Agriculture and Natural Resources 50 (2016) 125–132

Contents lists available at ScienceDirect

Agriculture and Natural Resources

journal homepage: http://www.journals.elsevier.com/agriculture-and-natural-resources/

Original article

Comparison of ghost fishing impacts on collapsible crab trap between conventional and escape vents trap in Si Racha Bay, Chon Buri province

Santiphong Putsa,[a, b, *] Anukorn Boutson,[c] Suriyan Tunkijjanukij[c]

[a] Graduate School, Kasetsart University, Bangkok 10900, Thailand
[b] Center for Advanced Studies for Agriculture and Food, Kasetsart University Institute for Advanced Studies, Kasetsart University(CASAF, NRU-KU), Bangkok 10900, Thailand
[c] Department of Marine Science, Faculty of Fisheries, Kasetsart University, Bangkok 10900, Thailand

ARTICLE INFO

Article history:
Received 14 November 2014
Accepted 29 July 2015
Available online 10 June 2016

Keywords:
Blue swimming crab
Crab trap
Escape vent
Ghost fishing
Portunus pelagicus

ABSTRACT

This study investigated the impacts of ghost fishing on collapsible crab traps targeting the blue swimming crab, *Portunus pelagicus*. The impacts were examined by a simulated lost-gear experiment to compare conventional and vented traps, with long-term diving monitoring from 6 January 2013 to 15 January 2014, at a depth of 4–6 m in Si Racha Bay, Gulf of Thailand. Twelve pairs of box-shaped traps 36 × 54 × 19 cm were compared using the conventional design and a vented trap with escape vents of 35 × 45 mm. Throughout the 374 d experiment, 520 individuals from 25 different species were entrapped in the conventional traps, with 19 were classified as target, and 501 individuals as by-catch species. In the vented traps, 222 individuals of 24 species were entrapped in total, of which 17 were classified as target and 205 as by-catch. The catch-per-unit-effort of all animals entrapped in conventional traps was significantly higher than in the vented traps at each time observation. Furthermore, the vented traps showed lower entrapment and mortality numbers than the conventional traps. These results demonstrate the positive functions of escape vents in reducing the negative impacts of ghost fishing, not only on the number of entrapped individuals but also on mortality rates.

Introduction

Ghost fishing can be defined as the ability of fishing gear to continue catching or trapping fish after all control of that gear has been lost by those using it to fish (Smolowitz, 1978) and also refers to derelict fishing gear either lost or abandoned which retains its capture function in water and continues to induce mortality of aquatic organisms without human control (Matsuoka et al., 2005). Trap loss occurs for several reasons including bad weather, bottom snags, navigational collisions, faulty fishing methods, vandalism and gear failure (Laist, 1995), the accidental or intentional removal of marker floats and traps by other vessels, heavy weather moving traps into deeper water and incidental removal of floats by large animals including sharks (Sumpton et al., 2003). Trap ghost fishing can occur through a variety of mechanisms. Theoretically, ghost fishing occurs when the contents of a lost trap (both target and by-catch species) die and attract more animals into the trap. These animals then die and attract more until the trap breaks down and ceases its capture function (Campbell and Sumpton, 2009) which has also been named auto-rebaiting, involving rebaiting by other species and lost traps also can attract more animals due to the trap alone (Breen, 1990). The materials used in the construction of the traps do not deteriorate easily, which increases the potential for animals entrapped and unaccounted mortality in lost traps for prolonged periods (Bullimore et al., 2001) including target, non-target and even endangered or protected species (Dayton et al., 1995). The impacts of ghost fishing on some commercial grounds have been estimated to be between 5 and 30 percent of total annual landings (Laist, 1995) and the mortality rate from ghost fishing is currently an intangible and remains of significant concern to both fishers and fisheries managers (Jennings and Kaiser, 1998). In a trap fishery in Kuwait, financial losses were estimated to range from 3 percent to 13.5 percent of the total catch value (Mathews et al.,

* Corresponding author.
E-mail address: santipong.ku@gmail.com (S. Putsa).
Peer review under responsibility of Kasetsart University.

http://dx.doi.org/10.1016/j.anres.2015.07.004

1987). Ghost fishing mortality at 25 simulated lost fish traps was estimated to be 1.34 kg per trap per day, or about 67.27 kg per trap and 78.36 kg per trap for 3 and 6 mth, respectively in Oman (Al-Masroori et al., 2004). Overall mortality from ghost fishing is dependent upon the number of ghost traps, trap location, season, length of ghost fishing period and the mortality rate per trap (Guillory et al., 2001; Matsuoka et al., 2005).

To reduce the negative impacts of trap ghost fishing, Al-Masroori et al. (2004) suggested that the traps should be equipped with time-release or degradable sections or panels, and sometimes openings are included in the traps to release undersized animals. Traps with escape windows or vents attached for a blue swimming crab (*Portunus pelagicus*) fishery in Thailand have been investigated by Boutson et al. (2009), who reported the escape vents (35 × 45 mm) in traps had a positive function in reducing the by-catch, discards and the catch of undersized target species as immature crab, while not affecting the catch efficiency of mature-sized crabs, and also had a high probability of reducing the negative impacts of ghost fishing.

