the boat with 2000 pots) due to they have to share the fishing ground with the other fishing gears particularly the with the trawlers. Pattern of the soak time was different, depended on the pot retrieval method of the commercial boat. If the last deployed pot was the first hauled and continue hauling from this last deployed pot until finished, the pattern become as Fig. 2.3, but if the first deployed pot was the first hauled and continue hauling, the pattern would become as Fig. 2.4. Different retrieval operation method may effect to the catch. CPUE on 8 Jan 2006 (start hauling from the last deployed pot) was slightly higher than on 5 May 2006 (start hauling from the first deployed pot).

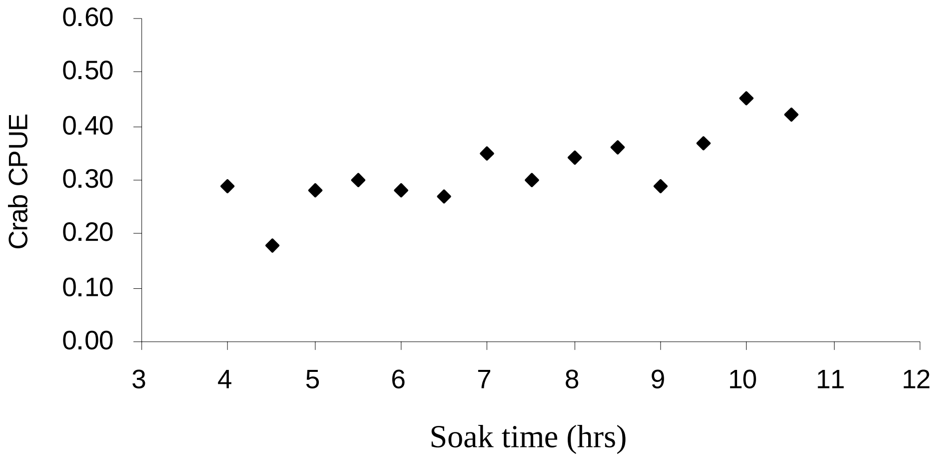


Fig. 2.3 Pattern of the crab CPUE (crab/pot) according to the soak time of commercial scale pot on 8 Jan 2006 when the hauling started from the last deployed pot (No. of pot = 2,013, CPUE = 0.32).

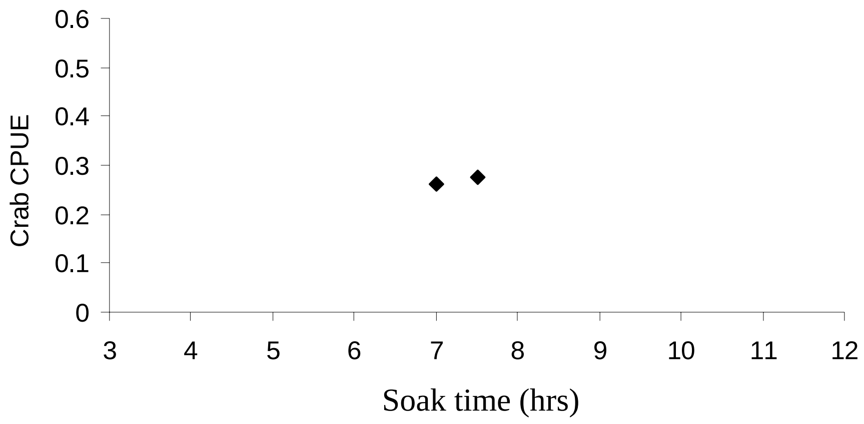


Fig. 2.4 Pattern of the crab CPUE (crab/pot) according to the soak time of commercial scale pot on 5 May 2006 when the hauling started from the first deployed pot (No. of pot = 2,120, CPUE = 0.27).

2.4 Discussion

The use of observers aboard commercial vessels is a useful method of obtaining data on catch composition (Allen et al., 2001). In this study, fishing ground has much influence on the catch of collapsible pot targeting blue swimming crab in the upper Gulf of Thailand. Different fishing ground induces the different of fishing operation, catch composition, crab size catch, and discard species. Because of the many larger of pot numbers onboard in commercial scale, the discard problems were bigger than small scale both in quantity and quality (numbers and species). However the fishing ground of commercial scale showed positively for catching the larger crab size. Hence, select the fishing ground can induce the blue swimming crab size selectivity. These findings are similar with Walmsley et al. (2007) who reported that analysis of the community structure of trawl catches indicated that there are significant differences between fishing areas on both coasts (inshore and offshore). These differences mirror community areas suggested by survey data, using research survey data, can be loosely correlated with those identified in the current study based on commercial catches.

Variations in characteristics of the pot fishery affected the catches, and set durations of pots and traps vary widely. Soak times have been shown to have important consequences for fisheries (Briand et al., 2001). Fish traps in the Caribbean can be set for days (Munro, 1974), spiny lobster *Jasus* spp. pots are typically set overnight (Frusher and Hoenig 2001), whereas durations of blue cod pot sets are in the order of 10–15 min to several hours (Cole at al., 2004).

The effect of soaking time on the retention characteristics of crab pots has been reported by Miller (1979a, b, 1990), and Zhou and Shirley (1997a). The crab catch usually increase rapidly during the first hours after setting a pot, but as time passes bait attractiveness will decrease and the growing number of crabs inside the pot may reach a level where they do not allow other crabs to enter, and the pot becomes saturated. Normally escape and entry rates of crabs will remain in balance for a while but later more crabs will leave the pots than go in. The retention characteristics of box and dome pots are completely different; box pot will keep the crab catch indefinitely and, though not baited, will allow the entry of fish and octopus, but dome pot will permit crabs and other organisms to escape and only crab conspecifics were attracted into the pots (Vazquez Archdale, et al., 2007). Using box or dome pots for population surveys will give completely different catch results; the effects of the different designs on the catches of crabs and other organisms are large over 1 day soaking and will increase further with longer soaking time (Vazquez Archdale and Kuwahara, 2005; Vazquez Archdale et al., 2006b).

The soaking time of commercial scale crab pot operations was quite short (3-11 hrs) due to the fishermen had to share the fishing ground with the trawlers. The trends of CPUE increased since the pot was not reach the saturation yet (Miller, 1979b; Fogarty and Addison, 1997). Retrieving operation method may effect the CPUE, by start retrieving from the last deployed pot showed the better CPUE than starting from the first deployed, possibly the starting from the last pot can give longer soaking time particularly pots that were deployed from the beginning. For confirming the effect of escape soaking time on CPUE, extensive comparative with the longer soaking time experiment will be required.

This study reveals that the crab size selectivity for small scale pot should be concerned while species selectivity for commercial scale. Estimates of the catch composition of Gulf of Thailand collapsible crab pot have highlighted issues of concern within the fishery. The results showed that the by-catch for both types of operation has still been in the level that we should take some mitigation measures. Although awareness of these issues can be used to advise in the formulation of a bycatch management plan, for several issues there is insufficient information on the scale of the problem. This highlights need for a programme specifically designed to answer the outstanding questions. A stratified approach is required to ensure that all fishing companies and fishing areas are adequately covered. Further, seasonal trends in catch composition or discarding pattern should be monitored, such that the efficiency of management strategies can be assessed.

Chapter 3

Use of escape vents to improve size and species selectivity of collapsible pot for blue swimming crab, *Portunus pelagicus* in Thailand

3.1 Introduction

Blue swimming crab *Portunus pelagicus* is an important coastal species in Thailand both for the domestic and export markets, with an annual production of around 40,000 tons (Fisheries Statistics of Thailand, 2007), worth about US $ 50 million value. Collapsible pot (Fig. 3.1) is a major fishing gear type together with the bottom gillnet for catching the crab. After introduction of the pot from Japan in 1981 (Okawara and Masthawee, 1981), intensive fishing activities by small scale operations using 200-300 pots per setting operation, and commercial longline type boats setting 2,000-5,000 or more pots, which has resulted in a decrease of catch per unit effort, and increased catch of smaller size blue swimming crab (Jindalikit, 2001). This trend requires urgent mitigation measures for resource conservation together with the renovation of the coastal environment, however, no practical success measures have so far been reported for resource management and stock enhancement.

Fig. 3.1 Collapsible crab pot; box shaped with the size of 36×54×19 cm.

In the crab pot fishery in Thailand, a large proportion of the catch consists of immature crabs and non-target species including other shellfish and finfish, which have to be discarded onboard after hauling if the species are of no or low economic importance. Boutson et al. (2005) reported that 32-42% of the blue swimming crab catch was immature based on onboard monitoring. The discard ratio (Matsuoka, 1997) by number for the crab was counted as 2.21 among all catch species, which means that 2.21 animals are discarded for every one commercially taken crab. In order to reduce the undersized of target species, bycatch and discards in pot fishing, escape windows or vents and other methods have been demonstrated and employed for the lobster traps (Stasko, 1975; Krouse, 1978; Nulk, 1978; Fogarty and Borden, 1980; Miller, 1990) and crab pots (Eldridge et al., 1979; Miller, 1990; Brown, 1982; Watanabe and Sasakawa, 1984; Guillory and Merrel, 1993; Nishiuchi, 2001). It is envisaged that the adoption of escape vents in pots for the crab can allow the escape of immature sized crabs, and furthermore reduce the proportion of other species and thus minimizing the discards.

There are other approaches aimed to reduce the catch of undersized crabs from pots, such as installing the escape panels (Eldridge et al, 1979; Brown, 1982, Guillory and Merrel, 1993; Guillory and Hein, 1998), increasing the mesh size (Watanabe and Sasakawa, 1984; Zhou, 1997; Guillory and Prejean, 1997; Vazquez Archdale et al., 2006), modifying the mesh shape (Guillory, 1998; Guillory and Hein, 1998), and comparing the pot shape or entrance design (Zhou, 1997; Vazquez Archdale and Kuwahara, 2005; Vazquez Archdale et al., 2006; Vazquez Archdale et al., 2007). The pot design should be decided according to the target species (Miller, 1990), while in Thailand, the box-shaped collapsible pot is the most popular type used in coastal areas, due to the good catch rate, low cost, and high portability which allow a large number to be loaded on a small deck space. The minor modification for use of escape vents to improve the selectivity of the conventional pot will require the fishermen's acceptance and cooperation. However as this also functions as a possible solution for the effects of ghost fishing if the pots are lost at sea (Arcement, 1993; Breen, 1985), pots for *P. pelagicus* in Australia were estimated to ghost fish for more than 4 years (Sumpton et al., 2003), the reduction of undersized crabs and bycatch by use of the vents will potentially be an effective management tool for this fishery.

In this study, laboratory experiments were firstly conducted for determining the possibility of modifying the collapsible pot by designing escape vents to improve size selectivity, focused on reducing the catch of immature blue swimming crabs. Comparative fishing trials were also conducted between the conventional and modified pots with escape vents to assess the crab size selectivity and other non target species composition.

3.2 Materials and Methods

The laboratory experiments were conducted at Sriracha Fisheries Research Station, Kasetsart University, Chonburi Province, Thailand, during February-May 2004. The shape, position and size of escape vents were examined to determine the most appropriate vent design and selectivity performance for reducing the catch of immature size crabs. Comparative fishing trials were conducted with two fishing operations in May 2005 in the coastal waters adjacent to the research station (Fig. 3.2) to compare the catch composition between conventional and vented pots to examine the crab size and species selectivity.

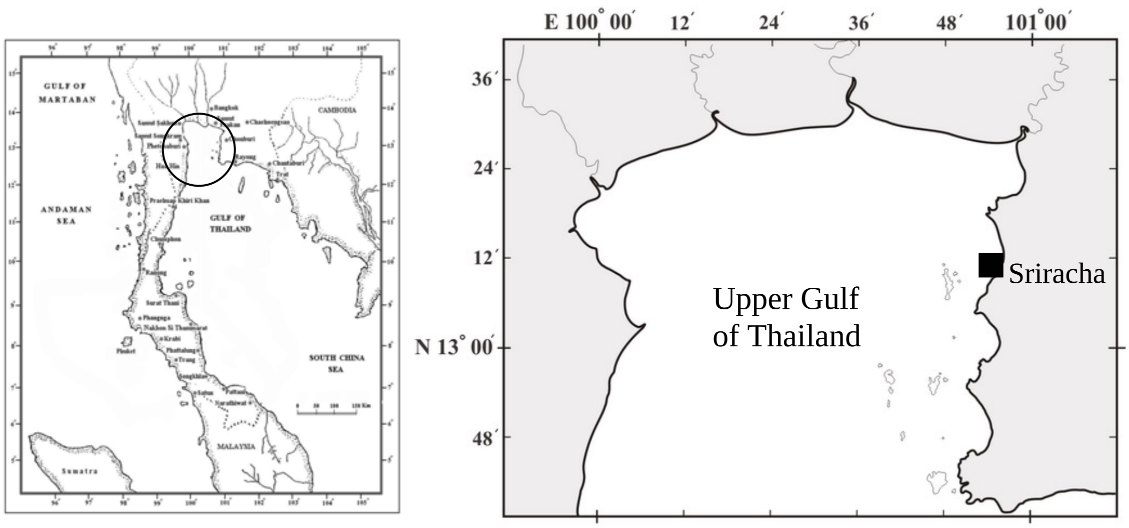


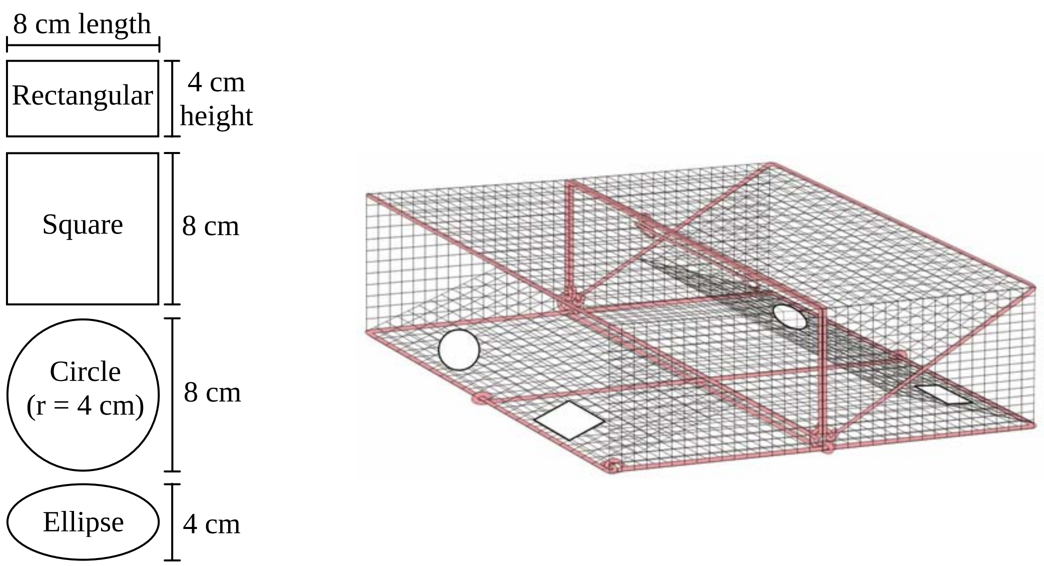
Fig. 3.2 Location map of study area (■).

3.2.1 Experimental Pot: Collapsible pots were obtained from the local fisherman. The pot is box-shaped, with the dimension of 36×54×19 cm having 2 slit entrances (Fig. 3.1), galvanized rod frame (4 mm diameter), and is covered with green polyethylene square-shaped mesh net of 38 mm mesh size. An iron hook is attached at the top panel for pot set-up and collapsible function.

3.2.2 Laboratory experiments: Outdoor experimental tanks measuring 1.7×1.7×1 m^3 with plastic shading cover were used. Filtered and aerated seawater of 28-30 °C was supplied into the tanks with 30 cm of sea water level, for covering the pot height of 19 cm.

Approximately 300 individuals in total of blue swimming crabs were collected by pot fishing in the coastal waters adjacent to the research station and kept in a stock tank for 3-5 days before the experiments. The crabs were measured for carapace length (CL) as defined by distance length between frontal and intestinal margins of the carapace and a size range of 26-70 mm was obtained. The carapace height (CH) was also measured to obtain the relationship with CL.

The appropriate design of escape vents was examined by comparing the different vent shapes among square, rectangle, circle and ellipse. All vent shapes were the same length of 80 mm, with different height for the rectangular and ellipse vent as 40 mm (Fig. 3.3(a)). The vent frame was made from 2 mm diameter wire, and was located at bottom sides of lower slope panel in the same pot as shown in Fig. 3(b). All the shapes were sufficiently large enough to allow all of the crabs to escape through the vent openings. One to three crabs were placed inside the pot, and the time required prior to escape recorded in daytime for from each vent shape for up to 50 escapes in total. New individuals were introduced to the pots to maintain the number of crabs in the pot after escape of an individual. If a previously-escaped crab was used for a second time, in order to avoid any recognition and selection of the escape vent position, the direction of the pot was changed by turning the pot. The crabs which did not escape during a 24-hrs period were replaced with new ones.



(a) (b)

Fig. 3.3 Four different shapes of escape vent (a), located at bottom sides of the lower slope panel (b), to observe the escape behavior of blue swimming crabs from the pot.

After assessing the most appropriate vent shape, the vent positions were examined by comparing 5 different locations in the pot; as the corner and center parts of the lower slope panel, the upper and lower parts of the side panel, and corner of the top panel, as shown in Fig. 3.4. The vents were located on both sides at the same position in the same pot, so as to monitor the escape behavior by the time recording for each escape from each vent position. Each individual crab was used only once in this experiment. The time recording was also done for every escape from each vent position for up to 50 escapes in total.

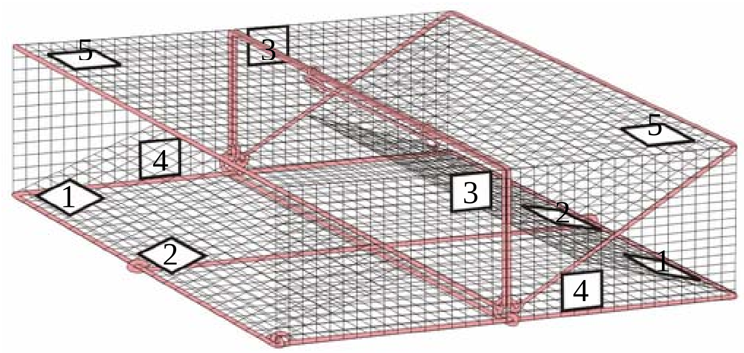


Fig. 3.4 Square-shape escape vents were located at 5 pairs of different positions; lower slope panel of corner (1) and center (2), of side panel upper (3) and bottom (4), and of top panel corner (5) to observe the escape behavior of the crabs from the same pot for the vent position experiment.

As the last phase of the laboratory experiment, the size selectivity performance of the escape vent was examined by placing crabs of known size groups in the pot in order to obtain precise size selection data (Miller, 1990), for vent sizes of 40, 45 and 50 mm in length and 35 mm fixed in height. Each size of vent was located at the bottom of the side panel according to the results of the vent position experiment. The crabs were grouped according to 5 mm CL classes in a range for 26-70 mm, by placing ten crabs of each size class range in the pot. Each vented pot was monitored in the experimental tank for 24 hours, for the number of crabs escaping and remaining inside. Here, the determination of the appropriate vent size to allow the escape of immature female blue swimming crab (CL< 46 mm) (Tuntikul, 1984) was the aim. The SELECT model (Tokai and Mitsuhashi, 1998; Millar and Fryer, 1999) was used to assess each escape vent selection by considering the selection range ($L_{75\%}$-$L_{25\%}$) and 50% selection length ($L_{50\%}$) (Jones, 1976; Sparre and Venema, 1998; Tokai and Mitsuhashi, 1998). The logistic selectivity curves were estimated using MS-Excel with solver, specified by two parameters, *a* and *b*, as the equation;

$$S(l) = \exp(a+bl)/[1+\exp(a+bl)]$$

The selectivity curves of the three vent sizes were estimated and the master curve (Tokai and Kitahara, 1989) according to the CL and vent length were determined.

3.2.3 Field experiments: The appropriate vent design as shape, location and dimension from the laboratory experiments was tested in fishing trials on 4 and 5 May 2005, in the shallow waters adjacent to the Sriracha Research Station, Faculty of Fisheries, Kasetsart University, in the upper Gulf of Thailand (Fig. 3.2) as a fishing ground for small scale crab pot fishermen, about 1-1.5 km from shore with the depth of 4-6 m, and substratum composed of muddy sand. Two escape vents of 35×45 mm were located at opposite sides of the pot as shown in Fig. 3.5, to compare with the conventional type of pot. Fifty pots of each type were used and all pots were deployed individually, connected to a 10-12 m length of polypropylene rope and marked with a buoy (Fig. 3.6). They were baited with approximately the same sized fresh trevally *Selaroides leptolepis* pierced and bound by wire at the center bottom of the pots. Both types of pot were dropped together as a pair in each deployed-position with intervals of 20-25 mm, with 1-day soaking time following the normal operation procedure of small-scale crab pot fishermen. Pots were retrieved and the catch species and size of individuals from each pot recorded.

Fig. 3.5 Escape vents (35×45 mm) were located at both sides at the bottom of the side panel for the field fishing trials.

