Evaluation of open-eyed and closed-eyed entrances on retention and escape of invasive swimming crabs and associated fauna from pots in their native range

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Running head: Trap entrance affects retention of invasive crabs

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Abstract:

Fishing trials targeting several invasive swimming crab species in their native habitat were undertaken using two types of collapsible pot, one with open-eyed entrances and another with closed-eyed ones, to analyze differences in catch retention between them. The open-eyed pot was dome-shaped with two funnel entrances located at opposite ends, while the closed-eyed one had two soft sleeves that ended in slits and had to be pushed through by organisms to ingress, supposedly reducing escape. Retention fishing trials (100 pot hauls/pot type) using a 1– day soaking and fish bait, confirmed no significant difference in crab catches between pot types; differences were only detected for large fish (morays and congers). A second set of 4 – day escape trials (20 pots/ type) was done to investigate how long organisms would be detained in the pots. Escape was significantly affected, and half-residences were typically delayed by 1 – 2 days for most crabs and fish in closed-eyed entrance pots because the entrances closed. Closed-eyed entrances hampered escape and might be useful when longer soakings are needed; but because no differences were detected in crab numbers between both entrance types at short soakings, we recommend open-eyed entrance pots in order to mitigate possible ghost fishing impacts from lost gear.

Additional keywords: traps, eradication, alien species, portunid crab, *Charybdis japonica*, *Portunus pelagicus*

Introduction

Although there is a long history of fishing-gear research for commercial exploitation, the recent problem of invasive alien crab species has made it necessary to develop and improve current pot designs. Research on invasive alien species eradication involves various aspects of pest control (Lafferty and Kuris 1996), such as education, prevention, bio-control as well as the improvement of fishing gear and methods for their removal. Previous research (Vazquez Archdale *et al.* 2003-2010b) has examined the traditional fishing gear/methods used in the country of origin of various invasive swimming crab species. The current study, which involved experimental fishing in their native range, examined the effect on crab catches and the retention of the caught organisms in dome-shaped pots (or 'opera house traps') fitted with two types of entrance, one open and the other closed-eyed, and assessed the possible application to pots used for sampling and eradication in countries suffering from alien crab infestations. The crab species targeted, the shore swimming crab (also called Asian paddle crab) *Charybdis japonica*, the blue swimming crab *Portunus pelagicus* and *Thalamita* spp., are native in Japan, but *C. japonica* is also invasive in New Zealand and Australia while the others have spread into the Mediterranean sea and they can be used as a model to study and develop better eradication trapping gear and sampling methods (Gust and Inglis 2006; MAF Biosecurity New Zealand technical paper 2008; Hourston *et al.* 2015).

The number of organisms retained in a pot does not necessarily represent how many had entered, as many will escape before they are hauled. Pot entrances that permit easy entry usually have high escape rates, and for this reason fishers have modified entrances and/or installed escape prevention devices to increase the retention of the catch. Sloping entrances upwards, installing separate chambers, fitting shutters or triggers that close the entrance opening after the target animal has pushed through have been commonly applied (Thomas 1956; High 1976; Miller 1990, 1980, 1979a). Other methods include slippery plastic collars installed in top-entrance pots (Miller 1980) and one-way triggers fitted on open entrances (High 1976; Zhou and Shirley 1997).

Previous research (Vazquez Archdale *et al.* 2007, 2006a) has examined the effect of open-eyed entrances and slit entrances on the ingress and egress of *C. japonica* and *P. pelagicus* from collapsible pots in Japan. Underwater video recordings of *C. japonica*'s behaviour around pots showed that dome-shaped pots fitted with open-eyed entrances caught 100% of the crabs contacting them, while only 31% could enter box-shaped pots installed with slit entrances (Vazquez Archdale *et al.* 2006a). Tank experiments confirmed these results (Vazquez Archdale *et al.* 2006b). Field experiments examining the escape of pot-captive swimming crabs also determined marked differences between open-eyed entrances and slits; crabs could escape from open-eyed entrance pots (100% for *P. pelagicus* and 78% for *C. japonica* within 7 days) but none could exit from box-shaped pots with slits (Vazquez Archdale *et al.* 2007).

The purpose of this study was to investigate the application of closed-eyed entrances installed in pots and to determine their effect on retention of swimming crabs and associated fauna caught in realistic field conditions. Closed-eyed entrance pots have two funnel entrances that taper towards the inner chamber of the pot, ending as a soft-sleeve with a slit at its end, and after an animal pushes through it will collapse again, closing the entrance and supposedly preventing escape. This entrance type is common in Japanese pots used for trapping octopus and conger eel, but no research concerning it could be found in the literature.