Collapsible-traps targeting blue swimming crab have recently become a major type of fishing gear operating year round in the Gulf of Thailand. The small-scale fishers operate their traps inshore with 200–300 traps/operation, and commercial boats operate with long-line settings of 2000–5000 traps/operation or more (Boutson et al., 2009). According to interviews by the author with fishermen (data unpublished), the traps are quite often lost at sea (about 3–20 traps/d for small-scale fisherman). Their traps are constructed using a galvanized rod frame covered with clear rubber tubing and are covered with green polyethylene (Fig. 1B) so that the traps are not easily degradable when lost at sea. However, the ghost fishing effects on blue swimming crab and other animals from trap fishing in Thailand have been not evaluated and reported. Accordingly, the objectives of this study were to examine the ghost fishing characteristics of the conventional trap used by small scale fishers compared to the vented trap. Specifically, the rates of entrance, escape and mortality of the target species and the by-catch species were assessed and compared between both trap types.

Materials and methods

Site selection

The study was conducted in Si Racha Bay, Chon Buri Province, in the upper Gulf of Thailand (Fig. 1A). This site features green mussel sea farming and it is a fishing ground for small-scale, crab-trap fisherman, about 0.8 km from shore with a depth of 4–6 m, and the substratum is composed of muddy sand.

Experiment protocol

In total, 24 new, collapsible crab traps were obtained from a fisherman to simulate lost traps at the study site. The traps have a box shape with dimensions of 360 × 540 × 190 mm and two slit entrances (Fig. 1B), a frame structure made from galvanized iron (4 mm diameter) covered with clear rubber tubing and the trap structure is covered with a green, square-shaped polyethylene net with a mesh size of 38 mm. There is a hook attached to the top panel that controls the trap set up and collapse function. Two trap designs were used in the experiment. The first type was 12 conventional traps which were the same as the local fishers used (Fig. 1B). The second trap type was 12 vented traps (Fig. 1C) with two escape vents consisting of a vent size of 35 × 45 mm, located on opposite sides of the bottom panel of the trap (Boutson et al., 2009).

The 12 simulated traps of each type were deployed in a paired experiment over 454 d from 6 January 2013 to 5 April 2014 at the