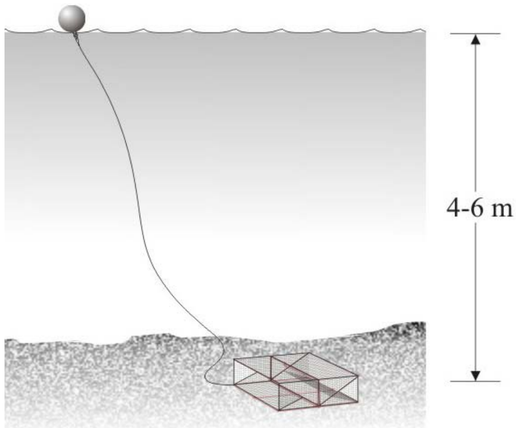


Fig. 3.6 The configuration of a deployed pot, individually set and connected with rope to the buoy.

The selection curve of 35×45 mm vent in fishing trials was analyzed and compared with that of the laboratory experiment results, through the assumption for fishing trial data that the catch numbers in each length class (5 mm intervals, 20-70 mm CL) in conventional pot were the number of crabs that could escape from the vented pot, and all catch numbers of larger size (>50 mm CL) from both types of pot were retained for the comparison analysis.

3.3 Results

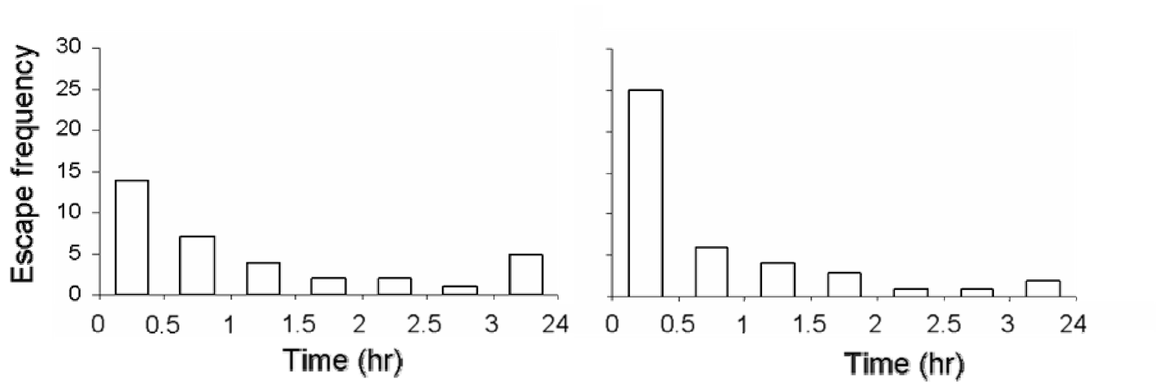
3.3.1 Laboratory experiments: The escape vents allowed the smaller blue swimming crabs to escape with different performances among the shapes, positions and sizes. The escape frequency comparison among different shaped vents (Table 3.1) shows the highest rate of escape with the square shape vent as 70%, followed with circle shape as 18%, rectangular as 10%, and ellipse was the worst. The square shape vent was the most superior, even with the same vent length of 80 mm for all shapes which would allow all crab sizes to escape out freely. The vent opening area may be the decisive factor for enhancing the crab escape while the square was superior to the circle, and the rectangular superior to the eclipse, even with the almost similar opening area. Fig. 3.7(a) shows the escape frequency from the square shaped vent against the time elapsed, as 14 individuals escaping in the first 30 minutes after starting the experiment.

Table 3.1 Frequency comparison of the crabs that escaped through the different shapes of escape vent

Escape vent shape	Dimension, height x length (cm)	Vent opening area $(cm)^2$	Frequency of escape	Percent escaping (%)
Rectangular	4 × 8	32	5	10
Square	8 × 8	64	35	70
Circle	8 × 8	50.3	9	18
Ellipse	4 × 8	25.1	1	2
		Total	50	100

Table 3.2 Frequency comparison of the crabs that escaped through the different positions of square vent

No.	Position of escape vent	Frequency of escape	Percent escaping (%)
1	Corner slope panel	7	14
2	Center slope panel	1	2
3	Upper side panel	0	0
4	Lower side panel	42	84
5	Corner top panel	0	0
	Total	50	100



(a) (b)

Fig. 3.7 Frequency of escape through the square vent (a) for shape experiment, and lower side panel vent (b) for vent position experiment.

Table 3.2 shows the escape frequency results for square vents among the different positions, which indicates that the best vent position was at the bottom of the side panel with the 84% of crabs escaped, followed by the corner position of the slope panel. Among the total number of escapes of 42 individuals from the lower side vent, 25 crabs escaped within the first 30 minutes as shown in Fig. 3.7(b). No individuals escaped from the top panel, and the upper part of side panel, for explaining the search behavior of crabs crawling on the bottom panel.

According to the observations of escape behavior, the CL is related to the vent length and CH related to the vent height, due to the 'side crawling' behavior of the crabs when escaping through the vents. The crab of just fitting size of CL and CH against the vent length showed the hard struggling for pushing its body through the vent, while the smaller crabs in most cases can escape smoothly through. Size selectivity according to the different escape vent lengths are shown as selectivity curves in Fig. 3.8(a), to give the probability of retained numbers among 10 individuals put in the pot for each CL class, which patterns are almost similar with shifting to the right when the vent length increases. Two further parameters are shown in Fig. 3.8; the selection range (SR) and 50% selection length ($L_{50\%}$) are used to compare the selection curves. The SR is determined by the slope of the curve and gives an indication of the size range selection that occurs, e.g. if all crabs below 30 mm CL escaped and all above 50 mm CL are retained, the SR will be 20 mm. The $L_{50\%}$ is indication at the CL class in which half of all crabs escape. The SR for vent lengths of 40, 45 and 50 were estimated ($L_{75\%}$ - $L_{25\%}$) to be 5.8, 4.0 and 4.9 mm, and the $L_{50\%}$ for vent lengths of 40, 45, and 50 mm were 39.1, 44.4, and 48.7 mm CL, respectively. The $L_{50\%}$ of 50 mm vent length was closest to the size of first maturity crab size (>46 mm CL), while the SR of 45mm vent was smaller than 50mm vent and rather smaller than of 40mm vent length (VL). According to similar pattern of selectivity curves in different vent length, the master curve was calculated for the ratio of CL/VL and shown in Fig. 3.8(b), 50% retention probability was 0.98, close to 1.00 for the value CL divided by the vent length, which support the precise selective function of rigid frame of vent to the hard body structure of the blue swimming crab.

The *CL* of mature female crabs in relation to *CH* is larger than the male (Tuntikul, 1984; Jindalikit, 2001). The size relation of female crab as $CH = 0.46CL + 3.8$ ($R^2 = 0.91$, n = 100). Though the best positive result for the vent shape was square, after considering of the relationship of the crab size (*CH* and *CL*) to vent size, we decided to set the vent design with nearly-square shape of 35 mm height with 45 mm length as shown in Fig. 3.5, as this allows practical as well as functional usage of the pots.

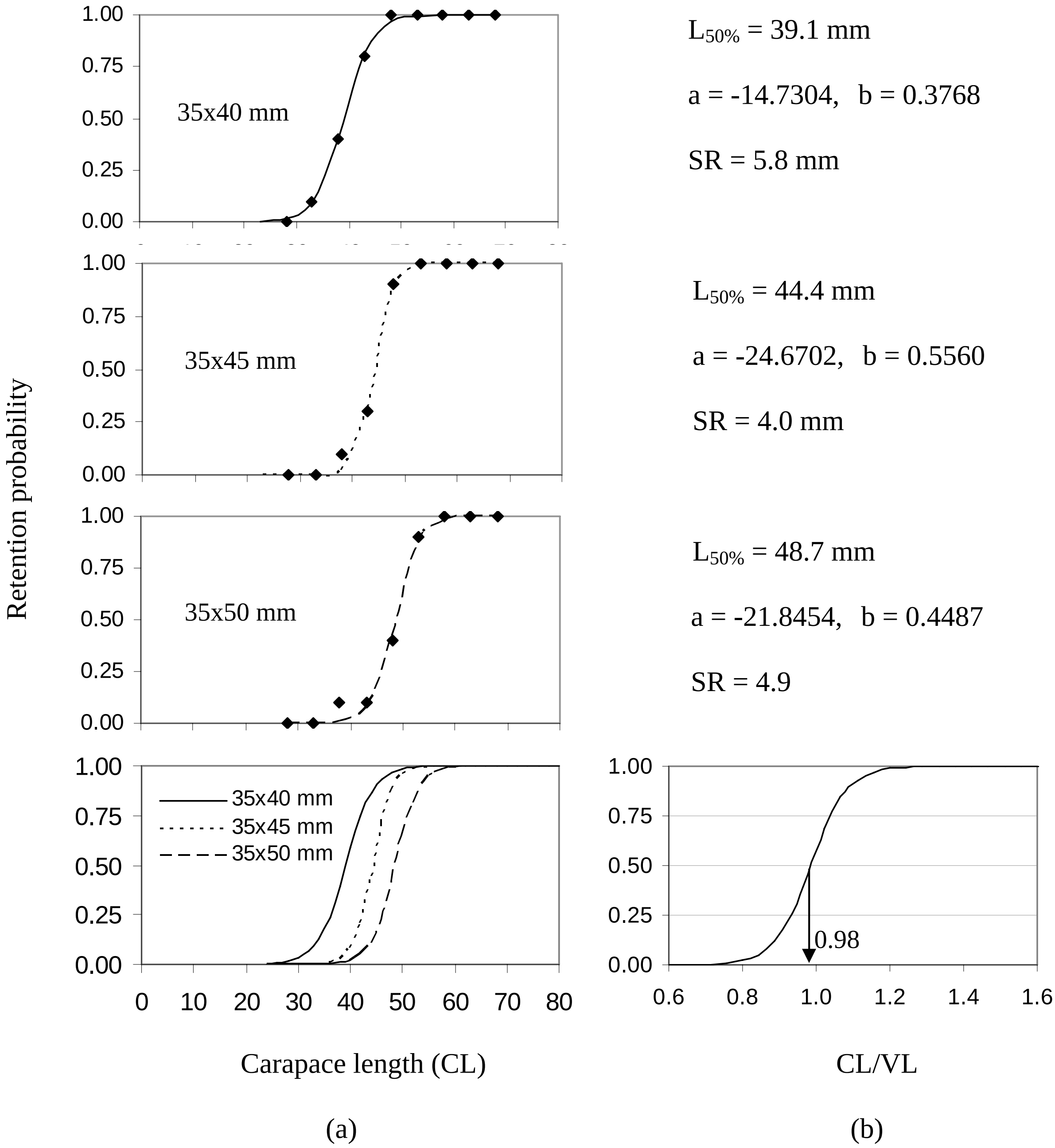


Fig. 3.8 (a) Size selectivity for blue swimming crab according to escape vent length when vent height was fixed at 35 mm, (b) master curve for crab size (CL) according to vent length (VL).

3.3.2 Field experiments

Regarding the comparative fishing trials, the catch comparison for blue swimming crab between conventional and vented pots is shown in Table 3.3. The vented pots could reduce the number of immature crabs caught from 61% to 14.3% on 4 May 2005 and from 80% to 7.7% on 5 May 2005. From the 2-days pooled catch, conventional pots caught 45 immature and 21 mature crabs, while vented pot caught 3 immature and 24 mature crabs. Those results show that the vented pot can reduce the number of immature size crabs caught while not reducing the catch efficiency for mature size crabs.

Table 3.3 Size comparison of blue swimming crab catch between conventional and vented pots on 4 and 5 May 2005

	Conventional Pot		Vented Pot		Total
	Mature	Immature	Mature	Immature	
4 May	5	20	12	1	38
5 May	16	25	12	2	55
Total	21	45	24	3	93

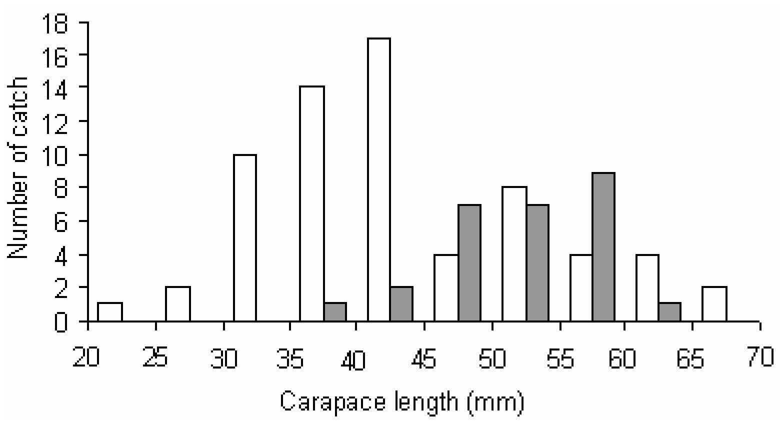


Fig. 3.9 Blue swimming crab size sampled with conventional pots (open columns) and vented pots (shaded columns).

The crab size (CL) from each pot type in comparative fishing is shown in Fig. 3.9. The vented pots showed a positive result clearly excluding the small size crabs while retaining the larger size when compared with the conventional pots. Crab size caught by vented pots was significantly larger than the size caught by conventional pots (Mann-Whitney U-test; Z = 4.27, $p < 0.01$). Size selectivity of 35×45 mm vent for the crabs from fishing trails was analyzed and shown in Fig. 3.10 as a comparison with the laboratory results. The selectivity curve from the trails shifts to the right as $L_{50\%}$ of 46.9 mm, with the SR of 4.0 mm same as in the laboratory. The two estimated selectivity curves are not the same with a lower probability of retention of larger CL for field trial selectivity, possibly due to the difference in number of crabs in each length class between laboratory and field conditions, particularly for the crabs at the length of 35-45 mm CL, which is the dominant size in the shallow fishing grounds used in the field trials.

The overall catch composition of crabs and other bycatch species for each pot type shows the differences in numbers, catch composition, their average size, range (Min-Max) and standard deviation (Table 3.4). Regarding the bycatch composition by number of individuals, Table 3.4 shows that the vented pots mainly caught fewer than conventional pots. This demonstrates the positive selective function of vents on the bycatch amount, while no significant differences on length size for each species that were caught in both types of pot (ANOVA, $p = 0.05$), except for the case of blue swimming crab. In the vented pot, none or less catch of some accidentally caught species were listed, such as smoothshelled crab, red crab, striped catfish, cardinal fish, gastropod and sea urchin.

Table 3.4 Catch composition between conventional and vented pots, from the 2 comparative fishing trials

Common name	Scientific name	Number of catch		Length size (mm)			
		Conventional	Vented	Conventional pots		Vented pots	
				Mean	Range (SD)	Mean	Range (SD)
1. Blue swimming crab*	*Portunus pelagicus*	66	27	43.9	21-70 (±10.5)	53.1	39-63 (±5.8)
2. Chinese filefish*	*Monacanthus chinensis*	33	24	77.1	34-113 (±18.5)	78.5	48-135 (±20.3)
3. Ridged swimming crab*	*Charybdis natator*	14	2	35.0	24-51 (±7.0)	39.5	33-46
4. Spiral melongena*	*Pugilina cochlidium*	10	13	65.3	58-84 (±7.2)	56.9	40-79 (±12.45)
5. Mangrove stone crab*	*Myomenippe hardwickii*	6	2	47.3	37-63	49.0	48-50
6. Toad fish	*Batrachus grunniens*	5	3	161.6	115-227	171.7	152-155
7. Sea urchin	*Diadema setosum*	2	1	41.3		32.0	-
8. Striped catfish*	*Plotosus anguillaris*	1	0	295.0	-	-	-
9. Cardinalfish	*Apogon* sp.	2	0	76.5	67-86	-	-
10. Smoothshelled crab	*Charybdis affinis*	1	0	29.0	-	-	-
11. Red crab	*Charybdis* sp.	1	0	49.0	-	-	-
12. Gastropod	Muricidae	1	0	35.0	-	-	-
13. Trumpeter*	*Pelates quadrilineatus*	0	1	-	-	120.0	-
14. Cuttlefish*	*Sepia pharaonis*	0	1	-	-	58.0	-
	Total	142	74	-	-	-	

* Indicate those species are of commercial value.

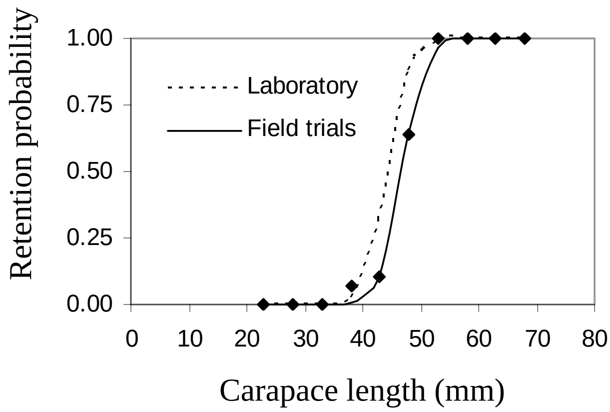


Fig. 3.10 Size selectivity of 35×45 mm escape vent for blue swimming crab from the field trials with $L_{50\%}$ = 46.9 mm, a = -25.9403, b = 0.5528, and SR = 4.0 mm, in comparison with the result from the laboratory observation.

3.4 Discussion

Pots are known to be highly selective for both species and sizes, due to their capture function as a passive gear using bait for attraction, as well as the entrance design with a non-return device. Exclusion of small organisms can be controlled by adding an escape opening (Eldridge et al., 1979; Brown, 1982; Guillory and Merrel, 1993; Guillory and Hein 1998). The selection performance can be established according to the gear designing such as the size, shape, location and construction material of the escape vents, particularly for crabs and lobsters which have rigid shells. Size selectivity of an escape opening can be quite precisely assessed by selectivity experiments conducted by placing crabs of a known size in pots with escape openings (Miller, 1990). The rigid exoskeleton and dexterity of decapods to orient themselves to the most advantageous position for escape can account for this precision in selectivity. The escape vent, however, only works when the captured animal can find the opening; so that more than one vent is usually recommended (Eldridge et al., 1979; Brown, 1982; 1993; Guillory and Hein 1998; Nishiuchi, 2001). Stasko (1975) suggested a general rule based on observations that *Cancer irroratus* and *Homarus americanus* oriented themselves such that the smallest opening through which an animal could be pushed through by hand was also the smallest opening it would pass through unaided.

Laboratory experiments to determine suitable escape vent to facilitate immature blue swimming crabs to escape revealed that the shape, position and size of the vents affected the crab escape from pots, similar with the results of Nulk (1978), and Brown (1982). The square shaped vents located at the bottom of the side panel were superior. Since the water in the experimental tank was clear under the high ambient light levels in daytime, the crabs could preferably select the vent to escape with the largest opening area as the square shape, followed by the circle shape. Bottom side panel showed the best position for the crabs to escape, these results are strongly related to the behavioral characteristics of the crabs while being confined inside the narrow space of the pot. From direct observations in the tank, the crabs usually remain in the bottom corner of pots unless there is absolute necessity, for example; foraging, avoiding attacks by larger crabs, or trying to escape out. They mainly move by side crawling around the corner area of bottom pot panel. This behavior provides the crabs with frequent opportunities to find the vents that are located at the position in the bottom side panel.

Laboratory observations revealed that the crabs escaped from vents by 'side crawling' behavior, hence their carapace length (CL) is related to the vent length, and the carapace height (CH) to the vent height. Brown (1982) also reported that escape-gap selection depends upon body length and depth rather than carapace width. Though the best vent shape was the square type in the laboratory experiment, it was not proportional to the crab body shape. The vent height was fixed at 35mm which was large enough for all immature crabs to escape. The square shape vent provides unnecessary space that can affect the selectivity for crabs and other bycatch species, consequently a nearly-square shape of

35mm in height and 45 mm in length which is more appropriate with the crab shape, as being confirmed in size selectivity experiments, was used (Fig. 3.8).

Eldridge et al. (1979) reported a self-culling pot where 2.5-inch diameter escape ports of two in the top and one in the bottom gave the best results to reduce sub-legal sized of blue crabs *Callinectes sapidus*, according to laboratory observations and field trials. They did not compare the escape position between top and bottom, while our laboratory observations confirmed that *P. pelagicus* rarely crawls up to the top panel. They also reported that the circular shape was superior to the rectangular one, due to the larger opening area in a circular shape.

The appropriate escape vent size was determined by the CL instead of CW as a parameter for the selectivity curves due to the side crawling. Regarding the size selectivity in Fig. 3.8, based on the 3 different sizes of escape vents (40, 45 and 50 mm in length × 35 mm in fixed height), a vent length of 50 mm can be the most suitable to release immature size crab because its $L_{50\%}$ of 48.7 mm is close to the size of sexual maturity (>46 mm *CL*) for ensuring a chance to reproduce at least once before being captured. This vent size of 50 mm length, however, can create the higher possibility of economic loss, particularly for small scale fishermen who operate in inshore areas and catch large amounts of small size crabs (Boutson et al, 2005), which all have a marketable value even though with a low unit price. Hence, vent size of 35×45 mm was employed in the field trials, with consideration on $L_{50\%}$ value, the closest to mature crab size as 44.4 mm, and also the smallest SR as 4.0 mm.