Materials and methods

Retention trials

Retention trials were conducted in a pond (70 m x 1000 m) located in Kagoshima City's Marine Park, southern Japan from June 4 to July 6, 2007 where the surface water temperature ranged from 21.5 – 29.8° C. This pond is closed to commercial fishers and is connected by concrete pipes to Kagoshima bay, thus allowing the unrestricted entry of the local marine organisms. It has a variable depth ranging from 2.5 to 4.5 m along the tidal cycle, which ensures extensive turnover of the water. The predominant crab species found there are the four-lobed swimming crab *Thalamita sima*, shore swimming crab *C. japonica* and blue swimming crab *P. pelagicus*.

Two types of collapsible pot (Kagotoku Shiroyama Kenmousha, Ise, Japan) were used (Fig. 1). Both were dome-shaped pots (iron rod frame and polyethylene diamond shaped netting, 2.3 cm mesh size; 73 cm long x 53 cm wide x 27 cm high). This mesh size is the smallest available in commercial pots in Japan and usually used to target octopus, but also considered appropriate for crab eradication because it will retain small crabs. One pot design had two open-eyed funnel entrances, which ended in an opening surrounded by a wire ring (diameter of 15 cm). The other pot type was fitted with closed-eyed entrances, which collapsed and ended in 13.5 cm slits that tended to remain closed because they lacked the wire ring at the opening.

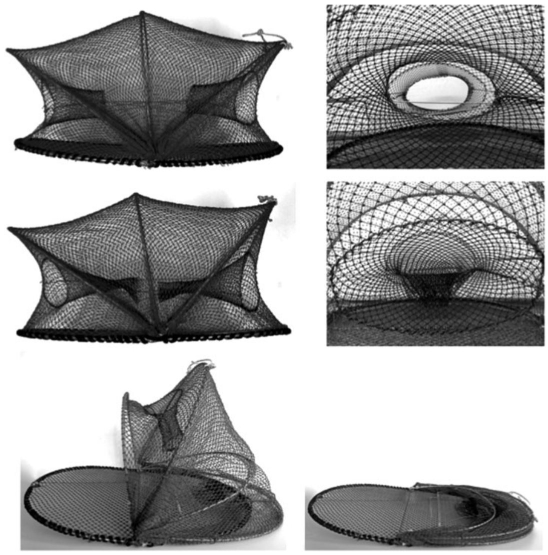

Fig. 1. Photographs of pot types and entrance details. The top panels show the open-eyed entrance pot, whereas the middle panels show the closed-eyed entrance pot. The folding metal frame and collapsed pot are shown in the bottom panels.

During the retention fishing trials the pots were soaked for 24 hours, which is the common duration used when trapping crabs locally; both pot types were baited with half a mackerel *Scomber japonicus* (about 100 g) by skewering it on a wire located between the entrances. On experimental days, five pots of each type (n = 10 pots) were placed on the pond's seafloor by divers and retrieved the next day. The pots' order was randomly assigned for each day's treatment and set at about 15 m intervals (Kaneda 1977) along a line following the eastern length of the pond. This procedure was conducted during 20 days until 100 pot hauls were completed for each pot type. The daily catch was released after identification and measurement, which was carapace width for crabs, carapace length for shrimp, total length for fish and body weight for octopus. Testing of both the catch and size differences of the various species captured in the two types of pot was performed, taking into account the replication at the individual dates..

Escape trials

The escape trials assessed retention rates of the caught organisms in the pots for a 4 – day period, and were carried out four times during four weeks (July 9 – August 3, 2007). Surface water temperatures ranged from 25.6 – 30.8° C from July to