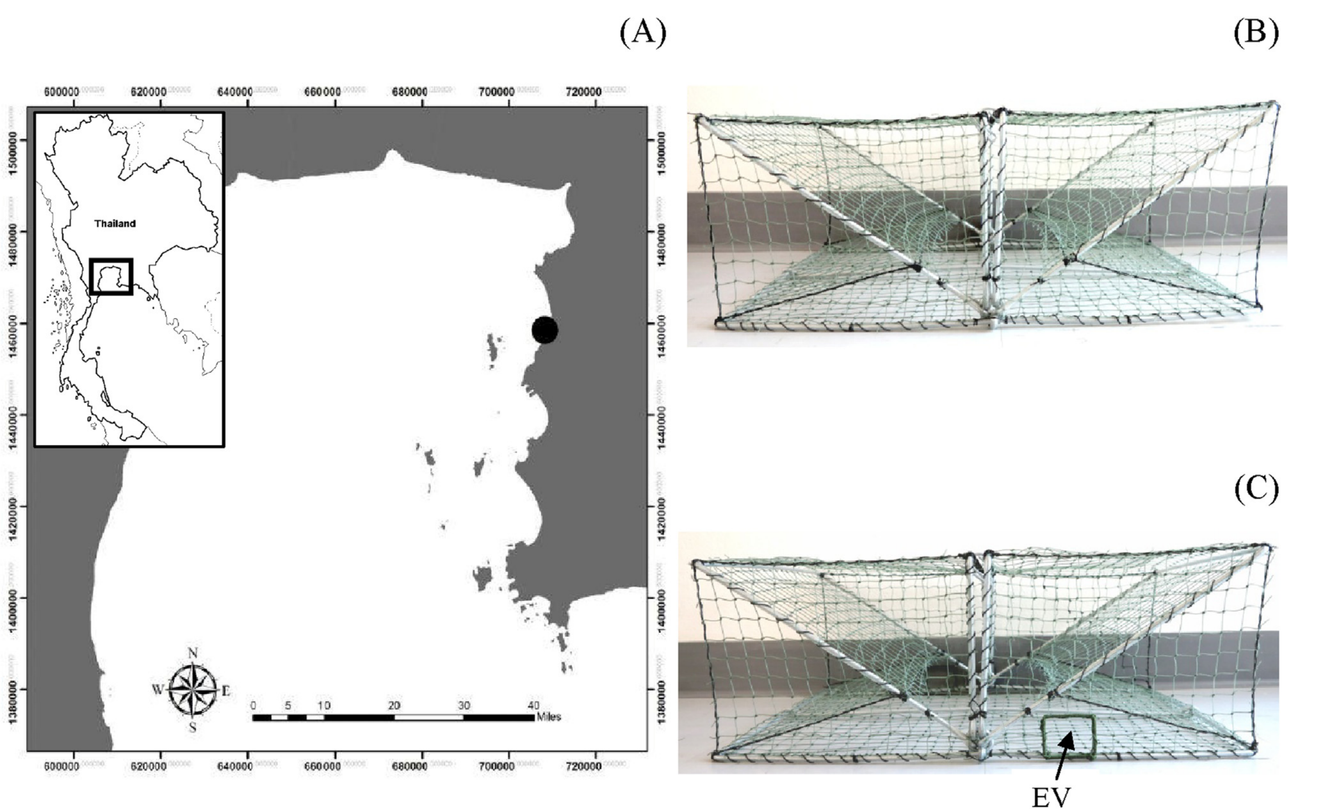

Fig. 1. (A) Location map of the study site (●) in Si Racha Bay, Gulf of Thailand; (B) Conventional trap obtained from local fishers 36 × 54 × 19 cm; (C) Vented trap with escape vents (EV; 35 × 45 mm) located on both sides of the bottom panel.

study site. In each pair, the traps were set the same distance apart (7 m), anchored with a 20 kg cement block to fix the position, attached to a polypropylene rope 10 m in length and marked with a surface marker buoy. Another buoy (underwater buoy) was set at a distance of 3 m from the cement block in case the surface buoy was lost (Fig. 2). Each trap was baited once only at the beginning of the experiment with approximately the same size of trevally (*Selaroides leptolepis*) pierced and bound with wire at the center of the bottom trap panel. A diver surveyed the traps immediately after deployment to confirm that the traps were deployed on the seabed correctly. During the experiment, six traps of each trap type were lost and the remaining six traps of both types were retrieved during the final monitoring (5 April 2014).

Data recording

Observations on each trap type were conducted by scuba diving in the daytime to monitor the situation after the deployment every day for the first 2 wk, then continuously every 2–3 d or 3–4 d for 3 mth and about once a month afterward up to 454 d (5 April 2014) from the initial trap deployment. On each dive, interference was minimized to maintain the conditions of a ghost fishing environment. Records were taken at each trap of: baited and trap conditions, the number of 'new entrapped', 'escaped' or 'dead' entrapped animals, the total length of fish and the carapace width (CW) of crabs using a ruler scale and estimates from the mesh size. The behavior and condition of trapped animals were observed using underwater video recording. The estimates of entrapped animal size and condition recorded for individual species from the previous monitoring were observed to distinguish new animals from those entrapped earlier. It was not possible to measure the size of all the fish such as the rabbit fish (*Siganus oramin*) and catfish (*Plotosus lineatus*) when there were many individuals in the same trap. However, they were readily identifiable on consecutive occasions from their injuries and numbers were counted from their pictures and video recording. It was assumed that an individual crab or fish trapped previously had escaped if there was no sign of the carapace and/or appendages at the next monitoring, while mortality was only confirmed if the carapace and/or appendages were present on the floor of the trap or on the seabed nearby during the observation times. Thus, it was possible to quantify the minimum mortality of captured animals per trap per year after initial trap deployment. During the experiment, some traps were lost, and those traps had animals trapped inside, in addition, at the last monitoring, when all the remaining traps were retrieved from the sea, some animals were still inside the traps. We classified all such animals as "no fate". Any trap damage was recorded but was not repaired in order to replicate authentically the conditions of lost traps.

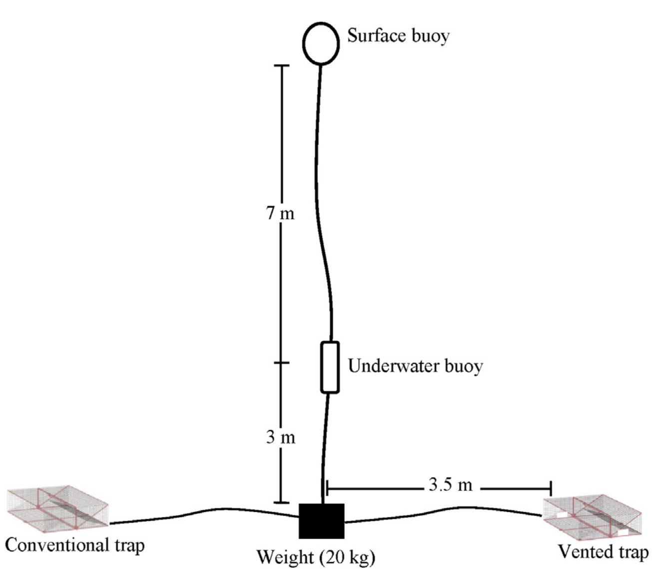

Fig. 2. Setting for pair of simulated lost traps.