Various parameters can affect the catch efficiency and selectivity in pot fishing that make it difficult to isolate them in comparative studies (Furevik and Løkkerborg, 1994). In the fishing trials at sea, we compared the catch composition for sizes of blue swimming crab and species with the same conditions of pot, bait, pot setting, fishing ground, operation date etc. between conventional and vented pots. The modified pot with vents resulted in a decreased catch of immature sized of blue swimming crabs, while maintaining the catch of mature size crabs without any effect on the mature size catch efficiency. The same results were reported by Eldridge et al. (1979) for blue crab *C. sapidus*, Brown (1982) for crabs *Cancer pagurus* and lobster *Homarus gammarus*, and Nishiuchi (2001) for hair crab *Erimacrus isenbeckii*, by modifying the pot with escape openings. Furthermore, the catch reduction of small sized crabs can be related to increase the catch of large sized crabs through reduction of the effects of pot saturation or space competition effect (Fogarty and Borden, 1980; Brown, 1982; Guillory and Merrel, 1993).

There are other studies which concern the size selectivity and catch efficiency improvement in pot fisheries as Watanabe and Sasakawa (1984) by mesh size modification, Guillory and Hein (1998) by the hexagonal mesh, Kim and Ko (1990) by increased number of funnel entrances. Vazquez Archdale et al. (2006) demonstrated that bigger mesh dome-shaped pot was more efficient for caching larger crabs of *Charybdis japonica* and *P. pelagicus* with less amount of bycatch. These ideas can be also applied to the collapsible pot improvement in Thailand in the future.

The reduction of immature crab catch while maintaining mature size catch, by modifying the pot with escape vents can be one of the options for establishing a more sustainable crab pot fishery in Thailand. The optimum vent design can also be an effective management tool for bycatch/discards and ghost fishing problems, through minimizing the mortality rate of bycatch species and targeted smaller individuals as reported for the blue crab pot fishery (Eldridge, 1979; Arcement, 1993). For confirming the effect of escape vents, extensive comparative fishing trials will be required, for the purpose of fishermen's acceptance both in the small scale for shallower waters and the commercial scale for deeper waters, together with the impact analysis for the reduction of mortality due to ghost fishing in the fishing ground.

Chapter 4

Study on blue swimming crab behavior for understanding the capture process, and comparison of slope net mesh size for improving the pot catching efficiency

4.1 Introduction

Pot and trap are simple, passive fishing gears that allow animals to enter and then make it hard for them to escape. This is often achieve by; 1) putting chamber in the pot or trap that can be closed once the animal enters and, 2) having a funnel that makes it difficult for the animals to escape.

Pots and traps are widely used to capture crustaceans and fishes (Miller, 1990; Cappo and Brown, 1996). Pots and traps may be baited or unbaited, depending on the target species. The capture process comprises attraction (unbaited traps presumably attract via their structure), approaches, entries, and exits (Fogarty and Addison, 1997). For several pot types, continuous data show that target species often may enter and depart from pots apparently at will (e.g. Jury et al., 2001). The catch rate of pots thus reflects the rate at which the target species enters and exits the pot, in relation to the timing of hauling. The capture process is complicated by the fact that entry and egress may be altered by presence or absence of prior entrants (Frusher and Hoenig, 2001). Frusher and Hoenig (2001) described seasonal changes in pot selectivity for spiny lobsters in Tasmania. Those changes reflect alterations of stock size composition during the fishing season, as large lobsters exclude small lobsters from pots, and larger lobsters are progressively removed from the population by the fishery over the season. The appropriate strategy for fishing therefore depends on the costs and benefits of setting and hauling, in relation to stock composition.

The historical development of fish-capture technology have been strongly related to the level of fish behavior knowledge (Arimoto, 2001). From this view point, it can be emphasized that the success of fishing technology largely depends on how much fish behavior knowledge has been utilized for fishing gear design and operation. The availability of relatively cheap video technology has improved understanding of fisheries and fishes. He (1993) observed behavior of cod around traps. Improved information regarding sizes of fish (e.g. Harvey et al., 2001), the relative abundances of fishes (e.g. Willis and Babcock, 2000), the behavior of fish entering and leaving traps, and as the pot is hauled (e.g. Cole et al., 2003), and the behavior of fish in areas that are relatively inaccessible to observers (e.g. He 2003) have all been enhanced by video observations. However, there remains considerable scope for technology to improve fisheries, and the behavior of fish toward fishing gear is ideal for such investigations.

In Korea, Japanese shore swimming crab *Charybdis. japonica*'s growth and reproduction (Kim, 2001), and behavior towards various pot shapes and types of entrance (Kim and Ko, 1987 and Kim and Ko, 1990) have been studied; but little is known of this crab's behavior, capture process. Research on different types of pot for other crab species have examined the effect of shape (Miller, 1979), mesh size (Sinoda and Kobayashi, 1969, Guillory and Prejean, 1997, and Jeong et al., 2000), and entrance type (Salthaug, 2002), number (Miller, 1990) and location (Smith and Sumpton, 1989) on capture efficiency. Nevertheless, there are few studies comparing the efficiency of different mesh size of collapsible pots targeting blue swimming crab

The aim of this study was to clarify the blue swimming crab behavior during capture process of the collapsible pot and compared of slop net (entrance net) mesh sizes implied to the catch efficiency of the crab pot.

4.2 Materials and Methods

Regarding the slope net mesh size comparison, two smaller mesh sizes of 25 and 18 mm were compared with the conventional one of 38 mm. The square shape net for attaching at slope net was modified by turning 90° from diamond mesh. The angle of slope net was 17°, the length was 19.8-20.9 cm up to the mesh size (Fig. 4.2(a)). The upper net panel was removed (Fig. 4.2(b)) for easier and clearer to observe and record the crab behavior by video camera.

The crab behavior observations and slope net mesh size experiments were conducted in the outdoor experimental tank measured the size of $1.7 \times 1.7 \times 1.0\ m^3$ with shield roofs and the 25 cm sea water level, for covering the pot height of 19 cm. Filtered and aerated seawater of 28-30 °C was supplied into the tanks, released the active crabs with the size of 35-45 mm carapace length (medium size), 10-12 individuals into the tank. The crabs were collected by pot fishing in the coastal waters adjacent to the research station and kept in a stock tank for 2-3 days before the experiments. Travelly *Selaroides leptolepis* was used as the bait and attached by the wire, located at the center of bottom pot panel. Drop the pots that had different slope net mesh size in the tank, record the crab behavior and approaching to entrap the pot by a video camera (Panasonic, Model GS 300).

Cathing efficiency was examined by comparing the different mesh sizes at the slope net. The time spent duration of the crabs on each slope net mesh size after as the first touch until being entrapped was evaluated. The un-entrapped crab (gave up) was recorded and analyzed. The crawling speed on the slope net was also measured and estimated the data from the video recording.

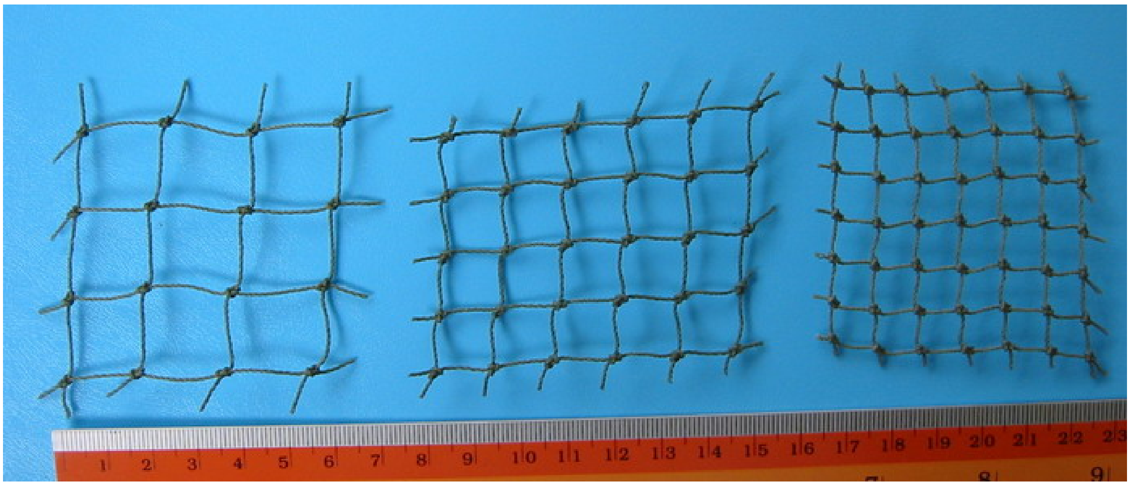
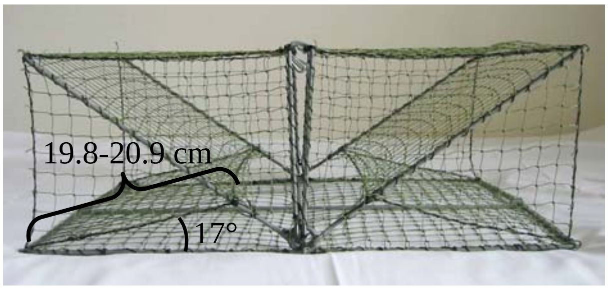


Fig. 4.1 The shape and bar of diamond mesh (38, 25 and 18 mm) after modified to be square (bar length is a half of mesh size).



(a)

(b)

Fig. 4.2 Slope net length and angle of the pot (a), the pot after was removed the upper net panel (b).

4.3 Results

The crawling patterns during the crabs crawled on the slope net since the first touch until being entrapped on 38 (conventional), 25, and 19 mm mesh size are shown in the Fig. 4.3-4.5 respectively. The crabs usually attempted to move forward trough the slope net by side crawling. However, if it was difficult to crawl up the net they moved downward and attempted to move up forward again. Crawling patterns on the slope net with smaller mesh size were more likely to be move straight forward than the conventional one (Fig. 4.3-4.5).

Time spent on the slope net until trapped for the mesh size of 18 and 25 mm tended to be shorter than that for 38 mm mesh net (Fig. 4.3-4.6). Three crabs gave up their attempts to enter the pots during crawling on 38 mm slope net, while no any gave up on 25 mm, and one individual gave up on 18 mm mesh size (Fig. 4.7). Average crawling speed on the tank floor was estimated as 10.3 cm/s, and the average maximum crawling speed on slope net mesh size of 38, 25 and 18 mm were 5.1, 5.9 and 4.7 cm/s respectively (Fig. 4.8).

The capture process comprised of attraction (with the bait), approached, and entered. The crabs attempted to escape after that. Key behavior patterns from the observations were; the crabs passed through the slope net by crawling (not swimming) to enter the pot. They never returned back if their claws can reach the ending edge of the net, but if not reached they moved backward or forward as the patterns in Fig. 4.3-4.5. After entered the pot, usually they directly approached to the bait and preferred start feeding at the belly part of the fish bait. After feeding they might take a rest first, then searched the way to escape out by crawling around the bottom pot panel and used a side of their claws push the side net panel to find the way to escape out. It was hard for them to escape out even the experimental pot without upper net panel (Fig. 4.2). From the observations in the experimental tank they usually remain at the bottom corner of the pots unless there is absolute necessity, for example; foraging behavior, avoiding other larger crabs, search the way to escape etc., during which they generally move by side walking around the corner of bottom side panel of the pot. The crabs sometimes showed territorial behavior to keep their own space while caging in the pot, fighting could happen if other crabs come closer.

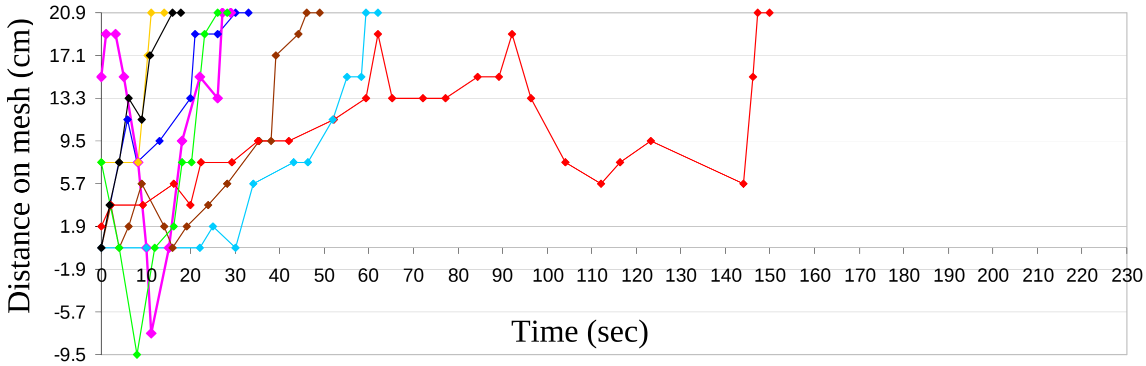


Fig. 4.3 Crawling patterns of the crabs on slope net mesh size of 38 mm (n = 8).

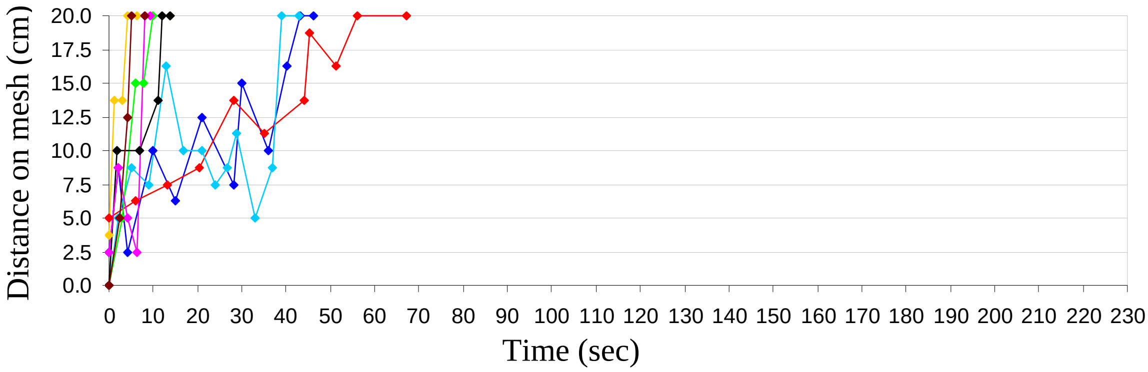


Fig. 4.4 Crawling patterns of the crabs on slope net mesh size of 25 mm (n = 8).

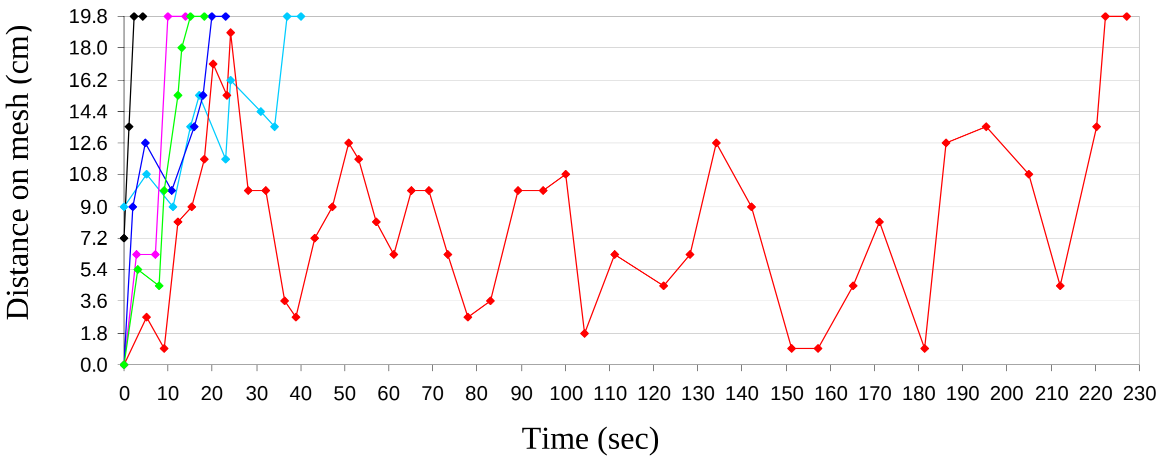


Fig. 4.5 Crawling patterns of the crabs on slope net mesh size of 18 mm (n = 6).

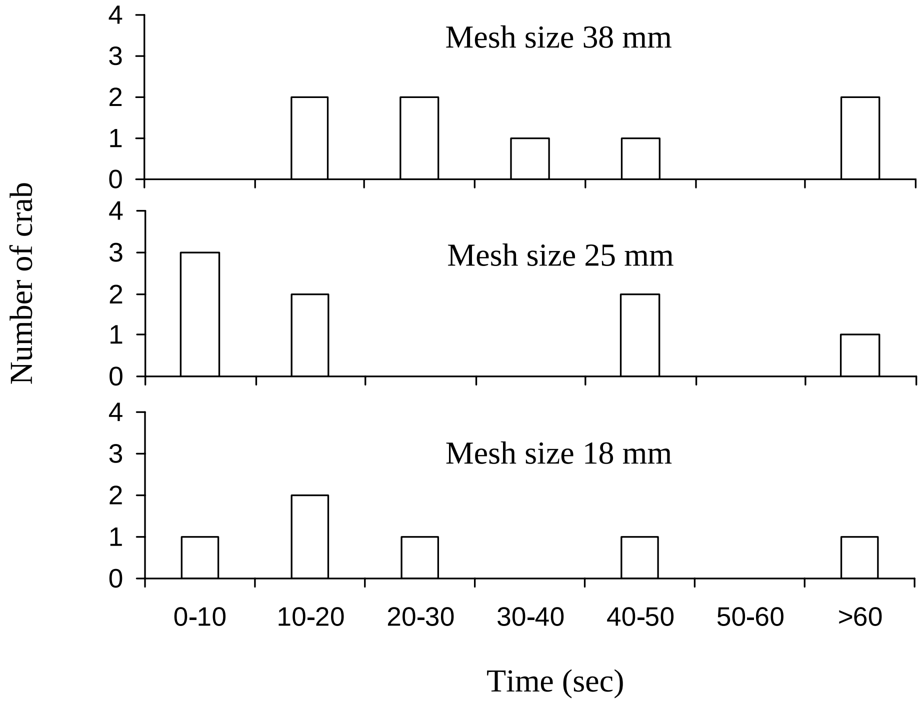


Fig. 4.6 Time spent on the slope net until trapped according to the different mesh sizes.

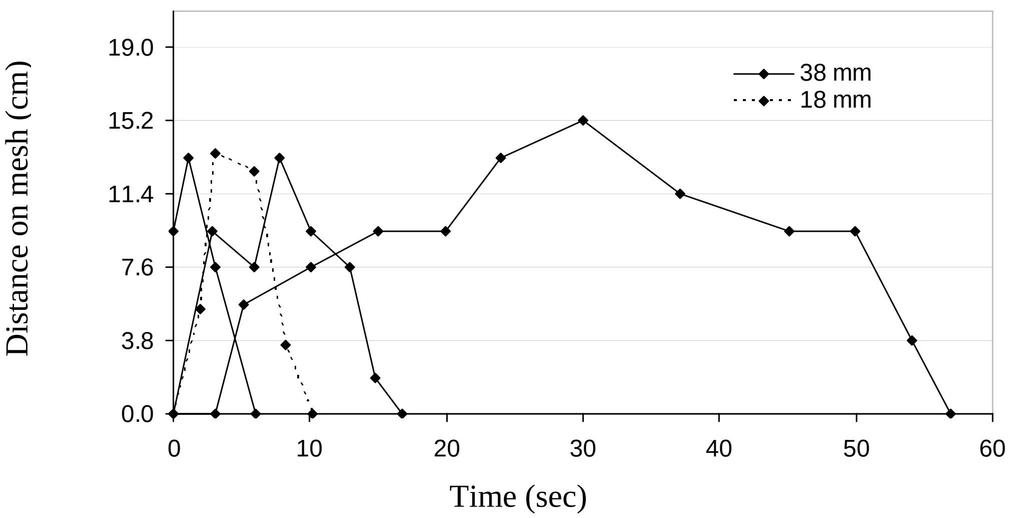


Fig. 4.7 Crawling pattern of the crabs in case of returning back (un-trapped)
(3 crabs returned back on 38 mm, and 1 crab on 18 mm mesh size).

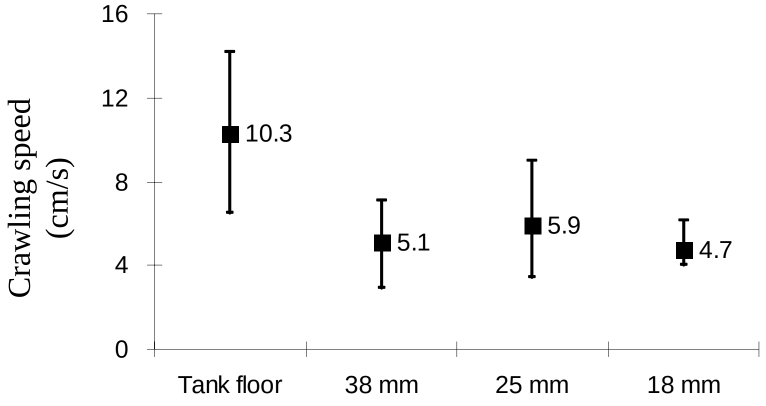


Fig. 4.8 Average crawling speed on the tank floor (n = 10) and average maximum crawling speed on slope net mesh size of 38 (n = 8), 25 (n = 8), and 18 (n = 6) mm.

4.4 Discussion

Smaller mesh size on the slope net tended to show the positive result to reduce the time spent and crawling struggling of the crabs from the first touch until entrapped. This result since they crawl on the small mesh easier than the conventional one. Though the average maximum speed among 3 mesh sizes had not much difference but the crawling patterns were different, by smaller mesh size showed that crab crawled backward less than the conventional and reduced possibility of the crab to give up (un-trapped). However, frequency of the data still is poor, the repetition of the experiment is recommended.