August. Five pots of each type were baited, set randomly on the pond's substrate on Monday (day 0) and retrieved the following day (Tuesday, day 1). Organisms in the catch were identified, counted, measured and marked. To reduce possible errors while marking and placing the caught organisms back into their pots, we worked on one pot at a time. The caught organisms from a pot were placed into a large tray containing a few centimeters of seawater, they were individually measured and tagged and placed in another tray, and after this procedure was completed, they were put back into their pot and divers returned it to its approximate location on the pond's substrate. Crabs were tagged with a plastic coloured tie (100 mm, Oomudenki, Co., Yoshikawa.) on their right cheliped; fish were marked by cutting a small notch on their dorsal or anal fin to distinguish them from newly captured ones. Following the first setting, the pots were not re-baited, only returned to their location with their marked organisms. On the next day (Wednesday, day 2) pots were retrieved and the caught organisms were examined for tags and marks; new crab catches were tagged using a different colour tie for each day and any new fish were also marked (recorded sizes were also used for identification). This procedure was repeated each day for the remaining two days (Thursday and Friday, days 3 and 4) to determine the number of organisms that were retained or escaped from each pot. On the 4th day, after gathering the data, the tags were removed from the crabs and all animals were released. Retention curves of the different catch organisms in the two pot types were statistically compared with a multi-level regression where replication was accounted for by week of the experiment and individual pot.

Data analysis

Generalized linear mixed models (GLMM) (Venables and Dichmont, 2004; Bolker *et al.* 2009) were used to assess the counts of species or taxa retained in the catch and their size. GLMM are particularly suitable with data obtained in experiments with different levels of crossed or nested blocking factors. Apart from the four-lobed swimming crab *T. sima*, most species occurred intermittently in the catches. To simplify the analyses, the data were grouped by their main taxonomic and size groups: four-lobed swimming crab, total crabs (all crabs except hermit crabs), crustacean non-target catch (hermit crabs and shrimps), large fish (morays and congers, > 25 cm), medium-sized fish (catfish and rockfish, typically 10 – 25 cm), small fish (all other fish species, typically < 10 cm), molluscs (mostly snails, but also sea hares and octopus) and others (sea cucumbers and jellyfish). Despite the grouping of the observations in the retention trials, the count data were typically over-dispersed, with typical coefficients of variation of the daily catch exceeding 200%. In pilot analyses of the count data, the negative binomial models showed consistently better goodness of fit than the Poisson models. When analyzing the size data (cm) in the retention trials, both the Gaussian and the gamma error models were used, depending on the fit of the model to the different taxa. Gear type (open or closed-eyed entrance pots) was considered the main experimental factor (fixed effect) and the day of the catch a random effect.

To analyze the escape data (4 – day trials), two general indices and one retention model were developed. Mortalities where excluded from the calculations, as it was impossible to judge whether these individuals would have escaped if they were alive. Only 2.2% and 1.9% of the organisms detected in open-eyed and closed-eyed entrance pots were found dead during the trials. For each taxon, the retention index was

= Number of escapees / (total number of individuals – dead individuals) (1)

and the escape rate:

= Number of escapees / total number of residence days of the taxon (2)

These two values characterized sufficiently the general behaviour of all species and groups.

The logistic retention curve gives a more dynamic view, and a suitable reference point to illustrate the escape efficiency is the half-residence time (R50%, days). This is the amount of time required for the stock of one taxon to drop by 50%, as estimated from the logistic curve. This curve was fitted to the individual data using a GLMM with binary error structure and logit link, and predictive curves with standard error bands were estimated. The fixed effects considered were the covariate time (days) and the type of entrance of the pot (open/closed-eyed). Only four taxa provided enough escape data in both types of pot to allow the fit of the model. These were four-lobed swimming crab, small- and medium-sized fish, and the snail *Batillaria cumingii*. Time zero (t0) for any individual was the day of first detection, no matter if the observation was performed on the first, second or third day of each series of experiments. The random factors considered were the week of the experiment (replicate) and the individual pots, which had unique identification, as well as the individually tagged organisms. All the mixed models were sorted by their improvement in the Akaike Information Criterion (ΔAIC), and tests of goodness of fit were performed by Analysis of Deviance (AoD). Statistical analyses were performed with R statistical software, version 2.15.1 (R Core Team 2013), including the packages glmmADMB, 3 version 0.7.3 (Bolker *et al.* 2012) for modeling and R-Stats for tests of goodness of fit. An alpha probability of 0.05 for rejection of the null hypothesis was used throughout.

Results

Retention trials

The effect of entrance type on the crab catch between pot designs was small, and though the numbers of crabs found in the closed-eyed entrance pots were slightly higher than those in open-eyed ones, these differences were not significant (see Fig. 2, Table S1 in the Supplementary material for detailed retention data, and Table 1 for summary statistics of the daily catches). The most numerous crab species caught was the small four-lobed swimming crab *T. sima*, followed by shore swimming crab *C. japonica*, blue swimming crab *P. pelagicus* and red swimming crab *Thalamita prymna*. Total crab catch was higher in the closed-eyed entrance pots, which captured a total of 467 individuals, while open-eyed ones only 388, corresponding to average catch rates of 4.7 (SD = 9.3) and 3.9 (SD = 7.6) crabs per pot and day (Table 1). Owing to the large residual variability superimposed on the daily variability (accounted for as a random variable), no significant differences were detected (ΔAIC=1.7; AoD, $P > 0.05$) in the mean daily counts of crabs in the two pot types (Table 2, top 'Retention trials').