Data analyses

This present study involved an analysis of 374 d of data only (6 Jan 2013–15 Jan 2014), excluding the data observed during the 3 mth thereafter, up to 5 April 2014. The catch rates of all animals and blue swimming crabs were calculated as the number of newly recorded animals entrapped in each trap, then combined to determine the total catch on each consecutive sampling occasion. The catch data were expressed as catch-per-unit-effort (CPUE) data (Equation (1)):

$$\mathrm{CPUE} = N_j/(E_p(t_j - t_i)) \qquad (1)$$

where N_j is the number of newly caught animals, E_p is the number of traps available and $t_j - t_i$ is the time interval since the previous observation (t_i) according to Bullimore et al. (2001).

The Mann–Whitney test was used to determine the crab size differences for entrapped, escaped and mortality between the conventional and vented traps. The potential numbers of commercial species entrapped per trap per year were estimated with the sum of the new entrapped number divided by the number of available traps at each interval monitored. Thus, it was possible to estimate the mortality due to ghost fishing per trap per year using the percentage dead of each species between conventional and vented traps in this experiment.

Results

The bait within the traps was consumed rapidly in both trap types studied. The bait in the vented traps was exhausted much more rapidly than in the conventional traps, so that by day 3, there were no remnants of the bait in the 12 vented traps, while only one of the conventional traps had any bait remaining on day 4 and this was eaten over the next few days.

Throughout the 374 d experiment simulating ghost fishing, there were many entrapped animals including target and by-catch species (no commercial value). The conventional traps entrapped significantly more animals than the vented traps ($p = 0.005$, t test), as shown in Table 1. The conventional traps had 25 different entrapped species (520 individuals), of which 371 (71%) were classified as commercial catch. Of these, rabbit fish ($n = 98$), toad fish ($n = 71$) and catfish ($n = 45$) dominated, while 149 (29%) were considered to have no commercial value from conventional traps, with sea urchin ($n = 105$) and butterfly fish ($n = 23$) dominating (Table 1). The vented traps entrapped 24 different species (222 individuals), of which 144 (65%) were classified as commercial catch. The dominant species of these were toad fish ($n = 41$), rabbit fish ($n = 19$) and blue swimming crab as the target species ($n = 17$). Of these, 78 (35%) were considered as non-commercial catch, such as sea urchin ($n = 55$) and butterfly fish ($n = 11$).

It was assumed that an individual crab or fish had escaped if there was no carapace or skin and skeleton found. The escape level was high from both conventional and vented traps types, 368 (71%) and 185 (83%) individuals, respectively. However, mostly the commercial species such as spiny rock crab, mangrove stone crab,

Table 1
Total number of entrapped, escaped, dead and no fated comparison between conventional traps (C) and vented traps (V) until 374 d after initial trap deployment.

Common name	Species name	No. of individuals							
		Entrapped		Escaped		Dead		No fated	
		C	V	C	V	C	V	C	V
Sea urchin	*Diadema setosum*	105	55	102	52	2	3	1	0
Rabbit fish[a]	*Siganus* sp.	98	19	56	13	42	5	0	1
Toad fish[a]	*Batrachus grunniens*	71	41	59	39	8	0	4	2
Catfish[a]	*Plotosus lineatus*	45	2	2	1	43	1	0	0
Spiral melogena[a]	*Pugilina cochlidium*	44	13	38	13	1	0	5	0
Mangrove stone crab[a]	*Myomenippe hardwickii*	37	14	27	14	9	0	1	0
Butterfly fish	*Coradion altivelis*	23	11	19	11	4	0	0	0
Ridged swimming crab[a]	*Charybdis japonica*	22	15	16	13	6	2	0	0
Blue swimming crab[a]	*Portunus pelagicus*	19	17	7	3	12	14	0	0
Spiny rock crab[a]	*Thalamita crenata*	17	4	15	4	2	0	0	0
Chinese filefish[a]	*Monacanthus chinensis*	5	5	4	2	0	3	1	0
Gray eel-catfish[a]	*Plotosus canius*	5	7	1	3	4	4	0	0
Indo-Pacific sergeant	*Abudefduf vaigiensis*	4	2	4	1	0	1	0	0
Sea cucumber	*Holothuria* sp.	4	2	4	2	0	0	0	0
Pony fish	*Leiognathus* sp.	3	0	0	0	3	0	0	0
Pink ear emperor[a]	*Lethrinus lentjan*	3	0	2	0	1	0	0	0
Octopus[a]	*Octopus* sp.	3	2	3	2	0	0	0	0
Puffer fish	*Tetraodon* sp.	2	1	2	1	0	0	0	0
Japanese threadfin bream[a]	*Nemipterus japonicus*	2	1	2	1	0	0	0	0
Japanese flathead	*Inegocia japonica*	2	1	0	1	2	0	0	0
Whipfin silver-biddy	*Gerres filamentosus*	2	2	2	2	0	0	0	0
Red soldier	*Holocentrus rubrum*	1	2	0	2	1	0	0	0
Goby fish	*Afurcagobius* sp.	1	1	1	1	0	0	0	0
Indian Ocean pinstriped wrasse	*Halichoeres vroliki*	1	1	1	0	0	1	0	0
Hermit Crab	*Coenobita* sp.	1	0	1	0	0	0	0	0
Orange-spotted grouper[a]	*Epinephelus coioides*	0	2	0	2	0	0	0	0
Swimming crab[a]	*Charybdis affinis*	0	2	0	2	0	0	0	0
Total		**520**	**222**	**368**	**185**	**140**	**34**	**12**	**3**

[a] = species of commercial value.

rabbit fish and toad fish escaped from vented traps at a higher rate than from conventional traps (Table 1).