The crabs usually remain at the bottom corner of the pots unless there is absolute necessity and they generally move by side crawling around the corner of bottom side panel of the pot. This behavior attributes the difficulty for the crabs to escape out even though the upper net panel of the experiment pot was removed.

Though the repetition of data among the three mesh sizes used during the experiment was poor, author suspect that the smaller mesh size was the main affecting crawling efficiency and related to capture efficiency, particularly reducing the un-trapping of the crabs that touched, crawled, and entrapped in the pot. On larger mesh, the spines of the crab's carapace and claws were fell down the slope net panel easily, and uncomfortable to move forward up, hence the crabs had to try to enter many times and spend the longer time on it, that increase the possibility to give up entering to the pot.

Crab behavior towards the netting of pots showed that reducing the mesh size of the bottom half of the entrance funnel in Scottish creels increased the catches of crabs and lobsters (Thomas, 1953). The effect of mesh size in pots has been reported to effect catching efficiency and size composition in the fishery of the crab *Chionoecetes japonicus* (Watanabe and Yamasaki, 1999). Mesh size differences affected the catching efficiency of pots and the size composition of the crab *C. japonicus*, where smaller meshes caught 1.2–2.9 times as many crabs as did the larger meshes, but mainly small ones (Sinoda and Kobayashi, 1969). Smaller mesh size of the pots retained more small crabs (Vazquez Archdale et al., 2006). Watanabe and Sasakawa (1984) found that the ability of the crab *Eromacrus isenbeckii* to climb a net was also affected by the mesh size. They reported that crab juveniles could climb 40° mm mesh netting; but not 90° mm because of their shorter legs. Fishing trials with the crab *E. isenbeckii* showed also that larger meshes resulted in lower total crab catches per pot; but with a notable decrease in the quantity of undersized crabs. Since the pots employed in this study had entrances with different mesh sizes this may have affected the efficiency of the crawling and the catch.

In the blue crab *Callinectes sapidus* pot fishery, Guillory and Hein, (1998) found that the shape of the meshes affected the catch and that hexagonal meshes caught a larger number of legal sized crabs, while smaller square and rectangular mesh sizes caught more undersized crabs than larger ones. Nishiuchi (2001) report that the legal size of hair crab *E. isenbeckii* can be selective and efficient when appropriate combination of mesh size, escape vents and entrances are used.

The crabs passed through the slope net by crawling to enter the pot and never returned back if their claws can reach the ending edge of slope net. During being entrapped inside the pot, usually the crabs remain but if they move they crawl mainly around the bottom panel. These behavior patterns can give the idea for shortening the slope net distance and reducing the pot height of the conventional pot design which should be proved in the future study. Through the behavior observations and slope net mesh size comparison; smaller mesh size, shorten the net panel at the slope net, and reducing the pot height are recommended points to consider for improving the catch efficiency.

Chapter 5

Comparative fishing trials between conventional and modified pots

5.1 Introduction

The blue swimming crab *Portunus pelagicus* is an important coastal species in Thailand both for the domestic and export markets, with an annual production of around 40,000 tons (Fisheries Statistics of Thailand, 2007), worth about US $ 50 million value. It is well known for the good taste. Collapsible pot is a major fishing gear type for catching the crab in the gulf of Thailand, where it is commercially exploited using bottom gill nets and pots, which has resulted in a decrease of catch per unit effort, and increased catch of smaller size blue swimming crab (Jindalikit, 2001).

Research on different types of pot for other crab species has examined the effect of shape (Miller, 1979), entrance type (Salthaug, 2002), number (Miller, 1990) and location (Smith and Sumpton, 1989) on capture efficiency. Nevertheless, there are few studies comparing the efficiency of different pots (Furevik and Løkkeborg, 1994, Vazquez Archdale et al., 2003, Vazquez Archdale et al., 2006 and Vazques Archdale and Kuwahara, 2005) particularly focusing on effect of mesh size and escape vent for collapsible box-shaped pot (Sinoda and Kobayashi, 1969, Guillory and Prejean, 1997, Guillory, 1998; Jeong et al., 2000).

Author has previously examined the appropriate vents to exclude the small size crab (Chapter 3), and compared mesh sizes at slope net to evaluate the catch efficiency (Chapter 4) including laboratory behavior observations towards the pot. In this chapter, fishing trials to compare the performance of conventional pot and modified pot (with vents and smaller mesh size at lower slope net) was investigated both in small scale and commercial scale crab pot. The aim of this study was to clarify the effect of escape vents and smaller mesh size of slope net on the catch of blue swimming crab and other bycath of the collapsible box-shaped pot. This study also attempted to improve the material of the vents by changing the material from the wire to twine of polyethylene to solve the problem of loosing the wire vent shape after the operation.

5.2 Materials and methods

5.2.1 Small scale crab pot

The comparative fishing among 4 different types of pot such as; conventional (control), smaller mesh size (25 mm) at slope net, smaller mesh size at slope net with 1×2 mesh vent (19×38 mm), and smaller mesh size at slope net with 1×3 mesh vent (19×57 mm) was tested in fishing trials on 19 and 20 Jan 2008, in the shallow waters adjacent to the Bang-Pra Beach, Chonburi Province, in the upper Gulf of Thailand (Fig. 5.1(a)) as a fishing ground for small scale crab pot fishermen, about 0.5-1.0 km from shore with the depth of 4-6 m, and substratum composed of muddy sand. Smaller mesh size was replaced at the lower slope panel and extended to the bottom panel of the pots. The escape vents were cut from mesh size at bottom side panel, strengthen the vent edge by binding with polyethylene twine diameter of 1 mm (Fig. 5.2). This method was made in order to solve the problem of loosing/changing the shape of wire vents after the operation. The vented pots for comparative trials became as shown in Fig. 5.3. Thirty pots of each type were used and all pots were deployed individually by employing a fisherman. Each pot connected to a 10-12 m length of polypropylene rope and marked with a buoy (Fig. 5.4). They were baited with approximately the same sized fresh trevally *Selaroides leptolepis* pierced and bound by wire at the center bottom of the pots. Four types of pot were dropped one by one with intervals of 20-30 m, with 13-15 hrs soaking time following the normal operation procedure of small-scale crab pot fishermen. Pots were retrieved and the catch species and size of individuals from each pot recorded.

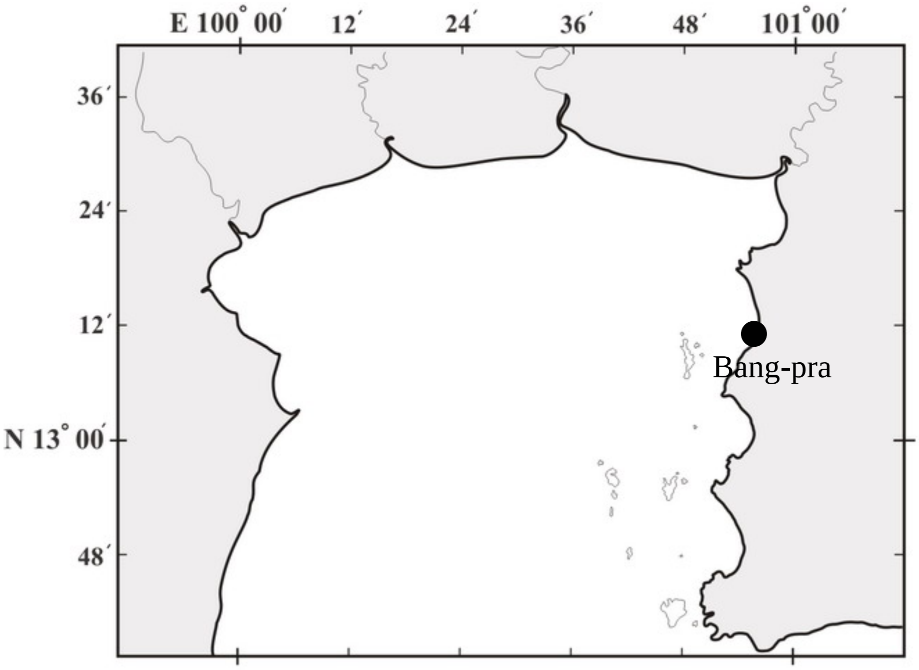
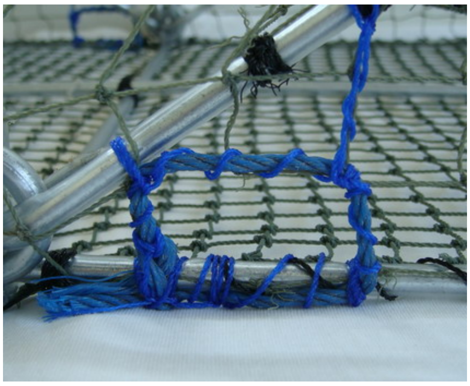


Fig. 5.1 Location map of study area (Bang-pra Beach, Chonburi Province).



(a)

(b)

Fig. 5.2 The vents were cut the mesh size and bound with polyethylene twine at the both both side of bottom side panel of the pot for comparative fishing trials [a = vent of 1×2 mesh (19×38 mm), b = vent of 1×3 mesh (19×56 mm)].

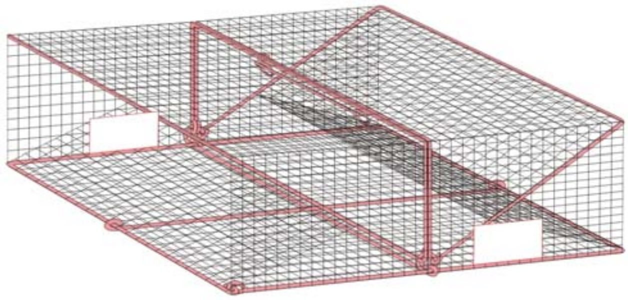


Fig. 5.3 Escape vents were located at both sides of the bottom of the side panel for the comparative fishing trials

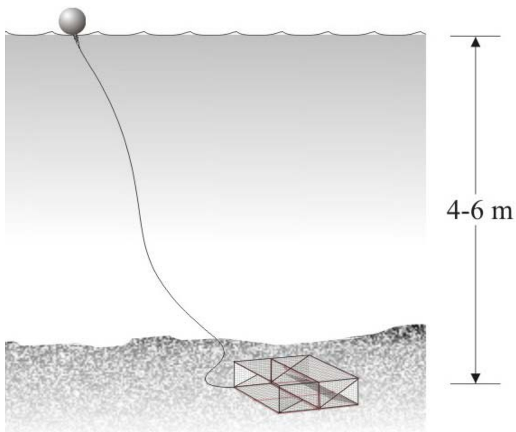


Fig. 5.4 The configuration of a deployed pot, individually set and connected with rope to the buoy.

5.2.2 Commercial scale crab pot

Three types of pot; conventional (control), smaller mesh size (25 mm) at slope net, and conventional pot with 1×3 mesh vented pot, were tested in the fishing trials at sea known as a fishing ground for commercial scale crab pot, northwest of Si-Chang Island, Chonburi Province, in the upper Gulf of Thailand (Fig. 5.5), 15-20 m depth, on 6 and 8 May 2008 by employing a commercial boat. The conventional pots were obtained from the crab boat. The smaller mesh size at slope net, and vented pots were prepared by cutting of 1×3 mesh and prepared the vents with the same method as in small scale comparison. Ninety pots of each type were used and all pots were deployed with long-line setting by the fishermen onboard. Each pot connected to a 2.5 m length of polypropylene branch line rope and connected to the main line. All pots were baited with approximately the same sized fresh tilapia *Oreochromis niloticus* pierced by a wire rod at the center bottom of the pots. Three types of pot were dropped type by type continuously in the early morning with intervals of 12 m, about 6 hrs soaking time following the normal operation procedure of commercial-scale crab pot fishermen. Pots were retrieved by hauler machine, and the catch species and size of individuals from each pot type were recorded and compared.

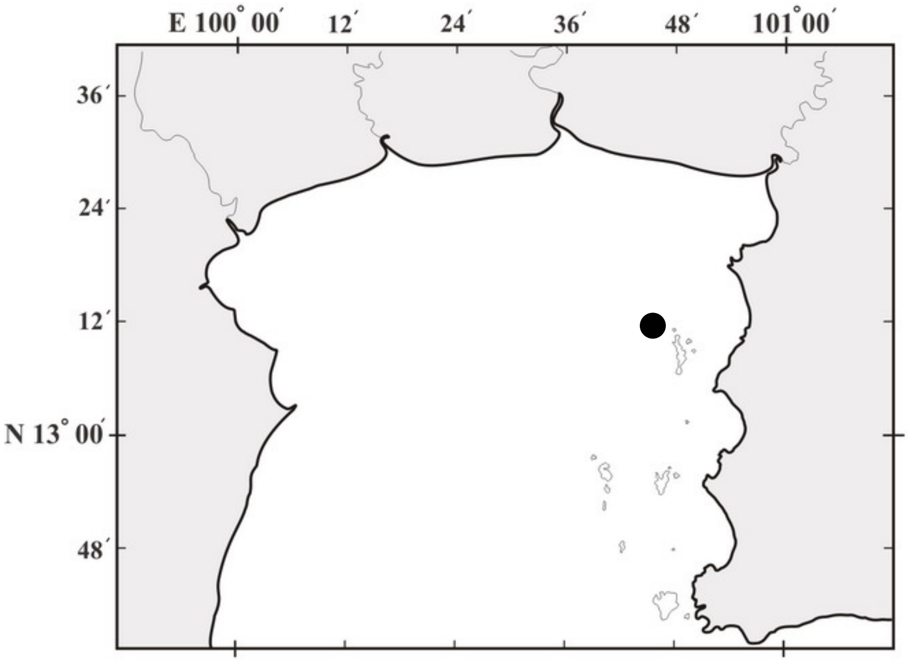


Fig. 5.5 Location map of study area (northwest of Si-Chang Island, Chonburi Province)

5.3 Result

5.3.1 Result from small scale

The overall catch (catch pooled on 19-20 Jan 2008) composition by number of blue swimming crabs and other bycatch species for 4 types of pot shows the differences in numbers, catch composition, their average length size, and size range (Min-Max) as in Table

5.1. Regarding the comparative for blue swimming crab, conventional pots were assumed as control pot, the smaller mesh size at slope net pots could increase the number of the crabs caught from 24 to 35 crabs, while the both types of vented pot (1×2 and 1×3 mesh) pots caught similar number with the control as 23 and 25 crabs respectively.

According to the bycatch composition by number of individuals, Table 3.5 showed that the main bycatch were ridged swimming crab, smoothshelled swimming crab and filefish. The others caught species were small number as incidentally catch. The smaller mesh size at slope net pots caught larger number of the main catch species than control, except for the case of ridged swimming crab. The smaller mesh size pot also caught species with larger than the both types of vented pot. These demonstrate the positive efficiency function of smaller mesh size at slope net on the catch amount.

The smaller mesh size at slope net with the vents of 1×2 and 1×3 mesh pots could reduce the number of all bycatch species while maintain the similar catch number of blue swimming crabs when compared with control pots (Table 3.5). Those results show that the vented pots can reduce the number of bycatch caught while not reducing the catch efficiency for the blue swimming crabs. And 1×3 mesh vented pots show the better positive results to reduce the bycatch compared with 1×2 mesh vented.

The blue swimming crab size from 4 different pots comparative fishing trials is shown in Fig. 5.6. Compared with the control pots, the smaller mesh size at slope net pots show the positive result to catch the small size crab (26-45 mm CL), the both of vented pots shows the positive result to reducing the small size of the crab catch while maintain the catch number of the larger size, particularly in 1×3 mesh vented pots (Fig. 5.6).

Table 5.1 The catch according to 4 different types of pot from 2 comparative fishing trials (pooled catch on 19, 20 Jan 2008, n = 30 pots/each)

Species	Conventional pot (Control)				Smaller ms at slope net				Smaller ms at slope net + (1x2 vent)				Smaller ms at slope net + (1x3 vent)			
	No. of catch	% by No.	Mean length	Size range	No. of catch	% by No.	Mean length	Size range	No. of catch	% by No.	Mean length	Size range	No. of catch	% by No.	Mean length	Size range
1. Blue swimming crab, *Portunus pelagicus*	24	25.8	39.9	31-52	35	36.8	40.7	29-51	23	31.9	41.2	32-50	25	41.7	45.24	27-60
2. Ridged swimming crab, *Charybdis natator*	58	62.4	32.8	21-49	48	50.5	32.0	14-50	35	48.6	30.5	16-44	24	40.0	28.13	18-36
3. Smootshelled swimming, crab *Charybdis affinis*	4	4.3	31.0	28-35	8	8.4	30.9	26-34	3	4.2	25.3	22-31	0	0	-	-
4. Filefish, *Monacanthus chinensis*	4	4.3	81.0	69-107	3	3.2	91	62-130	4	5.6	81.0	55-123	4	6.7	106.75	53-179
5. Flower moon crab, *Matuta planipes*	1	1.1	-	34	0	-	-	-	0	-	-	-	0	0	-	-
6. Mangrove stone crab, *Myomenippe hardwickii*	1	1.1	-	52	0	0	-	-	2	2.8	56.5	53-60	1	1.7	-	50
7. Hermit crab, *Clibanarius longitarsus*	1	1.1	-	78	0	0	-	-	1	1.4	-	67	0	0	-	-
8. Grunter, *Pelates quadrilineatus*	0	0	-	-	1	1.1	-	19	0	0	-	-	3	5.0	75.33	72-79
9. Spinefoot, *Siganus oramin*	0	0	-	-	0	0	-	-	2	2.8	138.0	131-145	0	0	-	-
10. Wrasse, *Halichoeres* sp.	0	0	-	-	0	0	-	-	2	2.8	133.5	132-135	0	0	-	-
11. Toad fish, *Batrachus grunniens*	0	0	-	-	0	0	-	-	0	0	-	-	2	3.3	163	156-170
12. Spiral melongena, *Pugilina cochlidium*	0	0	-	-	0	0	-	-	0	0	-	-	1	1.7	-	53
Total	93	100			95	100			72	100			60	100		

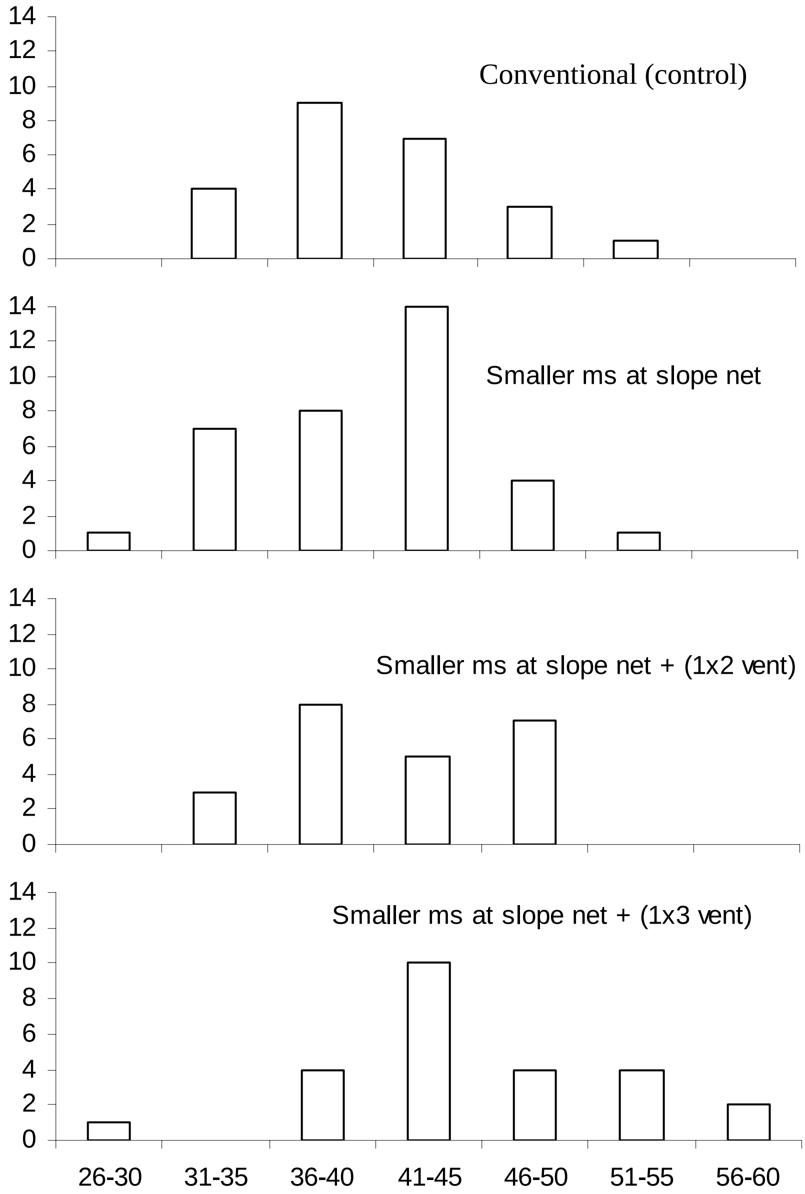


Fig. 5.6 Blue swimming crab size from different pots comparative fishing trials (catch pooled on 19-20 Jan 2008)**.**

5.3.2 Result from the commercial scale

Based on the comparative fishing trials on 6 and 8 May 2008 (catch pooled), the overall catch comparison among 3 different types of pot; conventional, smaller mesh size at slope net, and conventional with vents (1×3 mesh) is shown in Table. 5.2.