The CPUE for all animals trapped in conventional traps was significantly ($p < 0.01$) higher than in vented traps at each observation time as shown in Fig. 3. The number of entrapped animals between different observed periods did not differ significantly ($p > 0.05$) in conventional traps. In contrast, they differed significantly ($p < 0.05$) in vented traps. Divers observed some animal species were always resident in both trap types, such as toad fish and sea urchin. When the observation intervals were as long as a month, divers always found only new entrapped animals in the trap; in addition, the entrapped species diversity was reduced when compared with the initial experiment.

Over the course of the experiment, there were more entrapped species than for the target species (blue swimming crab), with relatively few target species retained in either trap type. The CPUE values of blue swimming crab entrapped in conventional and vented traps were calculated using the average catch per day per trap (Fig. 4). There was a clear trend in the CPUE for blue swimming crab. Initially, there was high entrapment in the first week, 37 percent ($n = 7$) and 59 percent ($n = 10$) in total for conventional and vented traps, respectively. It then declined rapidly to a minimum rate until 119 d and then increased again until lapsing with no more entrapments in either trap type. However, the present study showed low entrapment of blue swimming crab with a catch of 1.58 crabs per trap per year and 1.42 crabs per trap per year in conventional and vented traps, respectively (Table 3).

A comparison of the size (CW) of blue swimming crab entrapped in each trap type is shown in Fig. 5. The results show that when compared with conventional traps, vented traps entrapped fewer small crabs and retained the larger ones. Despite this difference, the catch efficiency was not significantly affected, with no significant difference between the two trap types ($p = 0.784$, t test). However, the average size (CW) of all the crabs entrapped in vented traps was

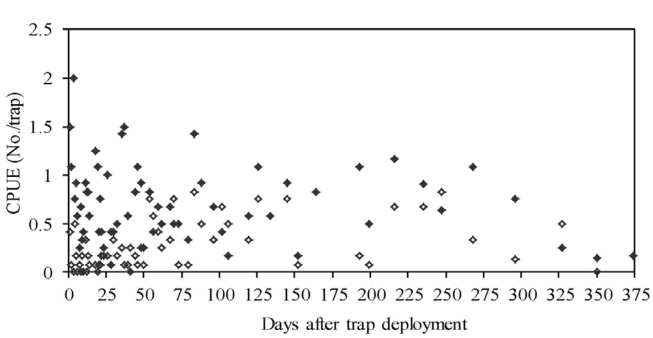

Fig. 3. Catch per unit of effort (CPUE) of entrapped animals between conventional (closed diamonds) and vented traps (open diamonds) after deployment.

Fig. 4. Catch per unit of effort (CPUE) for blue swimming crabs as target species between conventional (closed diamonds) and vented traps (open diamonds) after deployment.

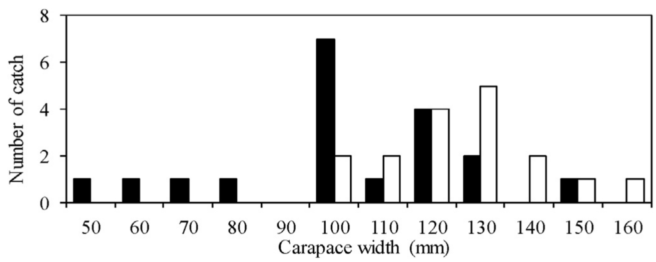

Fig. 5. Blue swimming crab size sampled with conventional traps (filled columns) and vented traps (clear columns).

significantly larger than in the conventional traps, as shown in Table 2 (Mann–Whitney *U* test, $p < 0.05$). The mortality of entrapped crabs was much higher than that of escaped crabs, as there were often carapaces found at the bottom of traps. Approximately 63.16 percent and 82.35 percent of all entrapped crabs were dead in the conventional and vented traps, respectively (Table 2). The average size (CW) of dead crabs was greater than that of escaped crabs for both trap types. Nevertheless, there was no significant difference (Mann–Whitney *U* test, $p > 0.05$) in the average size (CW) of dead crabs compared with escaped crabs for both trap types. The number of days of entrapment for escaped and dead blue swimming crabs varied with 1–30 d and 3–38 d for conventional traps, and 3–37 d and 3–43 d in vented traps, respectively.

The total entrapped number did not indicate the total mortality of animals associated with the ghost fishing traps. It was possible to confirm the mortality by monitoring the dead bodies of the entrapped animals remaining. According to diving observation, the total number of mortalities in conventional traps was higher than in vented traps, with 140 (27%) individuals and 34 (15%) individuals in total, respectively. The majority of dead commercial species observed in conventional traps were finfish such as catfish (43 individuals; 96%) and rabbit fish (42 individuals; 43%), while the vented traps had a very small number of dead for these same species with 1 (50%) individual and 5 (26%) individuals, respectively (Table 1).

Using the entrapped and escaped rates of commercial species during this experiment (Table 1), it was possible to estimate the mortality rate per trap per year for each species. The minimum mortality rates of *P. pelagicus* and other major commercially important by-catch species, such as *Siganus* sp., *Batrachus grunniens*, *P. lineatus* and *Pugilina cochlidium*, showed that the entrapped and mortality rates per year in each species from vented traps were lower than from conventional traps (Table 3).

Table 3
Comparison of number entrapped and dead commercial species between conventional and vented traps estimation with individuals per trap per year.

Species name	Entrapped/trap/year		Dead/trap/year	
	Conventional	Vented	Conventional	Vented
Crab				
Portunus pelagicus	1.58	1.42	1.00	1.17
Myomenippe hardwickii	3.30	1.17	0.80	0.00
Charybdis japonica	1.84	1.27	0.50	0.17
Thalamita crenata	1.42	0.33	0.17	0.00
Charybdis affinis	0.00	0.17	0.00	0.00
Fish				
Siganus sp.	8.25	1.71	3.54	0.45
Batrachus grunniens	6.16	3.37	0.69	0.00
Plotosus lineatus	3.75	0.17	3.58	0.09
Monacanthus chinensis	0.42	0.42	0.00	0.25
Plotosus canius	0.42	0.58	0.34	0.33
Lethrinus lentjan	0.25	0.00	0.08	0.00
Nemipterus japonicus	0.17	0.08	0.00	0.00
Epinephelus coioides	0.00	0.17	0.00	0.00
Molluscs				
Pugilina cochlidium	3.97	1.12	0.09	0.00
Octopus sp.	0.25	0.17	0.00	0.00

Discussion

The results of the present study showed that simulation traps can continue to capture various animals including commercial species for several months (more than a year) after the initial deployment of the traps. Other studies have also shown that some pots or traps have potential to function as traps over the long term due to the ghost fishing cycle (Bullimore et al., 2001; Hébert et al., 2001; Al-Masroori et al., 2004; Ramírez-Rodríguez and Arreguín-Sánchez, 2008). Conducting interviews with trap fishers in Oman, Al-Masroori et al. (2009) found that 95.7% of fishers were aware that the lost traps will continue to function for a long period and most of them (88%) confirmed losses were at an average of 18 traps per year and these traps would remain functional for at least 3.1 mth after being lost. In particular, traps for *P. pelagicus* in Australia were estimated to function for more than 4 yr (Sumpton et al., 2003). However, the current study found that the nets of six traps were damaged and the first was damaged 106 d after initial deployment. It was assumed that netting of traps was cut by crabs (mangrove stone crab) inhabiting inside, as there were fewer or no entrapped animals in those traps. Moreover, Matsuoka et al. (2005) reported the lost traps from both offshore and inshore fishing grounds were damaged by waves and fouled biologically, which had the effect of reducing the ghost fishing function when traps were lost.

The current experiment found that the fish bait within traps was either consumed or decomposed completely within 3 d in vented traps and within about 4 d in conventional traps. This finding was similar with that of Al-Masroori et al. (2004), who observed the bait within their trial traps in Oman was consumed on average within 3 d Campbell and Sumpton (2009) reported that the bait within pots in ghost fishing conducted in Queensland had been exhausted after 4 d. In contrast, Bullimore et al. (2001), who conducted a parlor pots experiment in the UK, reported the initial bait was exhausted after 27 d. This probably reflected differences in the oceanographic conditions of the regions, particularly the seawater temperature. Observations during daily diving revealed that the reason for the faster decomposition in vented traps was that conventional traps had entrapped more species in higher numbers

Table 2
Comparison of number and mean size of blue swimming crabs entrapped, escaped and dead between conventional and vented traps.

Parameter	Number of		Carapace width (mm)	
	Conventional traps	Vented traps	Conventional traps	Vented traps
			Mean ± SD	Mean ± SD
Entrapped	19	17	103.2 ± 25.0	125.9 ± 16.2
Escaped	7	4	97.1 ± 27.5	122.5 ± 17.1
Dead	12	13	106.7 ± 23.9	126.9 ± 16.5

during the first three days than vented traps had. It was assumed that smaller fish or crabs may have escaped through the escape vents before the traps were surveyed.

Various parameters can affect the catch efficiency, escape and mortality levels in trap ghost fishing. This experiment compared the catch composition for number and size of blue swimming crab under the same fishing ground conditions between conventional and vented traps. The traps with escape vents resulted in a decreased catch of small-sized blue swimming crabs, while maintaining the catch of larger-size crabs without any effect on the catch efficiency; these result are similar to those of Boutson et al. (2009). The numbers of entrapped crabs were not different between conventional and vented traps, indicating that in this study, the escape vents did not affect the numbers of the catch. The shape and entrance design of a trap was also important; Vazquez Archdale et al. (2006) found no significant differences among crab sizes between the slits entrances in Box traps (similar to those used in the current experiment traps) and the open entrances in Dome-S traps both having the same 2.3 cm mesh size. Conical and pyramidal traps were more catch efficient with large snow crabs than rectangular traps (Hébert et al., 2001).