Table 5.2 The catch number from comparative fishing trials (pooled catch on 6 and 8 May 2008, n = 90 pots/day/each type)

Common name	Scientific name	Number of catch		
		Convent-ional pots	Smaller ms pots	Conventional with vents pots
1. Blue swimming crab*	*Portunus pelagicus*	17	15	14
2. Filefish*	*Monacanthus chinensis*	10	12	14
3. Grunter*	*Therapon jarbua*	0	2	12
4. Smoothshelled swimming crab	*Charybdis affinis*	6	10	7
5. Square-shelled crab	*Galene bispinosa*	13	24	8
6. Octopus*	*Octopus* sp.	5	1	2
7. Murex shell	*Murex* sp.	3	0	3
8. Silver biddy*	*Gerres* sp.	0	0	1
9. Mantis shrimp*	*Miyakea nepa*	6	13	3
10. Shrimp*	*Penaeus* sp.	0	0	1
11. Cuttlefish*	*Sepia pharaonis*	1	3	0
12. Threadfin bream*	*Nemipterus* sp.	1	1	0
13. Butterfly fish	*Chaetodontoplus mesoleucus*	4	0	0
14. Goby	*Yongeichthys nebulosus*	4	2	0
15. Ponyfish	*Leiognathus* sp.	0	1	0
16. Toad fish	*Batrachus grunniens*	0	1	0
Total		53	70	51

* Indicate those species are of commercial value.

Since the catch from the 2 trials were very poor, hence the results might not clear and difficult to discuss. However, from the Table 5.2, the catch number of blue swimming crabs among 3 different pots were similar, it showed the largest catch in conventional pots as 17 crabs, followed with the smaller mesh size at slope net pots as 15 crabs, and conventional pot with vents was the least as 14 crabs.

The size of blue swimming crab from the comparative fishing is shown in Fig. 5.7. Compared with control pot, smaller mesh size at slope net pots showed the positive results to catch the small size crabs (31-45 mm CL) but slightly reduced the catch number of the larger (>45 mm) size crab, conventional pots with vents tended to reduce the small size crab while maintained the large crabs.

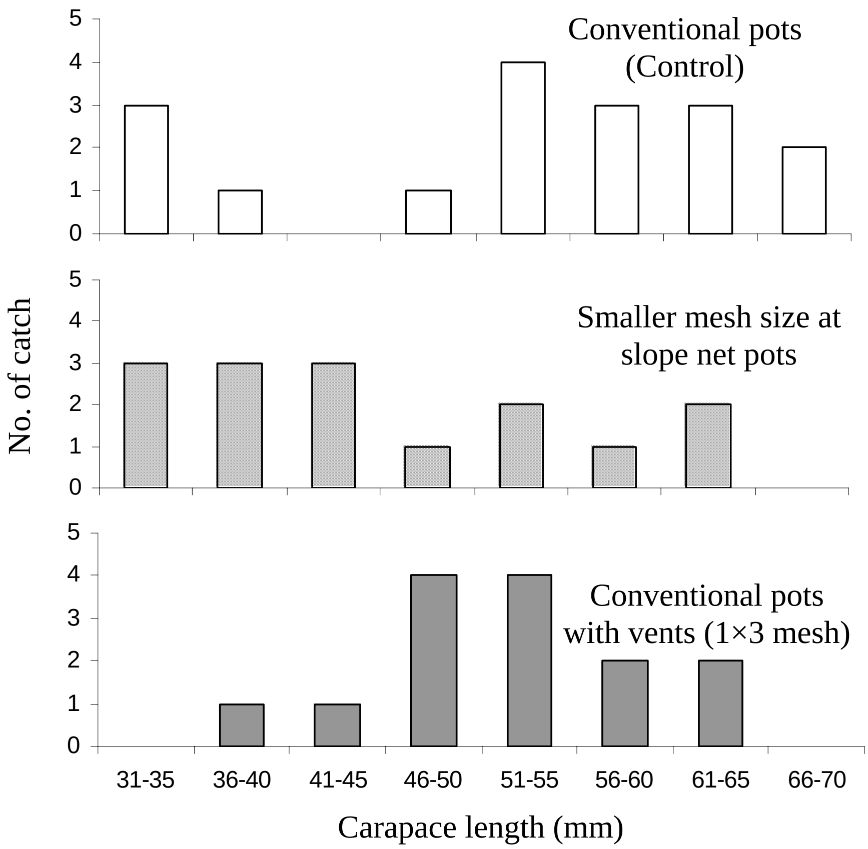


Fig. 5.7 Blue swimming crab size from the comparative fishing trials (catch pooled on 6, 8 May 2008).

The catch number comparison of some bycatch species between conventional pots VS convention pots with vents, and conventional pot VS smaller mesh size at slope net pots is shown in Fig. 5.8-5.9 respectively. Fig. 5.8, the vented pot showed the positive results to reduce the low/non commercial values such as square-shelled crab, butterfly fish and goby while showed the better catch on commercial value such as filefish and grunter, except for mantis shrimp. Fig. 5.9 showed that the smaller mesh size at slope net pots caught larger number of the main bycatch species than conventional. This demonstrates the positive efficiency function of smaller mesh size at slope net on the catch amount of bycatch species.

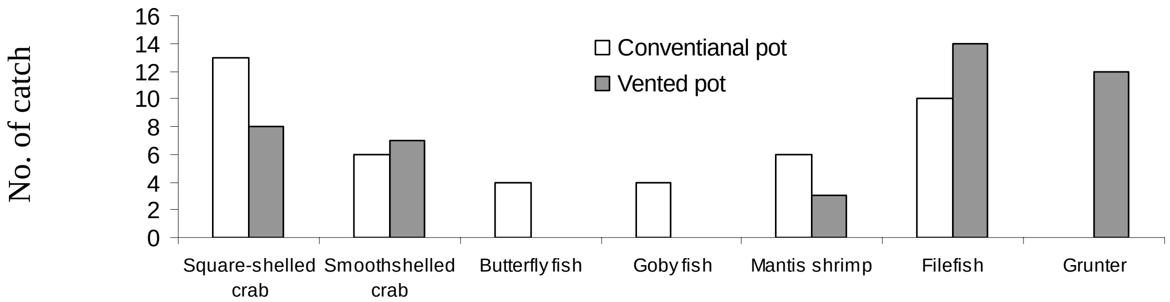


Fig. 5.8 Number of some catch species from conventional and vented pots.

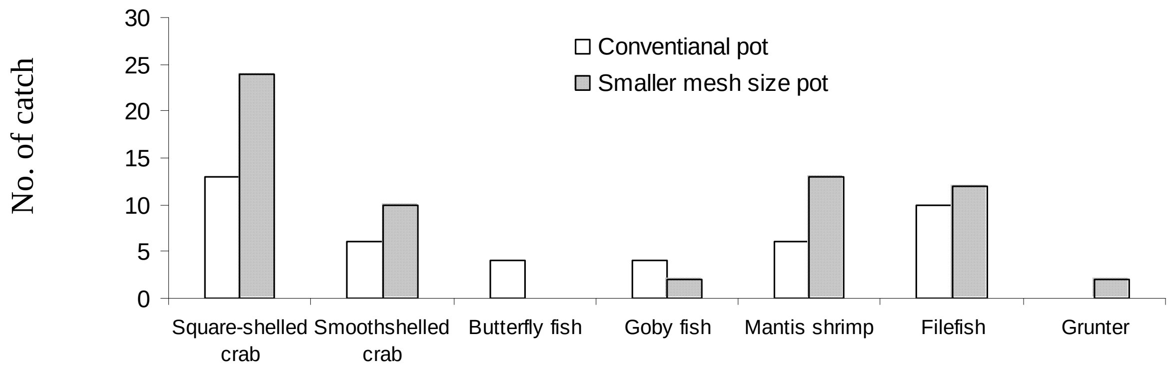


Fig. 5.9 Number of some catch species from conventional and smaller mesh size at slope net pots.

5.4 Discussion

Improving the escape vents by changing the material from wire to polyethylene twine showed the positive results to maintain the vent shape. The shape of vents is folded when the pots are collapsed, and can reform the shape again when the pots are set up (boxing) due to the specification of the shape material (polyethylene).

Though the poor catch through the fishing trials particularly on commercial scale, the smaller mesh size at slope net and escape vents were the main affecting blue swimming crab size and other species selection. Regarding behavioral observations in the laboratory (Chapter 3-4) determined that the small size can escape from the vent but they can not escape from the conventional pot because the tight slit entrances prevented the crabs from getting out (Vazquez Archdale et al., 2007).

Smaller mesh size at slope net could increase the crab catch species particularly the small size crabs, since it is easier for them to crawl through, and spines on the crab's carapace and claws would tangle with the netting material lesser. The effect of mesh size in pots has been reported to effect catching efficiency and size composition in the fishery of the crab *Chionoecetes japonicus* (Watanabe and Yamasaki, 1999). Thomas (1953) showed that reducing the mesh size of the bottom half of the entrance funnel in Scottish creels increased the catches of crabs and lobsters. Watanabe and Sasakawa (1984) reported mesh size could effect on climbing of Hair crab *Erimacrus isenbeckii*, juvenile crabs could climb on 40 mm mesh size but could not on 90 mm due to their shorter legs. Fishing trials with the crab *E. isenbeckii* (Watanabe and Sasakawa, 1984) showed also that larger meshes resulted in lower total crab catches per pot; but with a notable decrease in the quantity of undersized crabs. In the commercial scale trials, larger size of blue swimming crabs (>45 mm) were caught in small numbers the smaller mesh size pot, possibly due to the effect of other species in the pot which this type of pot catch the biggest number. Some species may be aggressive and preventing the crabs from entering the pot (Williams and Hill, 1982).

In the blue crab *Callinectes sapidus* pot fishery (Guillory and Hein, 1998), it was found that the shape of the meshes affected the catch and that hexagonal meshes caught a larger number of legal sized crabs, while smaller square and rectangular mesh sizes caught more undersized crabs than larger ones. Mesh size differences affected the catching efficiency of pots and the size composition of the crab *C. japonicus*, where smaller meshes caught 1.2–2.9 times as many crabs as did the larger meshes, but mainly small ones (Sinoda and Kobayashi, 1969). Vazquez Archdale et al. (2006) demonstrated that bigger mesh dome-shaped pot was more efficient for caching the larger crabs of *Charybdis japonica* and *Portunus Pelagicus* with less amount of bycatch. They suspect that entrance type and mesh size were the main effecting capture efficiency.

Differences in the catch amount of non-target species were found among all pot types. The smaller mesh size at slope net pot caught most, followed with the conventional, and the vented pot the least. The smaller meshes contributed to the catch and higher retention of the first. The vented pot retained less because its allowed for some of the catch to escape after the bait was consumed. However it may effect to some economic bycatch species for commercial scale crab pot, such as the mantis shrimp.

The vents contribute small size of blue swimming crabs to escape without any effect on larger size catch efficiency. They also allow some bycatch species that mostly be discarded from small scale pot fishery. Eldridge et al. (1979) demonstrated that escape ports could reduce in catch of sublegal crab *C. sapidus* 82%. Brown (1982) reported that, in the field trials the use of all escape gaps tested resulted in significant decreases in the number of undersized crabs and lobster retained. Nishiuchi (2001) found the legal size of hair crab *E.*

isenbeckii can be selective and efficient when appropriate combination of mesh size, escape vents and entrances is used.

The reduction small size crabs catch while maintaining larger size, through optimum escape vents selection would increase many benefits to pot fishery. The catch rate of small size crab will be decreased and may increase big size crab because of pot saturation effects that occur due to excessive retention of smaller crabs (Guillory and Merrell, 1993). Increased catches of legal-size crabs (probably the result of decreased competition for space within) have been reported in traps where escape vents were used to reduce sublegal catch (Fogarty and Borden, 1980; Brown, 1982; Guillory and Merrell, 1993). Bycatch species that associate to discard problems also will be decreased. And if the pot lost at sea, ghost fishing mortality would be reduced since the escape vents allow some captured animals to escape out. Mortality in vented traps was about one-third that of unvented because of a reduction in sublegal blue crab catch (Arcement and Guillory, 1993). The size of blue swimming crabs and species can be selective and efficient when appropriate combination of mesh size at slope net (entrance net) and escape vents is used for the box-shaped collapsible pot.

Chapter 6

Simulated ghost fishing experiment for collapsible crab pot in Thailand

6.1 Introduction

Ghost fishing can be defined as the ability of fishing gear to continue fishing after all control of that gear is lost by the fisherman (Smolowitz, 1978a). It refers to derelict fishing gears either lost or abandoned which remain their capture function in water and continue to induce mortality of aquatic organisms without human control (Matsuoka, 2005). Gear may be lost for a variety of reasons including bad weathers, bottom snags, navigational collisions, faulty fishing methods, abandonment, human error, vandalism, and gear failure (Laist, 1995). Pot ghost fishing can occur through a variety of mechanism; auto-rebaiting, rebaiting by other species, attraction by living conspecifics or attraction by the pot alone (Breen, 1990). The pot may kill through starvation of by facilitating cannibalism and predation. The ghost fishing mortality rate is currently an intangible and remains of significant concern to both fishers and fisheries managers (Jennings and Kaiser, 1988). Lost or abandoned gears have the potential to fish for prolonged periods (Erzuni et al., 1997; Bulltimore et al., 2001; Nakashima and Matsuoka, 2004) and ghost fishing accounts for between 5-30% of annual landings on some commercial grounds (Laist, 1995). In trap fishery of Kuwait financial losses due to ghost fishing may reach 3-13.5% of total catch value (Mathews et al., 1987). Irrespective of the fact that fishers are aware of the preceding risk factors, sustained losses due to ghost fishing continue to occur (Carr and Harris, 1994). The little known about the frequency of static gear loss of for how long such they continue to fish. The lack of information relating to this phenomenon results from the incidents and difficulty in undertaking long-term studies in a realistic manner (Bullimore et al., 2001; Matsuoka, 2005).

Estimates of proportion of fishing gears lost from fleets appear to be substantial. Considerable numbers of pots are also lost each year from some fishing operations, although estimates vary greatly between different studies. For example, Kruse and Kimker estimated that in 1990 and 1993; 31,600 pots for king crab *Paralithodes camtschaticus* fishery per year were lost in the North American Bristol Bay, whereas Paul et al. (1994) and Stevens (1996) estimated that losses from the same fishery were 20,000 and 70,000 pots per year respectively. Breen (1987) estimated that 11% of traps used in Dungeness crab *Cancer magister* fishery of British Columbia are lost in each year. Overall ghost mortality is dependent upon the number of ghost traps, trap location, season, length of the ghost fishing period and mortality rate per trap (Guillory, 2001; Matsuoka, 2005). The mortalities continue until the trap deteriorates sufficiently for holes to develop in the wire mesh, allowing captured individuals to escape. The life expectancy of vinyl-coated wire traps averages 2 years or more, depending upon salinity (Shively, 1997).

Pots ghost fishing, possibly the best information comes from underwater observations of simulated lost, and the studies short to long term must be carefully considered (Breen, 1990). Pecci et al. (1978) reported 30% escapement in American lobsters entering simulated lost traps, mortality rate was 25%, observed by divers. Breen (1987) simulated 10 lost Dungeness crab traps in a sheltered bay for 1 year, during which approximately 100 crabs died in the traps and still killing the crabs at a steady rate. Moran and Jenke (1989) simulated lost traps for various periods from 1 to 21 days. Traps were observed in the field with underwater video camera (Dews et al. 1988; Moran and Jenke, 1989) partly to examine possible ghost fishing.

Collapsible pot targeting blue swimming crab *Portunus pelagicus* (Fig. 6.1) has recently becomes a major type of fishing gear and operated over year in the Gulf of Thailand. Small scale fishermen operate their pots inshore with the numbers of 200-300 pots/boat while commercial scale fishermen operate further (offshore) with the numbers of 2,000-5,000 pots onboard. Both fishing types have possibilities to loss their pots at sea. According to the fishermen interview (Authors, unpublished), inshore fishermen may loss pots mainly as a result of float line either cut or sink due to tangle with others pot owners or other gears (particularly crab bottom gillnets) and some push net boats that conduct inshore (illegally) while offshore grounds lost pots as a result of trawlers activity. The ghost fishing effects on the blue swimming crab and other animals from the pot fishing in Thailand have been not evaluated and reported.

This study was undertaken by simulated lost collapsible pots to quantify the catch rate and estimate ghost fishing mortality of organism numbers, describe changes in catch rate over a year, and record any deterioration in the integrity of the simulated pots in a small scale fishing ground (inshore) in the upper Gulf of Thailand.

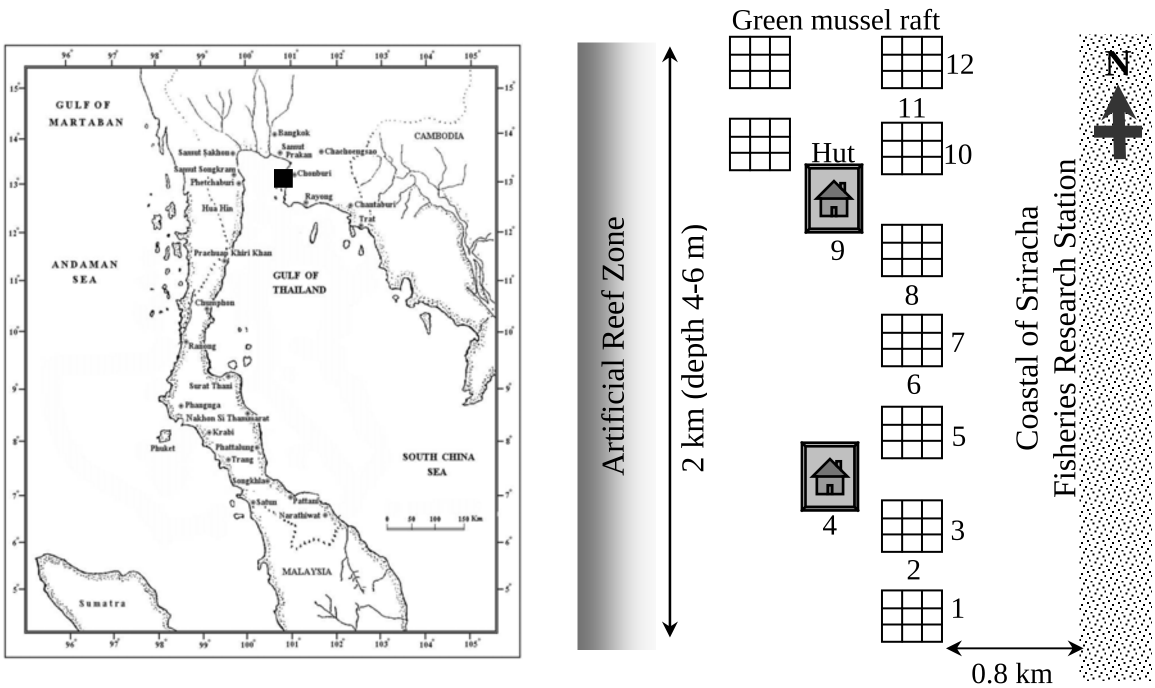
(a) (b)

Fig. 6.1 Collapsible pot with the size of 36×54×19 cm (a), and blue swimming crab, *Portunus pelagicus* (b).

6.2 Materials and methods

6.2.1 Site selection

The study site was located at coastal area of Sriracha Fisheries Research Station, Kasetsart University, Chonburi Province, in the upper gulf of Thailand (Fig. 6.2(a)). It is the green mussel sea farming of the station as well as a fishing ground for small scale crab pot fishermen, about 0.8 km from shore with the depth of 4-6 m, and the substratum composed of sand mix mud.



(a) (b)

Fig. 6.2 (a) Study site (■) where the simulated pots were set the deployment, and (b) positions of each pot; No. 1, 3, 5, 7, 10 and 12 set under the edge rafts; No. 2, 6, 8 and 11 set between the rafts, and No. 4 and 9 set beside the huts.

6.2.2 Experiment Protocol

Twelve new collapsible crab pots were obtained from a fisherman for simulating the lost gear in the study site. The pots have box-shaped, dimensions of 360×540×190 mm with 2 slit entrances (Fig. 6.1-a), frame structure made from galvanized iron and covered with green polyethylene square-shaped (modified from diamond-shaped) of 38 mm mesh size, and the hook was attached at the top panel for pot set up and collapse function.

The 12 simulated pots were deployed individually either between or under the edge of the green mussel rafts and beside the huts around the site as shown in Fig. 6.2-b, and marked with surface buoys on 26 April 2006 at the study site. Each pot was attached to a polypropylene rope by using 10-12 m length, and anchored with 20 kg cement block, baited (only the first deployment) with a trevally *Selaroides leptolepis* by piercing with the wire and bounded at the center of bottom pot panel.

6.2.3 Data recording

Observations on each pot were conducted by scuba diving in the day time to monitor the situation of each pot after the deployment as either every day or 2 days for the first week, then once a week for the first month, and about once a month afterward up to 369 days (30 Apr 2007) since the initial deployment. Each dive in each pot recorded the bait and pots conditions, identified the entire species, estimated the size, and observed their behavior and condition (e.g. active, exhaust, hurt). The estimates of entrapped animals length and condition recording for individual species from previous monitoring were observed to distinguish new animal from the old entrapped.

6.2.4 Data analysis

During the simulation, entire animals of each pot were recorded and separated the new catch from old. The animals were identified following Allen (2000) and Matchacheep (2004), commercial and non-commercial were categorized. Catch rates were calculated as the number of newly recorded animals entrapped of each pot, then combined to determine the total catch on each consecutive sampling occasion. Season was also examined the effect to the catch. Because the inter-sample period and number of pots varied throughout the simulate experiment, the catch data were expressed as Catch-Pet-Unit-Effort (CPUE) data with the following formula (Bullimore et al., 2001);

$$CPUE = N_j/(Ep(t_j - t_i))$$

Where N_j = number of newly caught animals,

Ep = number of pots available, and

$t_j - t_i$ = days interval since the previous observation (t_i).

Catch rate does not provide an indication of the total actual mortality of individuals associated with the ghost fishing pots. Mortality was confirmed when diving observed the dead bodies remain of individuals in the pot. The mortality of a species is denoted as (Matsuoka, 2005);

$$Nm = Eg \times m,$$

where Eg is the number of ghost fishing gear in the fishing ground, and m is the mortality rate per gear during a unit period of time. The m was monitored on dead bodies of animals underwater or can be estimated as;

$$m = n_e \times k_m,$$

where n_e is the number of animal entering into pots by a species in a unit period of time, and the k_m is the death rate out of n_e. We used only catches (all species) of the first monitoring (27 Apr 2006, day 1) to analyze the escapement and mortality rate because the observations were more frequent in beginning month until 35 days after initial deployment, which we could investigate the cause (escaped or dead) of reduced numbers of animals inside the pots, and assumed that all escaped animals survived. The days that entire animal escaped or dead were recorded, thus we were able to find the relation between the mortality rate when the time passed until day 34. Based on the derivable relation, quantify the mortality of newly animals captured per pot per month were estimated and cumulated the mortalities up to approximately 1 year after initial deployment.

6.3 Results

The fish bait within pots was either consumed or decomposed completely in 3 days, by day 2 fragments were observed in 8 of 12 pots, and by day 4 had no any remnants of the bait.

Throughout 369 days of the experiment, 22 different species entered the simulated lost pots and were identified as shown in Table 6.1. The pots entrapped 224 animals in total which were classified as commercial catch 50.9 % (114 animals, 16 species) and as by-catch 49.1 % (no marketable value, 110 animals, 6 species) by number. Of the bycatch, toad fish and sea urchin dominated, comprised 52.7% (n = 58) and 36.4 % (n = 40) respectively. The entire animals of each pot were recorded and the new catch separated from old, then combined to determine the total catch at various time intervals after first deployment as shown in the table. It also shows the numbers of pot available in each monitoring and the mean catch/pot/year of each species. The 12 pots catch minimum of 7.10 toad fish *Batrachus grunniens*, 5.62 sea urchins *Diadema setosum*, and 5.47 ridged swimming crabs *Charybdis natator* per pot/year. Other 19 species entrapped the pots including commercial species such as, spiral melongena *Pugilina cochlidium*, filefish *Monacanthus chinensis*, catfish *Plotosus canius*, etc. During the monitoring, 1 pot lost by day 22 and further, 5 pots in total lost in day 97. After that, available pot numbers reduced due to damaging from accumulation of fouling organisms.

CPUE for all animals according to the days passed throughout the simulation is shown in Fig. 6.3. It increased rapidly after initial deployment to a maximum rate by day 135 and then decreased inverse with function of time afterward with accumulation of fouling organisms until reach a minimum by day 231, and tended to increase again until by day 369. Months were also categorized to examine the season effect throughout the experiment as shown in the figure (Fig. 6.3). Season may effect on catch rate, the CPUE showed the best positive result in the rainy season (May-Oct), followed with summer (Feb-Apr) and winter (Nov-Jan) was the least. CPUE increased in the rainy season perhaps the cause of nutrient abundant from rainy run off and the pots were still in good condition in beginning period. The CPUE increasing due to the numbers of entire animals increased while the kinds of species were similar (Table 6.1). The catch rate in summer was higher than winter though the experiment pots in summer have immersed in the study site longer and more fouling organisms accumulated, this result probably indicates the magnitude of ghost fishing impacts by season.

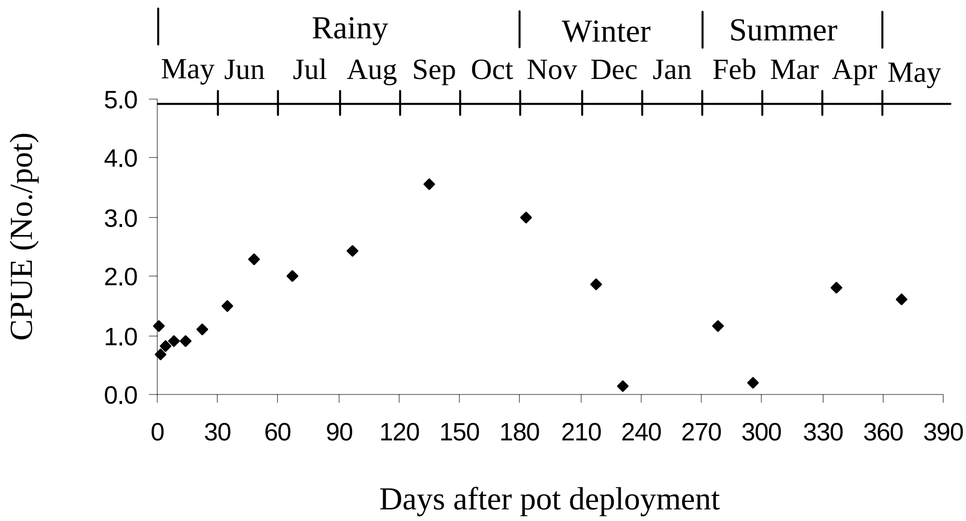


Fig. 6.3 CPUE of entrapped animals according to the days (seasons were categorized) after pots deployment.

Table 6.1 Newly entire animals of simulated pots at various time intervals from day 1 (26 April 2006) until day 369 after initial deployment (number of pots reduced from 12 to 7 by lost, then further to 5 by damaged), mean catch/pot/year calculated from sum of the total new entry divided by the number of available pots at each interval monitoring

	Monitoring date	27 Apr	28	30	4 May	10	18	31	13 Jun	2 Jul	1 Aug	8 Sep	26 Oct	30 Nov	13 Dec	29 Jan	16 Feb	29 Mar	30 Apr	
		Days from initial deployment																		
		1	2	4	8	14	22	35	48	67	97	135	183	218	231	278	296	337	369	Mean catch /pot/year
		Number of pots available																		
Common name	Species	12	12	12	12	12	11	10	10	9	7	7	7	7	7	6	5	5	5	
1. Toad fish	*Batrachus grunniens*	1	1	4	4	2	2	5	8	6	3	4	5	3	1	4	1	2	2	7.10
2. Sea urchin	*Diadema setosum*	0	0	0	0	0	1	1	3	1	4	12	7	7	0	2	0	1	1	5.62
3. Ridged swimming crab*	*Charybdis natator*	6	3	0	1	7	5	1	4	4	1	1	7	0	0	1	0	2	4	5.47
4. Spiral melongena*	*Pugilina cochlidium*	2	1	3	0	1	2	1	3	1	1	3	0	0	0	0	0	0	0	1.85
5. Chinese filefish*	*Monacanthus chinensis*	1	1	0	4	0	0	0	0	0	1	1	1	0	0	0	0	1	1	1.33
6. Catfish*	*Plotosus canius*	0	0	0	0	0	1	2	2	2	0	2	0	1	0	0	0	0	0	1.14
7. Brittle star	*Ophiotrix* sp.	0	0	0	0	0	0	0	0	0	3	0	0	2	0	0	0	2	0	1.11
8. Mangrove stone crab*	*Myomenippe hardwickii*	1	1	0	0	1	0	2	0	2	2	0	0	0	0	0	0	0	0	0.96

Table 6.1 (Continue)

9. Red soldier fish	*Holocentrus rubrum*	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0.49
10. Emperor*	*Lethrinus* sp.	1	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0.35
11. Whiptail*	*Pentapodus setosus*	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0.28
12. Hermit crab	*Calibanarius longitarsus*	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0.24
13. White-spotted spinefoot*	*Siganus oramin*	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0.21
14. Synaptid sea cucumber	*Leptosynapta* sp.	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.17
15. Pink shrimp*	*Metapenaeus* sp.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0.14
16. Spider crab	*Dorippe dorsipes*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0.14
17. Ponyfish	*Leiognathus* sp.	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0.11
18. Sergeant Major*	*Abudefduf vaigiensis*	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0.10
19. Wrasse	*Halichoeres* sp.	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0.09
20. Grunter*	*Terapon* sp.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.08
21. Octopus*	*Octopus* sp.	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.08
22. Silver biddy*	*Gerres* sp.	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.08
	Total	14	8	10	11	11	12	15	23	18	17	25	21	13	1	7	1	9	8	27.16

* Indicates those animals are commercial category

Throughout the experiment, divers observed that some animal species were always resident in the pots because previously observed animals were frequently observed on subsequent monitoring dive, such as toad fish, sea urchin and filefish, but some of them for example brittle star, mangrove stone crab and red soldier fish, entrapped by occasionally. And if the observation intervals were long (about 1 month) divers always found only new catches in the pots, this finding demonstrated that as animals died or escaped they were replaced by new catches. The relation of CPUE according to the days elapsed after pots initial deployment for each entrapped animals (top 10 species) is shown in Fig. 6.4.

The entry rate (CPUE) does not indicate the total mortality of animals associated with the ghost fishing pots. We were able to confirm the mortality with monitoring dead bodies of the entrapped animals remained. According to diving observation of the catches by day 1 (27 Apr 2006) subsequently, the catches were examined that 4 individuals escaped from the pots by 3 days (Table 6.2); 2 ridge swimming crabs (one escaped by day 1, another one by day 3) and 1 grunter (escaped by day 1), we assumed that all of escaped animals survived. The all remainders dead in the pots (confirmed by dead bodies or fragments remained) with the different day, e.g. we found the first dead body of a ridged swimming crab by day 3, the filefish by day 13, and the toad fish by day 35. Those results showed the entire animals of 21.4 % escaped while 78.6% dead in the pots by 34 days as shown in the Table 6.2. Mortality rate (cumulative dead numbers) in pots according to the days elapsed after initial entrapped of the observed catches (day 1) can be expressed by the following equation (Fig. 6.5);

$$y = 0.3133\text{Ln}(x) - 0.2775, \qquad R^2 = 0.98,$$

where y = mortality rate, and x = time by days

We assumed that the escapement and mortality of others newly catches were same with the day 1 catches. Based on the equation above, the mortality of each newly catches for each interval monitoring was estimated and showed the result per pot/month as in Table 6.3. The day 1 catches were dead 0.92 individual/pot/month, and the accumulated mortality indicates that each pot killed animals 19.0 individuals/pot/year. This finding takes no account of animals that may have entered and dead in the pots (or dead after escaped) without being observed by diving.

Pots conditions and some phenomena since day 1 after initial deployment until day 369 have shown in Fig. 6.6. The pots started rusty at frame structures by day 4 and further when the time passed, however their structures integrity throughout of approximately 1 year study. The first damage on mesh was found in the day 14 at the bottom side panel since the pot scratching with sea floor. Divers sometimes observed the entire animals exhausted, hurt, or attempted to escape from the pots (e.g. Fig. 6.6-c). The first completely damaged pot (no more function) was found in day 278, because fouling organisms particularly green mussels attached and grew up until the entrances (slope nets) were closed and no animal could enter. Another one pot completely was damaged since the covered nets were cut and holed by the organisms together with pot scratching due to buoy rope entangled with anchor rope of the mussel raft until became big holes and allowed all captured animal to escape out. Five of 12 pots tended to remain their capture function in the second year after original deployment (Table 6.1 and Fig. 6.3).

Table 6.2 The escape and mortality analysis of the catches by day 1 (27 Apr) after the days passed (examined from the monitoring by day 1, 3, 7, 13, 21 and 34 after initial entrapped)

The catch by day 1		No. of animals		Days after initial entrapped	
Common name	No.	Escaped	Dead	Escaped	Dead
Ridged swimming crab	6	2	4	1, 3	3, 7(2), 13
Emperor	1	0	1	-	7
Filefish	1	0	1	-	13
Mangrove stone crab	1	0	1	-	13
Spiral melongena	2	0	2	-	13, 21
Whiptail	1	0	1	-	21
Toad fish	1	0	1	-	34
Banded grunter	1	1	0	1	-
Total	14	3	11		
% escapement	21.43				
% mortality	78.57				

Table 6.3 Mortality estimations (per pot/month) of newly catches at various time monitoring intervals based on the derived equation

Day(s) after deployment	No. of pots	No. of newly catches	No. of mortality from the estimation, $y = 0.3133\text{Ln}(x) - 0.2775$		
			By day 30 after entrapped	Per pot per month	Cumulative mortality
1	12	14	11.03	0.92	0.92
2	12	8	6.30	0.53	1.44
4	12	10	7.88	0.66	2.10
8	12	11	8.67	0.72	2.82
14	12	11	8.67	0.72	3.55
22	11	12	9.46	0.86	4.41
35	10	15	11.82	1.18	5.59
48	10	23	18.13	1.81	7.40
67	9	18	14.19	1.58	8.98
97	7	17	13.40	1.91	10.89
135	7	25	19.70	2.81	13.71
183	7	21	16.55	2.36	16.07
218	7	13	10.25	1.46	17.53
231	7	1	0.79	0.11	17.65
278	6	7	5.52	0.92	18.57
296	5	1	0.79	0.16	18.72
337	5	9	7.09	1.42	20.14*

* Indicate the mortality per pot per year (catches by day 369 was excluded due to they were the second year catch).

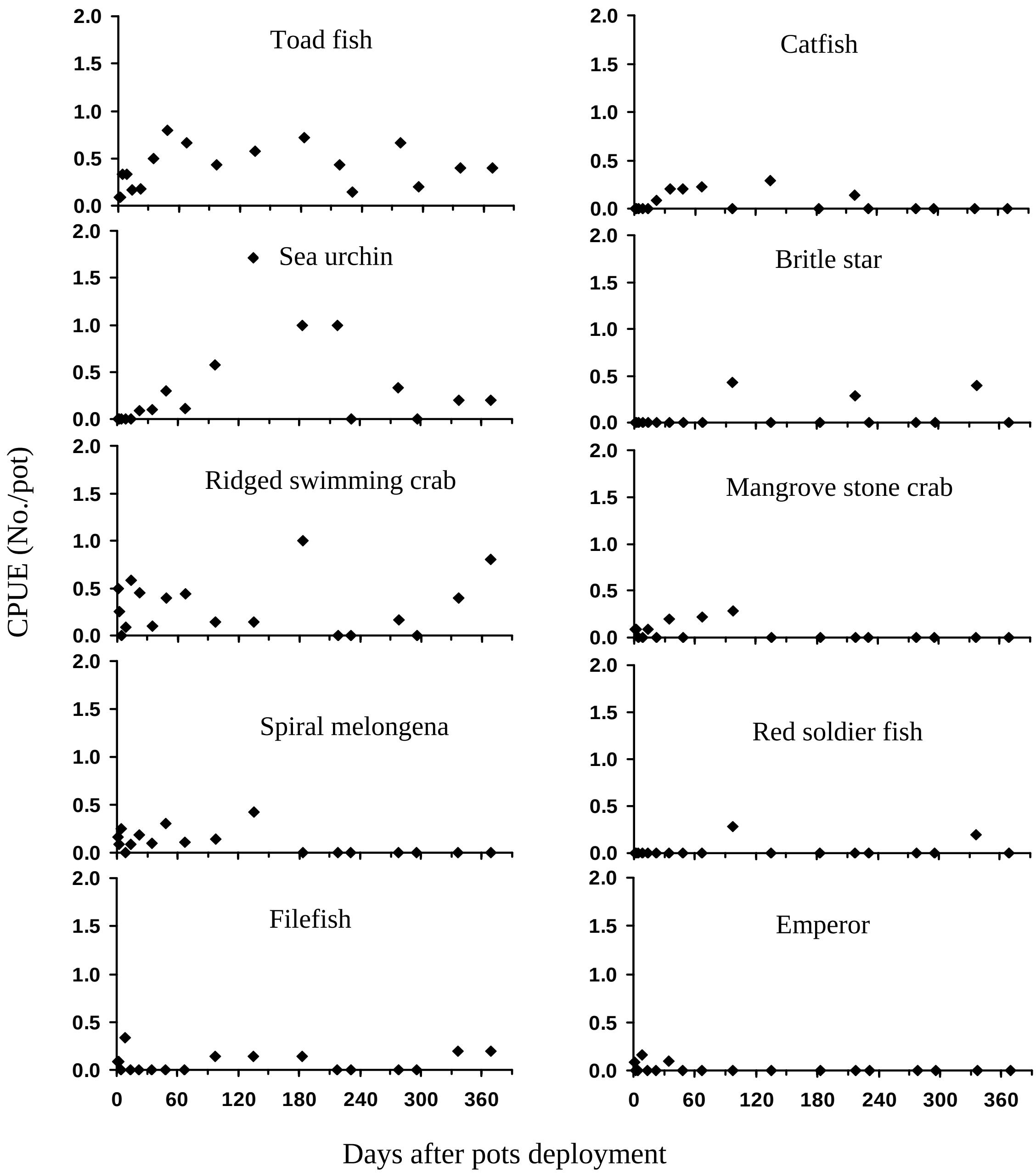


Fig. 6.4 CPUE of top ten entire species according to the days after pots deployment.

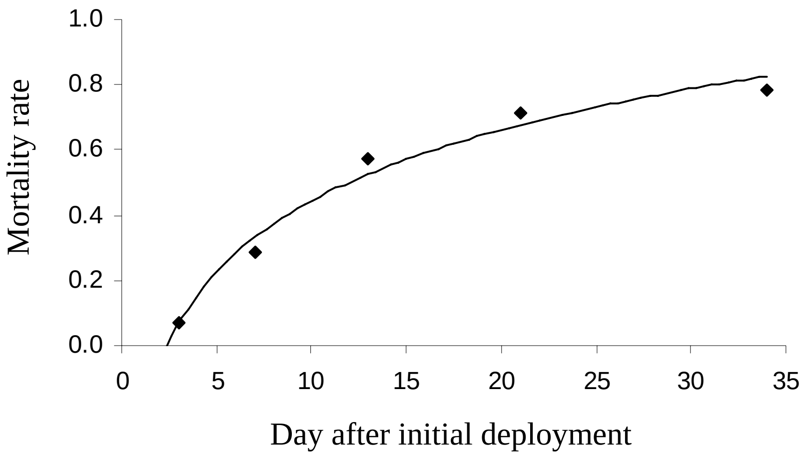


Fig. 6.5 Relationship between mortality rate and the days after initial entrapped (analyzed from the day 1 catches); $y = 0.3133\text{Ln}(x) - 0.2775$, $R^2 = 0.98$.

(a) 1 day

(b) 14 days

(c) 22 days

(d) 135 days

(e) 231 days

(f) 369 days

Fig. 6.6 Pot conditions and some phenomena after deployment since day 1 until 1 year approximately, (a) pot and bait by day 1, (b) toadfish and ridged swimming crab inside the pot by day 14, (c) alive wrasse pushed through the mesh to escape out, (d) pot and red soldier fish by day 135 which the CPUE reached the maximum, (e) pot and filefish inside by day 231, and (e) pot with fouling organisms by day 369.

6.4 Discussion

The results of simulation pots demonstrate that lost pots can continue to entrap animals including the commercial species for several months after initial bait within has been consumed or decomposed. Some pots still have potential to function more than 1 year with the integrity of them throughout the study (Breen, 1987; Matsuoka, 1999; Bullimore, 2001; Al-Masroori et al., 2004).

The fish bait within pots was either consumed or decomposed completely by 3 days. This finding similar with Al-Masroori et al. (2004) that observed the bait within their trials traps in Oman was consumed within averages of 3 days, but different from Bullimore et al. (2001) who conducted the experiment in UK and reported the initial bait was exhausted after day 27. This probably reflects differences of the oceanographic conditions of the regions particularly seawater temperature. In the simplest form of ghost fishing, trapped animals die in lost traps and their bodies act as bait (Von Brandt 1984) to attract new fish which eventually die until the pot deteriorates. The dead animals in our pots perhaps provide food and attract the others become trapped. Hence, the catch rate increased after deployment. The initial bait was completely consumed within 3 days, if entire animals dead, they decayed and acted as bait luring more others into the pots. Thereafter, continuous cycle of capture, decay and attraction for as long as the gear remains intact (Carr et al., 1990; Kaiser et al., 1996). Many species were entrapped, the pots may be rebaited by species other than the target species and can attract the others to entrap. According to the observations, divers saw some entire animals were eating the dead body in pots, this observation concurs with those in related studies (Kaiser et al., 1996). Alaska king crab are rebaited when Pacific halibut or Pacific cot enter and die (High and Worlund, 1979). In crustaceans, cannibalism of newly molted individuals may occur. Pecci et al. (1978) observed this in simulated lost

American lobster traps, Demory (1971) observed this phenomenon for Dungeness crabs *Cancer magister* entered.