The trap condition also had an effect on other catches (Stevens et al., 2000). To ascertain the catch rates, it is necessary to know the number of active ghost fishing traps (Stevens et al., 2000). In the current 12-paired traps experiment, the catch rate estimation of blue swimming crabs as the target species was low for both conventional and vented traps, with 1.58 individuals per trap per year and 1.42 individuals per trap per year, respectively. The CPUE was high at the beginning and declined over time for both trap types. This could have been due to the initial baiting while the traps were still in good condition. However, the catch numbers declined until 119 d, which may have been affected by the identity of the initial occupant animals inside. A second pulse of catches occurred again (126–145 d) with the entrapment of five crabs in the conventional and two crabs in the vented traps, perhaps because the traps had dead fish in them which acted as an attractant, similar to the report by Campbell and Sumpton (2009). In agreement with Bullimore et al. (2001) it was noted that dead fish would provide a source of food for more crustaceans that became entrapped. Furthermore, crabs could continue to enter lost traps, even without bait (Stevens et al., 2000). In the current study, the CPUE values of blue swimming crabs in both trap types showed a similar trend of catch rate as was observed in the simulation of lost parlor traps by Bullimore et al. (2001) who reported that the CPUE values of spider crabs and brown crabs declined over time with a similar pattern for both crabs and then increased again at 333 d after deployment, which may have been due to rising water temperatures. The number and CPUE of crabs (*Cancer johngarthi*) per trap decreased exponentially with longer soak times (Ramírez-Rodríguez and Arreguín-Sánchez, 2008). Similar results showed that the number of trapped crabs declined overtime due to escapes, predation, mortality and reduced capture rates (Stevens et al., 2000).

Some species such as toad fish and sea urchin dominated the catches since they were resident species, and represented the majority found in the last period of observation in the current study. It is suggested that they were able to easily escape and re-enter the traps because the results showed high escape numbers for both species. These results may affect the CPUE of all entrapped animals as shown in Fig. 3, as both simulated trap types continued to catch animals for more than 1 yr. Nevertheless, a reduced catch rate and diversity of species were found in last period, as could be expected as both species did not attract others animals to enter the traps and there was fouling organism accumulation on the traps.

The escape rate in the simulated traps was large for both trap types because any major species trapped could escape in high numbers, such as sea urchin and toad fish. The escape vents were a very effective by-catch reduction tool, as fewer entrapped animals were found in vented traps than in the conventional traps, which was similar to the results reported by Ayana (2010) and Boutson et al. (2009). The entrapped blue swimming crabs were larger in the vented traps than in the conventional traps, thus the escape rate in vented traps was less than in the conventional traps. Similarly, it was reported that smaller king crabs may be more active than larger crabs (Godøy et al., 2003) and Guillory (1993) also observed that smaller blue crabs (*Callinectes sapidus*) were more likely to escape than larger individuals. The smaller king crabs were the first to leave the rectangular traps because they had an easier passage through the entrance from inside the traps (Godøy et al., 2003). The catch number of undersized rock lobster (*Jasus frontalis*) decreased as the diameter of the escape vents increased (Arana et al., 2011). Trap entrance design can also facilitate escape. Vazquez Archdale et al. (2006) found that the Box traps (slits entrance) had fewer escapes of non-target species than did Dome traps (open entrance) after the bait was consumed. However, the current experiment found that some crab and fish could escape from the trap, even though they were larger than the size of escape vents. It was assumed that they escaped through the slits entrance.

The first blue swimming crabs left the conventional traps within 1 d (CW size = 70 mm) and left the vented traps in 3 d (CW size = 100 mm) after entrapment. Godøy et al. (2003) reported it was possible that crabs left traps after a few days because the odor of the bait was exhausted. Those results were consistent with other crab species (mangrove stone crab, ridged swimming crab, spiny rock crab and hermit crab) where there was a high percentage of escapes in both trap types because generally these crabs were smaller than blue swimming crab. However, the current study showed no difference in the size of blue swimming crabs between those that escaped and those that died in traps. Of these situations, it is suggested that they could escape through the slit entrance. However, this was contradicted by Vazquez Archdale et al. (2007) who reported that *P. pelagicus* and *Charybdis japonica* could not escape over 7 d from box-shaped traps with a narrow slit entrance (similar to the current experiment), whereas 100% of crabs escaped from the dome shaped traps. The escape rates for tagged *Paralithodes camtschaticus* from rectangular traps were as high as 92 percent (Godøy et al., 2003).