Toad fish, sea urchin and ridged swimming crab dominate the catches since they have been the resident species. Animals with small number of CPUE such as brittle star, mangrove stone crab, red soldier, etc., entered the pots by occasions. The CPUE increased up to 135 days then decreased afterward, this trend showed particularly with the dominated catches. After reached the maximum level, the catch rate declined together with seasonal change and fouling organism accumulation on pots. Catches in pots may affected by the identity of the initial occupants. In the first period, pots were still in good condition, it was possible that the CPUE increased not only from rebaiting mechanism but also the attraction of occupied animals inside, thus perhaps the reasons of increasing the catch rate with similar species. Some species of fish are attracted to live conspecifics in un-baited pots (Munro, 1974). Fish and crustaceans continue to enter simulated lost pots even without bait, this may also much effect to the increased catch rate and supported those presented by High and Worlund (1979) who reported that king crabs continue to enter un-baited pots for up to 16 days. Dungeness crabs empty traps months after simulated trap loss (Breen, 1987). Munro (1983) describes fish traps that catch fish un-baited. Juvenile reef fishes in Florida use traps as shelter (Sutherland et al., 1983). For such pots an auto-rebaiting mechanism is not necessary for ghost fishing to occur (Breen, 1990). However, in some cases, dead animals repel conspecifics, Hancock (1974) presented evidence that the crabs *Cancer pagurus* were not attracted to trap bait with the crabs *Carcinus maeanas*. For some species, conspecific repellency may prevent or reduce ghost fishing (Breen, 1990). Miller and Addison (1995) found that the presence of American lobsters within a pot deters entry of smaller crab species. Similarly, the presence of recently molted brown crabs within pots deterred entry of conspecifics (Addison, 1995). The catch rate decreased after 135 days, because in shallow water organisms are rapidly overgrown with encrusting biota that makes the pots more visible and reduces their fishing capabilities (Erzini et al., 1997).

Seasonality is also an important factor in ghost fishing (Stevens, et al., 2000). Our experiment pots showed the best catch rate in rainy season as a result of rich nutrients abundant that run off to the coastal sea in this season. Besides, the pots also were deployed in the beginning of this season, hence they still were in good condition to keep functions. Breen (1987) found vary crab numbers in pots at different times of the year and recommended that a study must be conducted all year round to obtain the best estimate of crab ingress rate. Guilory (1993) reported the recruitment of blue crabs associated to ghost pots, mortality and escapement all varied seasonally. Baited snow crab traps lost during the spring fishing season may not continue to catch snow crab after reaching their saturation levels (Miller, 1979). However, once a lost trap reaches its saturation level, captured individuals will die due to cannibalism and predation lowering the saturation level. Although the number of newly-captured is negligible after the spring fishing season, the catch increases again to its saturation level before the following spring, which reinitiates a ghost fishing cycle (Hebert et al., 2001).

We were able to confirm mortality only for the day 1 catches (0.92 individuals/pot/month and 78% of entrapped animals dead in pots). Since the dead bodies were completely either decomposed or consumed by few days, hence shortening the day intervals for subsequent monitoring was recommended. High turnover rates can lead to high capture and mortality rate; 2/3 of blue crabs entering traps died or escaped within 2 weeks (Guillory, 1993). There is a temporary balances between catch and escape rate (Munro, 1974; Dew et al., 1988; Bullimore et al., 2001). Thus is not possible to estimate mortality from a single observation of recovered traps because the number of crabs in the trap represents a balance of continuous ingress, egress, and mortality rates (Steven et al., 2000).

Pual et al. (1994) found only a 10% mortality rate in Tanner crabs during a 90-d starvation period in laboratory conditions, but they found 100% mortality of those crabs during the 140-d post-starvation period when crabs were offered unlimited food. Breen (1987) studied clearly demonstrates that entry, escapement, and mortality rates of crabs in lost pots is a dynamic process. He showed that unbaited traps caught Dungeness crab at the same rate one year after being lost, and estimated that lost traps caught 17 Dungeness crabs per year, which almost half (9.3) died, and the remainders escaped. It must be noted that mortality rate (*m*, *km*) and n_e change according to the time after the gear loss (Matsuoka, 1999). It was also reported the catch and *m* changed complicatedly together with, seasons, elapsed time, and associated ghost fishing species (Vienneau and Moriyasu, 1994; Stevens at al., 2000; Bullimore et al., 2001). Most experiments to find *m* were conducted with test animals which were initially put in a gear by researchers for subsequent monitoring (e.g. Kimker, 1994), however this method is applicable only to animals which are sufficiency resistant to stress and less damages by handling (Matsuoka, 2005).

In our simulated pots, the entire animal escapement by 34 days was low (21.43 %) while mortality was high (78.57%) when compare with the other reports (e.g. Pecci et al., 1978; Breen, 1985; Guillory, 1993; Kimker, 1994), perhaps due to different of species and design of pot. Ghost-fishing potential varies for different fisheries and pot designs. Parrish and Kazama (1992) found that the majority of lobsters were able to escape traps, whereas parlor-type traps lead to mortalities of 12-25% for American lobster (Smolowitz, 1978b). Vazquez Archdale et al. (2007) showed the evidence that, by 7 days there was no crabs (*Portunus pelagicus* and *Charybdis japonica*) escaped from collapsible box-shaped pots with the tight slit entrances (similar with our experiment pots) but 100% of the crabs escaped from the dome shaped. Even when animals manage to escape from ghost fishing traps, they may die as a result of their confinements. High and Worlund (1979) demonstrated this effect experimentally for Alaska king crabs. According to our estimations, entire animals were killed 20.1 individuals/pot/year, seem to be low mortality, that was because it excluded the animals that may have entered and dead in the pots or dead after escaped without being observed by the diving. Besides, our study site is not an intensive fishing ground, impacts on intensive ground may be more serious if the pot ghost fishing occurred. The pots lost in offshore fishing ground (deeper water) which are less damaged by waves and less fouled biologically may continue ghost fishing longer than inshore site (Carr et at., 1990; Kaiser et al., 1996; Matsuoka, 2005).

It is noted that the blue swimming crab, target species (of fishermen who use this gear) was not entrapped in any throughout the experiment. An explanation is, probably as the result that they can eat the bait from outside. The initial bait was pierced and attached at the center of bottom pot panel, and completely either consumed or decayed within 3 days. If there is no crab entrapped the pots by the first 3 days, opportunity to catch might be much decreased. Even though animals in pots die and act as new bait luring the crab into but the bait is not fixed, sea current can flow the bait to pot side panel, consequently the crab can feed from outside. Authors have observed such the crab behavior in laboratory tank (Authors, unpublished).

The pots are constructed with more durable materials and have a rigid structure. Consequently, they can ghost fish for much longer periods than nets. Pots for *P. pelagicus* in Australia were estimated to ghost fish for more than 4 years (Sumpton, 2003). Divers observed some fish and crabs hard attemped to push through the mesh to escape from the pots, e.g. the wrasse in Fig. 6.6(c), similar findings were reported by Bullimore et al. (2001) and Al-Masroori (2004). As those results, escape panels or biodegradable materials are recommended. The escape panels have been introduced to reduce negative impacts from ghost fishing (Pecci at al, 1878; Smolowitz, 1978a; Breen 1987; Arcement and Guillory, 1993; Al-Masroori, 2004). Regardless of the phase of fishing, the use of such vents is a conservation practice that must be encouragement in pot fisheries (Smolowitz, 1978b). Incorporation of sub-legal gaps into the construction of traps could also prevent retention of under-sized finfish or shellfish (Al-Masroori et al., 2004). Future studies should be carried out to investigate the number of ghost fishing pot in the fishing ground (number of fisherman, number of operation, gear loss rate etc.). Some more complete assessments of ghost fishing will be required estimates for rate ingress, egress, as well as mortality rate, specifically investigate that determine and confirm the level of impacts according to the seasonal change. Eventually, calculate potential economic loss to the fishery sector and test the solution by using the escape vents aimed for reducing the ghost fishing negative impacts.

References

Chapter 1

Breen, P.A., 1990. A review of ghost fishing by traps and gillnets. In: Shomura, R.S., Godfrey, M.L. (Eds), Proceedings of the Second International Conference on Marine Debris, 2-7 Apr 1989. Honolulu, Hawaii, pp. 571-599. NOAA Tech. Memo. NMFS-SWFSC-154, NMFS Southwest Fish. Sci. Cent., Honolulu.

Brown, C.G., 1982. The effect of escape gaps on pots selectivity in the United Kingdom crab (*Cancer pagurus* L.) and lobster (*Homarus gammarus* (L.)) fisheries. J. du Conseil International pour I'Exploration de la Mer. 40, 127-134.

Bullimore, B.A., Newman, P.B., Kaiser, M.J., Gilbert, S.E., Lock, K.M., 2001. A study of catches in a fleet of ghost fishing pots. Fish. Bull. 99, 247-253.

Department of Fisheries. Fisheries Statistics of Thailand in 2004. Fisheries Statistics of Thailand, Fishery Economic Division. 2007.

FAO. 1995. Code of conduct for responsible fisheries. Food and Agriculture Organization of the United Nations, Rome, 1-41.

Glass, C.W., Wardle, C.S. 1995. Studies on the use of visual stimuli to control fish escape from codends. II. The effect of a black tunnel on the reaction behavior of fish in otter trawl codends. Fish. Res. 23, 165-174.

Jennings, S., Kaiser, M.J., 1998. The effects of fishing on marine ecosystem. Adv. Mar. Biol. 34, 201-352.

Jindalikit, J., 2001. Reproductive biology of blue swimming crab *Portunus pelagicus (Linnaeus, 1758)* in the upper Gulf of Thailand. Department of Fisheries, Bangkok. (in Thai with English abstract)

Koike, A., 1979. Selectivity of pot, in Selectivity of Fishing Gears, Koseishakoseikaku. Tokyo, 97-111.

Laist, D.W., 1995. Marine debris entanglement and ghost fishing: a criptic and significant type of bycatch. In: Proceedings of the Solving Bycatch Workshop, September 25-27, 1995, Seattle, Washington. pp. 33-40.

Matsuoka, T., 2005. A review of ghost fishing: scientific approaches to evaluation and solutions. Fish. Sci. 71, 691-702.

Matsuoka, T., 2000. Selectivity of fishing gear. Kanagawa International Fisheries Training Centre, Japan International Cooperation Agency (JICA), 19-55.

Okawara, M., Masthawee, P. 1981. Survey of trap fishing (II) (A brief report). *SEAFDEC Misc. Papers*. 9, 1-11.

Shepherd, G.R., Moore, C.W., Seagraves, R.J., 2002. The effect of escape vents on the capture of black sea bass, Centropristis striata, in fish traps. Fish Res. 54, 195-207.

Smolowitz, R.J., 1978a. Trap design and ghost fishing: an overview. Mar. Fish. Rev. 40, 2-8.

Sparre, P., Venema, S.C., 1998. Introduction to tropical fish stock assessment-part 1: Manual. FAO Fisheries Technical Paper 306/1 (Rev. 2). Rome, FAO.

Zhou, S., Shirley, T.C., 1997a. A model expressing the relationship between catch and soak time of trap fisheries. N. Am. J. Fish. Manage. 17, 482-487.

Chapter 2

Allen, M., Kilpatrick, D., Armstrong, M., Briggs, R., Pérez, N., Course, G., 2001. Evaluation of sampling methods to quantify discarded fish using data collected during discards project EC/094 by Northern Ireland, England and Spain. Fish. Res. 49, 241–254.

Alverson, D.L., Freeberg, M.H., Pope, J.G., Murawski, S.A., 1994. A global assessment of fisheries bycatch and discard. FAO Fish. Tech. Pap. 339, 233.

Beverton, S.J., Holt, S.J., 1957. On the dynamics of exploited fish populations, Fish. Invest. (Series 2) 19, 533.

Briand, G., Matulich, S.C., Mittelhammer, R.C., 2001. A catch per unit effort-soak time model for the Bristol Bay red king crab fishery, 1991-1997. Can. J. Fish. Aquat. Sci. 58, 334-341.

Cappo, M., Brown, I.W. (Eds.), 1996. Evaluation of sampling methods for reef fish population of commercial and recreational interest. Technical Report of CRC Reef Research Centre No. 6. CRC Reef Research Centre, Townsville, Queensland, 72 pp.

Cole, R.G., Alcock, N.K, Tovey, A, Handley, S.J., 2004. Measuring efficiency and predicting optimal set durations of pots for blue cod *Parapercis colias*. Fish. Res. 67, 163-170.

Forgarty, M.J., Addison, J.T., 1997. Modeling capture processes in individual traps: entry, escapement and soak time. ICES J. Mar. Sci. 54, 193-205.

Frusher, S.D., Hoenig, J.M., 2001. Impact of lobster size on selectivity of traps for traps for southern rock lobster (*Jasus edwardsii*). Can. J. Fish. Aquat. Sci. 58, 2482-2489.

Galbraith, R.D., Stewart, P.A.M., 1995. Fishing effort: a gear technologist's perspective. ICES CM 1995/B:28.

Jury, S.H., Howell, H., O'Grady, D.F., Watson III, W.H., 2001. Lobster trap video: in situ video surveillance of the behavior of *Homarus americanus* in and around traps. Mar. Freshw. Res. 52, 1125-1132.

Miller, R.J., 1979a. Entry of *Cancer productus* to baited traps. J. Cons. Int. Explor. Mer. 38 (2), 220-225

Miller, R.J., 1979b. Saturation of crab trap: reduced entry and escapement. J. Cons. Int. Explor. Mer. 38 (3), 338-345.

Miller, R.J., 1990. Effectiveness of crab and lobster traps. Can. J. Fish. Aquat. Sci. 47, 1228-1251.

Munro, J.L., 1974. The mode of operation of Antillean fish traps and the relationships between ingress, escapement, catch and soak. J. Cons. Int. Explor. Mer. 35, 337-350.

Parente, J, 2004. Predictors of CPUE and standardization of fishing effort for the Portuguese coastal seine fleet. Fish. Res. 69, 381-387.

Saila, S.B., 1983. Importance and assessment of discard in commercial fisheries. FAO Fish. Circ. 755, 1-62.

Vazquez Archdale, M.F., Anasco, C.P., Hiromori, S., 2006b. Comparative fishing trials for invasive swimming crabs *Charybdis Japonica* and *Portunus pelagicus* using collapsible pots. Fish Res. 82, 50-55.

Vazquez Archdale, M.F., Anasco, C.P., Kawamura, Y., Tomiki, S, 2007. Effect of two collapsible pot designs on escape rate and behavior of the invasive swimming crabs *Charybdis Japonica* and *Portunus pelagicus* using collapsible pots. Fish Res. 85, 202-209.

Vazquez Archdale, M.F., Kuwahara, O., 2005. Comparative fishing trials for *Charybdis Japonica* (A. Milne Edwards) using collapsible box-shaped and dome-shaped pots. Fish. Sci. 71, 1229-1235.

Zhou, S., Shirley, T.C., 1997a. A model expressing the relationship between catch and soak time of trap fisheries. N. Am. J. Fish. Manage. 17, 482-487.

Walmsley, S.A., Leslie, R.W., Sauer, W.H.H., 2007. Bycatch and discarding in the South African demersal trawl fishery. Fish. Res. 86, 15-30.

Chapter 3

Arcement, E., Guillory, V., 1993. Ghost fishing in vented and unvented blue crab traps. Proc. LA. Acad. Sci. 56, 1-7.

Boutson, A., Arimoto, T., Mahasawasde, C., Mahasawasde, S., Tunkijjanukij, S., 2005. Bycatch and its reduction for blue swimming crab pot in Thailand. Kagoshima University, the steering committee for the colloquium on fishing technology, Round table meeting for fishing technology No.50, 38-39.

Breen, P.A., 1985. Ghost fishing by Dungeness crab traps: A preliminary report. Can. Manuscr. Rep. Fish. Aquat. Sci. 1848, 51-55.

Brown, C.G., 1982. The effect of escape gaps on traps selectivity in the United Kingdom crab (*Cancer pagurus* L.) and lobster (*Homarus gammarus* (L.)) fisheries. ICES J. Mar. Sci. 40, 127-134.

Brown, R.S., Caputi, N., 1986. Conservation of recruitment of the western rock lobster (*Panulirus cygnus*) by improving survival and growth of under size rock lobsters captured and returned by fishermen to the sea. Can. J. Fish. and Aquat. Sci. 43, 2236-2242.

Department of Fisheries., 2007. Fisheries Statistics of Thailand in 2004. Fisheries Statistics of Thailand, Fishery Economic Division.

Eldridge, P.J., Burrell, V.G., Steele, G., 1979. Development of a self-culling blue crab pot. Mar. Fish. Rev. 41, 21-27.

Fogarty, M.J., Borden, D.V., 1980. Effects of traps venting in gear selectivity in the inshore, Rhode Island American lobster, *Homarus americanus* fishery. Fish. Bull. 77, 925-933.

Furevik, D.M., Løkkerborg, S., 1994. Fishing trials in Norway for torsk *(Brosme brosme)* and cod *(Gadus morhua)* using baited commercial pots. Fish. Res. 19, 219-229.

Guillory, V., 1998. Blue crab, *Callinectes sapidus*, retention rates in different trap meshes. Mar. Fish. Rev. 60, 35-37.

Guillory, V., Hein, S., 1998. An evaluation of square and hexagonal mesh blue crab traps with and without escape rings. J. Shellfish. Res. 17, 561-562.

Guillory, V., Merrell, J., 1993. An evaluation of escape rings in blue crab traps. La. Dep. Wildl. Fish., Tech. Bull. 44, 29 p.

Guillory, V., Prejean, P., 1997. Blue crab trap selectivity studies: Mesh size. Mar. Fish. Rev. 59, 29-31.

Jindalikit, J., 2001. Reproductive biology of blue swimming crab *Portunus pelagicus* (Linnaeus, 1758) in the upper Gulf of Thailand. Department of Fisheries, Bangkok. (in Thai language with English abstract)

Jones, R., 1976. Mesh regulation in the demersal fisheries of the South China Sea area. South China Sea Fisheries Development and Coordinating Programme, SCS/76/WP/34.

Kim, D., Ko, K. 1990. Fishing mechanism of pots and their modification. 4. An experiment for modifying the pot for crab, *Charybdis japonica.* Bull. Korean Fish. Technological Soc., 310-314.

Krouse, J.S., 1978. Effectiveness of escape vent shape in traps for catching legal-sized lobster, *Homorus americanus*, and harvestable-sized crabs, *Cancer borealis* and *Cancer irroratus*. Fish. Bull. 76, 425-432.

Matsuoka, T., 1997. Discard in Japanese marine capture fisheries and their estimation. In IJ. Clucas & DG. James, eds. Papers presented at the Technical Consultation on Reduction of Wastage in Fisheries. Tokyo. FAO Fisheries Report No. 547 (suppl.). Rome, FAO.

Millar, R.B., Fryer, R.J., 1999. Estimating the size-selection curves towed gears, traps, nets and hooks. Rev. Fish Biol. Fish. 9, 89-116.

Miller, R.J., 1990. Effectiveness of crab and lobster pots. Can. J. Fish. Aquat. Sci. 1990; 47, 1228-1251.

Nulk, V.E., 1978. The effects of different escape vents on the selectivity of lobster traps. Mar. Fish. Rev. 40(5-6), 50-58.

Nishiuchi, S., 2001. Size selectivity of hair crab pots. Rev. Fish. Sci. 9, 13-26.

Okawara, M., Masthawee, P., 1981. Survey of trap fishing (II) (A brief report). SEAFDEC Misc. Papers. 9, 1-11.

Sparre, P., Venema, S.C., 1998. Introduction to tropical fish stock assessment-part 1: Manual. FAO Fisheries Technical Paper 306/1 (Rev. 2). Rome, FAO.

Stasko, A.B., 1975. Modified lobster pots for catching crabs and keeping lobsters out. J. Fish. Res. Board Can. 32, 2515-2520.

Sumpton, W., Gaddes, S., McLennan, M., Campbell, M., Tonks, M., Good, N., Hagedoorn, W., Skilleter, G., 2003. Fisheries biology and assessment of the blue swimmer crab (*Portunus pelagicus*) in Queensland. The State of Queensland, Department of Primary Industries, Project No. 98/117. 156 p.

Tokai, T., Kitahara, T., 1989. Methods of determining the mesh selectivity curve of trawl net. Nippon Suisan Gakkaishi. 55, 643-649.

Tokai, T., Mitsuhashi, T., 1998. SELECT model for estimating selectivity curve from comparative fishing experiments. *Bull. Jpn. Soc. Fish. Oceanogr.* 62, 235-247. (in Japanese with English abstract)

Tuntikul, S., 1984. Biology of blue swimming crab in the Gulf of Thailand. Department of Fisheries, Bangkok. (in Thai language)

Vazquez Archdale, M., Añasco, C.P., Hiromori, S., 2006. Comparative fishing trials for invasive swimming crabs *Charybdis japonica* and *Portunus pelagicus* using collapsible pots. Fish. Res. 82, 50-55.

Vazquez Archdale, M., Añasco, C.P., Kawamura, Y., Tomiki, S., 2007. Effect of two collapsible pot designs on escape rate and behavior of the invasive swimming crabs *Charybdis japonica* and *Portunus pelagicus*. Fish. Res. 85, 202-209.

Vazquez Archdale, M., Kuwahara, O., 2005. Comparative fishing trials for *Charybdis japonica* using collapsible box-shaped and dome-shaped pots. *Fish. Sci.* 71, 1229-1235.

Watanabe, Y., Sasakawa, Y., 1984. A preliminary note on pot selections for the size of the rock crab. Bull. Fac. Fish. Hokkaido Univ. 35, 225-233.

Zhou, S., Shirley, T.C., 1997. Performance to two red king crab pot designs. Can. J. Fish. Aquat. Sci. 54, 1858-1864.

Chapter 4

Arimoto, T., 2001. Fish behaviour for improving fish capture technology. Kanagawa International Fisheries Training Centre, Japan International Cooperation Agency (JICA), 1-18 pp.

Cappo, M., Brown, I.W. (Eds.), 1996. Evaluation of sampling methods for reef fish population of commercial and recreational interest. Technical Report of CRC Reef Research Centre No. 6. CRC Reef Research Centre, Townsville, Queensland, 72 pp.

Cole, R.G., Alcock, N.K., Handley, S.J., Grange, K.R., Black, S., Cairney, D., Day, J., Ford, S., Jerrett, A.R., 2003. Selective capture of blue cod *Parapercis colias* by potting: behavioural observations and effects of capture method on peri-mortem fatigue. Fish. Res. 60**,** 381–392.

Forgary, M.J., Addison, J.T., 1997. Modeling capture processes in individual traps: entry, escapement and soak time. ICES J. Mar. Sci. 54, 193-205.

Frusher, S.D., Hoenig, J.M., 2001. Impact of lobster size on selectivity of traps for traps for southern rock lobster (*Jasus edwardsii*). Can. J. Fish. Aquat. Sci. 58, 2482-2489.

Guillory, V., Hein, S, 1998b. An evaluation of square and hexagonal mesh blue crab traps with and without escape rings. J. Shellfish Res., 17(2), 561-562.

Guillory, V., Prejean P., 1997. Blue crab trap selectivity studies: mesh size, Mar. Fish. Rev. 59, 29–31.

Harvey, E., Fletcher, D., Shortis, M., 2001. A comparison of the precision and accuracy of estimates of reef-fish lengths determined visually by divers with estimates produced by a stereo-video system. Fish. Bull. 99, 63–71.

He, P., 1993. The behaviour of cod around a cod trap as observed by an underwater camera and a scanning sonar. ICES Mar. Sci. Symp. 196, 21–25.

He, P., 2003. Swimming behaviour of winter flounder (*Pleuronectes americanus*) on natural fishing grounds as observed by an underwater video camera. Fish. Res. 60, 507–514.

Jeong E., C. Park, S. Park, J. Lee, T. Tokai, 2000. Size selectivity for male red queen crab *Chionoecetes japonicus* with extended SELECT model, Fish. Sci. 66, 494–501.

Jury, S.H., Howell, H., O'Grady, D.F., Watson III, W.H., 2001. Lobster trap video: in situ video surveillance of the behavior of *Homarus americanus* in and around traps. Mar. Freshw. Res. 52, 1125-1132.

Kim, K.B., 2001. Growth and reproduction of *Charybdis japonica* (A. Milne-Edwards) (Decapoda: Portunidae) in Korean waters. PhD thesis, Department of Marine Biology, Graduate School, Pukyong National University, Pusan (in Korean, with English abstract).

Kim D. and K. Ko, 1987. Fishing mechanism of pots and their modification. 2. Behavior of crab, *Charybdis japonica*, to net pots, Bull. Korean Fish. Soc. 20, 348–354 (in Korean, with English abstract).

Kim, D., Ko, K., 1990. Fishing mechanism of pots and their modification. 4. An experiment for modifying the pot for crab, *Charybdis japonica*, Bull. Korean Fish. Soc. 23(4), 310–314 (in Korean, with English abstract).

Miller, R.J., 1979. Entry of *Cancer productus* to baited traps, J. Cons. Int. Explor. Mer. 38, 220–225.

Miller R.J., 1990. Effectiveness of crab and lobster traps, Can. J. Fish. Aquat. Sci. 47, 1228–1251.

Nishiuchi, S., 2001. Size selectivity of hair crab pots. Rev. Fish. Sci. 9, 13-26.

Salthaug, A., 2002. Do triggers in crab traps affect the probability of entry?, Fish. Res. 58, 403–405.

Smith, G.S., Sumpton W.D., 1989. Behavior of the commercial sand crab *Portunus pelagicus* (L) at trap entrances, Asian Fish. Sci. 3, 101–113.

Sinoda, M., Kobayashi T., 1969. Studies on the fishery of Zuwai Crab in the Japan Sea-VI. Efficiency of the Toyama kago (a kind of crab trap) in capturing the Beni-zuwai crab, Nippon Suisan Gakkaishi 35(10), 948–956.

Thomas H.J., 1953. The efficiency of fishing methods employed in the capture of lobsters and crabs, J. Cons. Int. Explor. Mer. 18, 333–350.

Vazquez Archdale, M., Añasco, C.P., Hiromori, S., 2006. Comparative fishing trials for invasive swimming crabs *Charybdis japonica* and *Portunus pelagicus* using collapsible pots. Fish. Res. 82, 50-55.

Watanabe, Y., Sasakawa Y., 1984. A preliminary note on pot selections for the size of the rock crab, Bull. Fac. Fish. Hokkaido Univ. 35(4), 225–233.

Watanabe, Y., Yamasaki, S., 1999. Catch variation and the soak time of gear in the pot fishery for the red queen crab *Chionoecetes japonicus*. Nippon Suisan Gakkaishi. 65, 642-649.

Willis, T.J., Babcock, R.C., 2000. A baited underwater video system for the determination of relative density of carnivorous reef fish. Mar. Freshw. Res. 51**,** 755–763.

Chapter 5

Arcement, E., Guillory, V., 1993. Ghost fishing in vented and unvented blue crab traps. Proc. LA. Acad. Sci. 56, 1-7.

Brown, C.G., 1982. The effect of escape gaps on traps selectivity in the United Kingdom crab (*Cancer pagurus* L.) and lobster (*Homarus gammarus* (L.)) fisheries. ICES J. Mar. Sci. 40, 127-134.

Department of Fisheries., 2007. Fisheries Statistics of Thailand in 2004. Fisheries Statistics of Thailand, Fishery Economic Division..

Eldridge, P.J., Burrell, V.G., Steele, G., 1979. Development of a self-culling blue crab pot. Mar. Fish. Rev. 41, 21-27.

Fogarty, M.J., Borden, D.V., 1980. Effects of traps venting in gear selectivity in the inshore, Rhode Island American lobster, *Homarus americanus* fishery. Fish. Bull. 77, 925-933.

Furevik, D.M., Løkkeborg, S., 1994. Fishing trials in Norway for torsk (*Brosme brosme*) and cod (*Gadus morhua*) using baited commercial pots. Fish. Res. 19, 219–229.

Guillory, V., 1998. Blue crab, *Callinectes sapidus*, retention rates in different trap meshes. Mar. Fish. Rev. 60, 35-37.

Guillory, V., Hein, S., 1998. An evaluation of square and hexagonal mesh blue crab traps with and without escape rings. J. Shellfish. Res. 17, 561-562.

Guillory, V., Merrell, J., 1993. An evaluation of escape rings in blue crab traps. La. Dep. Wildl. Fish., Tech. Bull. 44, 29 p.

Guillory, V., Prejean, P., 1997. Blue crab trap selectivity studies: Mesh size. Mar. Fish. Rev. 59, 29-31.

Jeong, E., Park, C., Park, S., Lee, J., Tokai T., 2000. Size selectivity for male red queen crab *Chionoecetes japonicus* with extended SELECT model, Fish. Sci. 66, 494–501.

Jindalikit, J., 2001. Reproductive biology of blue swimming crab *Portunus pelagicus (Linnaeus, 1758)* in the upper Gulf of Thailand. Department of Fisheries, Bangkok. (in Thai with English abstract)

Kim D, Ko K. Fishing mechanism of pots and their modification. 4. An experiment for modifying the pot for crab, *Charybdis japonica*. Bull. Korean Fish. Technological Soc. 1990; 310-314.

Miller, R.J., 1979. Entry of *Cancer productus* to baited traps. J. Cons. Int. Explor. Mer. 38, 220–225.

Miller, R.J., 1990. Effectiveness of crab and lobster pots. Can. J. Fish. Aquat. Sci. 1990;47, 1228-1251.

Nishiuchi, S., 2001. Size selectivity of hair crab pots. Rev. Fish. Sci. 9, 13-26.

Salthaug, A., 2002. Do triggers in crab traps affect the probability of entry?, Fish. Res. 58, 403–405.

Sinoda, M., Kobayashi T., 1969. Studies on the fishery of Zuwai Crab in the Japan Sea-VI. Efficiency of the Toyama kago (a kind of crab trap) in capturing the Beni-zuwai crab, Nippon Suisan Gakkaishi 35(10), 948–956.

Smith, G.S., Sumpton, W.D., 1989. Behavior of the commercial sand crab *Portunus pelagicus* (L) at trap entrances. Asian Fish. Sci. 3, 101–113.

Thomas, H.J., 1953. The efficiency of fishing methods employed in the capture of lobsters and crabs. J. Cons. Int. Explor. Mer. 18, 333–350.

Vazquez Archdale, M., Anraku K., Yamamoto T., Higashitani N., 2003. Behavior of the Japanese crab 'Ishihani' *Charybdis japonica* (A. Milne Edwards) towards two collapsible baited pots: evaluation of capture effectiveness. Fish. Sci. 69, 785–791.

Vazquez Archdale, M., Añasco, C.P., Kawamura, Y., Tomiki, S., 2007. Effect of two collapsible pot designs on escape rate and behavior of the invasive swimming crabs *Charybdis japonica* and *Portunus pelagicus*. Fish. Res. 85, 202-209.

Vazquez Archdale, M., Añasco, C.P., Hiromori, S., 2006. Comparative fishing trials for invasive swimming crabs *Charybdis japonica* and *Portunus pelagicus* using collapsible pots. Fish. Res. 82, 50-55.

Vazquez Archdale, M., Kuwahara, O., 2005. Comparative fishing trials for *Charybdis japonica* using collapsible box-shaped and dome-shaped pots. Fish. Sci. 71, 1229-1235.

Watanabe, Y., Sasakawa, Y., 1984. A preliminary note on pot selections for the size of the rock crab. Bull. Fac. Fish. Hokkaido Univ. 35, 225-233.

Watanabe, Y., Yamasaki, S., 1999. Catch variation and the soak time of gear in the pot fishery for the red queen crab *Chionoecetes japonicus*. Nippon Suisan Gakkaishi. 65, 642-649.

Williams, M.J., Hill, B.J., 1982. Factors influencing pot catches and population estimates of the portunid crab *Scylla serrata*. Mar. Biol. 71, 187-192.

Chapter 6

Addison, J.T., 1995. Influence of behavioural interactions on lobsters distribution and abundance as inferred from pot-caught samples. ICES Mar. Sci. Symp. 199, 294-300.

Allen, G., 2000. Marine Fish of South-East Asia. Periplus Edition (HK) Ltd., 292 p.

Al-Masroori, H., Al-Oufi, H., McIlwain, J.L., McLean, E., 2004. Catches of lost fish traps (ghost fishing) from fishing grounds near Muscat, Sultanate of Oman. Fish. Res. 69, 407-414.

Arcement, E., Guillory, V., 1993. Ghost fishing in vented and unvented blue crab traps. Proc. LA. Acad. Sci. 56 (1) 1-7.

Breen, P.A., 1985. Ghost fishing by Dungeness crab traps: A preliminary report. Can. Manuscr. Rep. Fish. Aquat. Sci. 1848, 51.55.

Breen, P.A., 1987. Mortality of Dungeness crabs caught by lost traps in the Fraser River Estuary, British Columbia. N. Am. J. Fish. Manage. 7, 429-435.

Breen, P.A., 1990. A review of ghost fishing by traps and gillnets. In: Shomura, R.S., Godfrey, M.L. (Eds), Proceedings of the Second International Conference on Marine Debris, 2-7 Apr 1989. Honolulu, Hawaii, pp. 571-599. NOAA Tech. Memo. NMFS-SWFSC-154, NMFS Southwest Fish. Sci. Cent., Honolulu.

Bullimore, B.A., Newman, P.B., Kaiser, M.J., Gilbert, S.E., Lock, K.M., 2001. A study of catches in a fleet of ghost fishing pots. Fish. Bull. 99, 247-253.

Carr, H.A., Amaral, E.H., Hulbert, A.W., Cooper, R., 1990. Underwater survey of simulated lost demersal and lost commercial gill nets of New England. In Marine debris: sources, impacts and solutions (J. M. Coe and D. B. Rogers, eds.), p. 171-186. Springer, New York, NY.

Carr, H.A., Harris, J., 1994. Ghost fishing gear: have fishing practices during the few years reduced the impact? In: Coe, J.M., Rogers, D.B. (Eds.), Seeking Global Solutions. Miami, FL. Springer-Verlag, New York.

Demory, D., 1971. Abandoned crap pots near Cannon Beach, Oregon. Fish Comm. Oregon, Res. Div., Shellfish Invest. Inf. Rep. 70-6: 1-5.

Dews, G., K. Sainsbury, W. Whitelaw, and M. Moran. 1988. CSIRO goes fish trapping on NW Shelf. Aust. Fish. 47(9): 28-29.

Erzini, K., Monteiro, C., Ribeiro, J., Santos, M., Gaspar, M., Monteiro, P., Borges, T., 1997. An experimental study of gill net and trammel net ‘ghost-fishing’ off the Algarve (southern Portugal). Mar. Ecol. Prog. Ser. 158, 257-265.

Guillory, V., 1993. Ghost fishing by blue crab traps. N. Am. J. Fish. Manage. 13, 459-466.

Guillory, V., 2001. A review of incidental fishing mortalities of blue crabs. Pages 28-41 in V. Guillory, H.M. Perry, and S. Vanderkooy, eds. Proceedings of the Blue Crab Mortality Symposium. Gulf States Marine Fisheries Commission.

Hancock, D.A., 1974. Attraction and avoidance in marine invertebrates-their possible role in developing an artificial bait. J.Cons. 35, 328-331.

Hebert, M., Miron, G, Moriyasu, M, Vienneau, R, DeGrace, P., 2001. Efficiency and ghost fishing of snow crab (*Chionoecetes opilio*). Fish. Res. 52, 143-153.

High, W.L., Worlund, D.D., 1979. Escape of king crab (*Paralithodes camtschatica*) from derelict pots. NOAA Technical Report, NMFS SSRF-734, 1-11.

Jennings, S. and Kaiser, M.J., 1998. The effects of fishing on marine ecosystem. Adv. Mar. Biol. 34, 201-352.

Kaiser, M. J., Bullimore, B.A., Newman, P.B., Lock, K.M., and Gilbert, S.E., 1996. Catches in 'ghost-fishing' set nets. Mar. Ecol. Prog. Ser. 145, 11-16.

Kimker, Al. 1994. Tanner Crab Survival in Closed Pots. Alaska Fishery Research Bullentin 1(2), 179-183.

Kruse, G. H., Kimker A., 1993. Degradable escape mechanisms for pot gear: a summary report to the Alaska Board of Fisheries. Alaska Department of Fish and Game (ADFG), Regional Information Report 5J93-01, 23 p.

Laist, D.W., 1995. Marine debris entanglement and ghost fishing: a criptic and significant type of bycatch. In: Proceedings of the Solving Bycatch Workshop, September 25-27, 1995, Seattle, Washington. pp. 33-40.

Matchacheep, S., 2004. Marine animals of Thailand (in Thai). 2nd edition, Rungsilp-karnpim, Ltd., Bangkok, pp. 310.

Mathews, C.P., Gouda, V.R., Riad, W.T., Dashti, J., 1987. Pilot study for the design of a long life fish trap (Gargoor) for Kuwait's fisheries. Kuwait Bull. Mar. Sci. 9, 221-234.

Matsuoka, T., 1999. Ghost-fishing by lost fish-traps in Azuma-cho water, Mini Rev. and Data File Fish. Res. 8, 64-69.

Matsuoka, T., 2005. A review of ghost fishing: scientific approaches to evaluation and solutions. Fish. Sci. 71, 691-702.

Miller, R.J., Addison, J.T., 1995. Trapping interactions of crabs and American lobster in laboratory tanks. Can. J. Fish. Aquat. Sci. 52, 315-324.

Miller, R.J., 1979. Saturation of crab trap: reduced entry and escapement. J. Cons. Ins. Explor. Mer., pp. 38, 338–345.

Moran, M.J., Jenke, J., 1989. Effects of fish trapping on the Shark Bay snapper industry. Western Australian Department of Fisheries. Fish. Rep. 82, 1-29. Munro, J.L., 1974. The mode operation of Antillean fish traps and the relationships between ingress, escapement and catch. J. Cons. 35, 337-350.

Munro, J.L., 1983. The composition and magnitude of trap catches in Jamaican waters. In: J.L. Munro (editor), Caribbean coral reef fishery resources, ICLARM Studies and Review 7. p. 33-49.

Nakashima, T., Matsuoka, T., 2004. Ghost-fishing ability decreasing overtime for lost bottom-gillnet and estimation of total of mortality. Fish. Sci. 70, 728-734.

Parrish, F.A., Kazama, T.K., 1992. Evaluation of ghost fishing in the Hawaiian lobster fishery. Fish. Bull. 90, 720-725.

Paul, J. M., Paul, A.J., Kimker, A.T., 1994. Compensatory feeding capacity of 2 brachyuran crabs, Tanner and Dungeness, after starvation periods like those encountered in pots. Alaska Fish. Res. Bull. 1, 184-187.

Pecci, K.J., Cooper, R.A., Newell, C.D., Clifford, R.A., Smolowitz, R.J., 1978. Ghost fishing of vented and unvented lobster, *Homarus americanus*, traps. Mar. Fish. Rev. 40, 9-43.

Shively, J.D., 1997. Degradability of natural materials used to attach escapement panels to blue crab traps in Texas. Texas Parks and Wildlife Department, Final Rep. SK Proj. NA67FD0034.

Smolowitz, R.J., 1978a. Trap design and ghost fishing: an overview. Mar. Fish. Rev. 40, 2-8.

Smolowitz, R.J., 1978b. Trap design and ghost fishing: discussion. Mar. Fish. Rev. 40, 59-67.

Stevens, B.G., 1996. Crab bycatch in pot fisheries. In solving bycatch: considerations for today and tomorrow, p. 151-158. Alaska Sea Grant Program Report 96-03. Univ. Alaska Fairbank, Juneau, Ak.

Stevens, B.G., 2000. Ghost fishing by Tanner crab (Chionoecetes bairdi) pots off Kodiak, Alaska: pot density and catch per trap as determined from sidescan sonar and pot recover data. Fish. Bull. 98, 389-399.

Sumpton, W, Gaddes, S, McLennan, M, Campbell, M, Tonks, M, Good, N, Hagedoorn, W, Skilleter, G. 2003. Fisheries biology and assessment of the blue swimmer crab (*Portunus pelagicus*) in Queensland. The State of Queensland, Department of Primary Industries, Project No. 98/117. 156 p

Sutherland, D.L. Beardsley, G.L, Jones, R.S., 1983. Results of a survey of the South Florida fish-trap fishing grounds using a manned submersible. Northeast Gulf Sci. 6(2), 179-183.

Vienneau, R., Moriyasu, M., 1994. Study on the impact of ghost fishing on snow crab, *Chionoecetes opilio*, by conventional conical trap. Can. Tech. Rep. Fish. Aquat. Sci. 1984, 1-9.

Vazquez, Archdale, M., Añasco, C.P., Kawamura, Y., Tomiki, S., 2007. Effect of two collapsible pot designs on escape rate and behavior of the invasive swimming crabs *Charybdis japonica* and *Portunus pelagicus*. Fish. Res. 85, 202-209.

Von Brandt, A. 1984. Fish catching methods of the world. 3rd edition, Fishing News Books, U.K., 418 p.

Acknowledgements

First of all, I feel deeply appreciate to Prof. Dr. Takafumi Arimoto for his counsel as an exceptional supervisor. Not only the great advices about my research study but also many very good experiences that he provided for me through all 3 years during my study here, Fish Behavior Section, Tokyo University of Marine and Technology (TUMSAT).

I thank to Dr. Hiroshi Inada, Dr. Seiji Akiyama for their comments to improve my research works and dissertation, also extend my thanks to Prof. Dr. Tadashi Tokai for his advice about the selectivity curve.

I express the gratitude to Assoc. Prof. Chaichan Mahasawasde and Assist. Prof. Dr. Suriyan Tunkijjanukij for their strong recommendations and encouragements from Thailand until I got the opportunity to come to study here. I am also indebted to Prof. Dr. Tatsuro Matsuoka who opened my mind about the selectivity of fishing gear and be my inspiration to study about that from the JICA Fishing Technology Training Course in Japan (2001).

I extend my sincere thank to Dr. Kazutaka Yanaze (Tutor) for all of his helps and guidance during my studying at TUMSAT. I thank to Mr. Nopporn Manajit for some drawing figures in this dissertation and all of his others helps, and extend to other PhD students at this laboratory; Dr. Abduh Ibnu Hajar and Mr. Norfrizal from Indonesia, Ms. Kim Bu Yeong from Korea for their very good friendships through out my study.

I also thank to Mr. Alongot Intarachart, the head of Sriracha Fisheries Research Station, Faculty of Fisheries, Kasetsart University, and the staffs of station for their assistances and the accommodation during my study research activities in Thailand. This study was supported the finance by Ministry of Education, Japanese Government Scholarship (MONBUKAGAKUSHO: MEXT).

Finally, I would like to thank my great mother and father, my wonderful wife and family in Thailand for their forever best wishes and encouragements.

September 2008