The conventional traps showed high numbers of entrapment and fewer escapes than from the vented traps. Consequently, the estimations of mortality in the conventional traps were higher than in the vented traps, especially for rabbit fish and catfish as commercial values with mortality rates of 3.54 individuals per trap per year and 3.58 individuals per trap per year, respectively. These results suggest that schooling fish were involved and when some entered the traps, it was possible that this attracted others in same species to enter the same traps, where they remained until they died. According to the current experiment, mortality estimates of entrapped blue swimming crabs were 1.00 crabs per trap per year and 1.17 crabs per trap per year for conventional and vented traps, respectively. These appear low because the study site was not in an intensive fishery area and perhaps the impacts would have been more serious if trap ghost fishing occurred in intensively fished areas.

The main reason for mortality in blue swimming crab in the experiment was as a result of starvation after the bait had been exhausted, which was consistent with other reports that a large amount of mortality occurred due to starvation (Stevens et al., 2000). One study reported that 83.6 percent of dead crabs were completely eaten or decayed within a week of being found dead (Campbell and Sumpton, 2009). The overall mortality from ghost fishing is dependent upon the number of ghost traps, trap design, trap location, season, the length of ghost fishing period and the mortality rate per trap (Bullimore et al., 2001; Godøy et al., 2003; Guillory et al., 2001; Matsuoka et al., 2005). For example, the impact of ghost fishing on some commercial grounds has been estimated at between 5 and 30 percent of total annual landings (Laist, 1995). Ghost fishing in a crab fishery reported by Hébert et al. (2001) showed that the loss of 1000 conical traps would kill 84,194 snow crabs (*Chionoecetes opilio*) or 48.2 t per year. In a single trap fishery in Kuwait, the financial may losses ranged from 3% to 13.5% of the total catch value (Mathews et al., 1987). The simulated ghost fishing mortality loss from 25 fish traps was estimated at 1.34 kg per trap per day, or about 67.27 kg per trap and 78.36 kg per trap for 3 and 6 mth, respectively, in Oman (Al-Masroori et al., 2004). Stevens et al. (2000) considered that a fishery of Tanner crab (*Chionoecetes bairdi*) in Alaska that had an average crab loss of 1.5 per trap was not high. Godøy et al. (2003) observed that in a study using deliberately lost traps, red king crab (*P. camtschaticus*) entered and escaped relatively easily over time so that while the mortality rate due to lost traps is not easy to estimate, it was probably low and so in this case it was reasonable to believe that lost traps did not substantially contribute to crab mortality. However, the mortality rate from ghost fishing is currently an intangible and remains of significant concern to both fishers and fisheries managers (Jennings and Kaiser, 1998). Nevertheless, the current study found that large-sized fish, such as gray eel-catfish and orange-spotted grouper escaped from the traps, with the average size being 30 cm (4 fish) and 37.5 cm (2 fish), respectively.

Divers also observed some behavior of entrapped animals, as fish and crabs moved through the mesh to escape from the traps and bumped on the net webbing inside (rabbit fish, red soldier fish and butterfly fish) similar to the findings of Bullimore et al. (2001), Al-Masroori et al. (2004) and Matsuoka et al. (2005). Matsuoka et al. (2005) presumed that the unusual behavior which was never exhibited in the natural environment, was attributable to the high density and consequent stress from being in a trap with other animals. The blue swimming crabs were often in a bottom corner of traps, particularly when there was more than one individual in the same trap, and animals did not move, as could be deduced from the sediment accumulated on those carapaces. This finding was similar to Boutson et al. (2009) who observed blue swimming crabs in the tank and suggested the crabs remained in the corner for foraging and to avoid attacks by larger crabs.

Conclusion

This study conducted a comparative simulated trap experiment to evaluate the ghost fishing impacts between conventional and vented traps. The traps can continue to ghost fish for more than 1 yr. The results showed a reduction in the small-sized crab catch through escape vent traps, while maintaining the large-sized catch. In addition, vented traps could also reduce entrapment of by-catch and discards. This was an effective way to minimize the mortality rate of smaller individuals of target species and in particular for by-catch species. Three priority countermeasures to ghost fishing were proposed by Matsuoka et al. (2005)—prevent fishing gear loss, retrieval or improved design of gear and the development of more rapid degradation of fishing gear when lost. Future studies should be carried out to investigate the number of ghost fishing trap in Si Racha Bay using information collected on the number of fishers, the number of traps in operation and trap loss rate among other data. Eventually, it should be possible to calculate the potential economic loss and the negative impact to the fishery sector from fishing gear losses.

Conflict of interest statement

The authors declare that there are no conflicts of interest.

Acknowledgments

The authors are grateful to the officers at the Si Racha Fisheries Research Station, Kasetsart University for their kind assistance during the field experiments. We would like to thank Mr Asirawat Preecha for his support as a diving buddy and for recording some data. We also thank the anonymous reviewers for their valuable comments. A special thanks is recorded to Professor Richard S. Lavin for assistance with English in an earlier version. This work was partially supported by the Center for Advanced Studies for Agriculture and Food, Institute for Advanced Studies, Kasetsart University under the Higher Education Research Promotion and National Research University Project of Thailand, Office of the Higher Education Commission, Ministry of Education, Thailand.

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