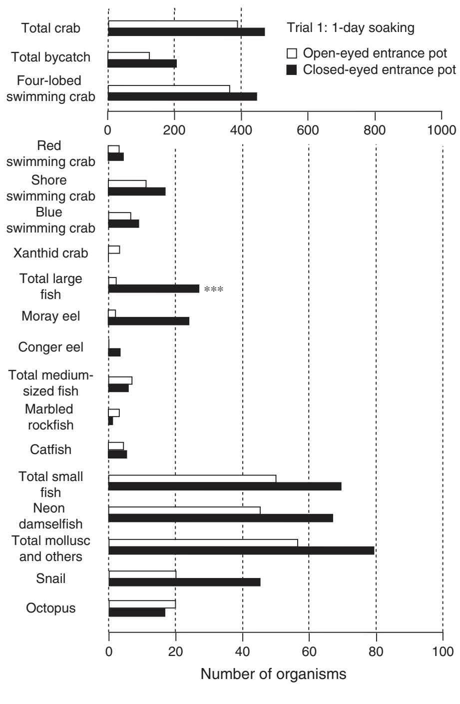

Fig. 2. Abundance of main organisms and groups found inside open- and closed-eyed entrance pots after 1-day deployment. ***, $P < 0.001$. 'Total crab' includes all crabs except hermit crabs, 'total large fish' combines congers and morays, 'total medium-sized fish' refers to marbled rockfish and catfish, 'total small fish' comprises neon damselfish, cardinal fish and gobies and 'total mollusc and others' comprises snails, octopus, sea hares, ivory shells, sea cucumbers and jellyfish.

Regarding the non-target organisms caught, they consisted mostly of neon damselfish *Chromis notata*, snails *B. cumingii*, octopus *Octopus vulgaris* and morays *Echidna nebulosa*; non-target abundances were more than double in the closed-eyed entrance pot than in the open-eyed one ('Total bycatch' row, Table S1). However, only large fish (i.e. morays and congers *Conger japonicus*) showed highly significant differences in the mean daily counts between the two pot types (ΔAIC=18; AoD, *P* < 0.001, Table 2, top 'Retention trials'). While diving on the pots, it was observed on some occasions that eels showed different ingress behaviours depending on entrance type. While they only pushed their head trough the open-eyed entrances to steal the bait and backed out, when they brushed against the sleeves of the closed-eyed entrances they were induced to swim forward, being captured in the process. No significant differences were detected in the catch of the other groups between both entrance designs, which indicates that closed-eyed entrances are not a deterrent to entry.

Table 1. Catch statistics of the main groups in the retention trials (1-day soaking)

Data are the mean ± s.d. counts per pot and day in five open- and five closed-eye pots during the 20 days of the experiment

Catch organisms	Open	Closed
Total crabs (five spp.)	3.9 ± 7.6	4.7 ± 9.3
Total non-target crustaceans	0.2 ± 0.4	0.42 ± 0.91
Total large fish (two spp.)	0.05 ± 0.22	0.68 ± 0.94
Total medium fish (two spp.)	0.18 ± 0.38	0.15 ± 0.48
Total small fish (three spp.)	0.8 ± 1.7	1.2 ± 2.3
Total molluscs and others (six spp.)	0.5 ± 1.0	0.67 ± 1.70

With regard to the sizes of the organisms retained in the catch, no significant differences were observed between the open and closed-eyed entrance pots (in all comparisons *P* > 0.05). The congers and morays retained in the open-eyed entrance pots (n = 2) were about 9 cm larger than those collected in the closed-eyed ones (n = 24), but their abundances were too small to allow meaningful statistical size comparisons.

Escape trials

The daily fluctuations in the numbers of the major organisms and groups detained in the two pot types (n = 20 pots/entrance type) are illustrated in Figure 3. Crab abundance fluctuations were not evident, but as time elapsed differences appeared in large, medium-sized and small fish; while the abundance of all fish sizes decreased over time in the open-eyed entrance pots, the medium-sized fish increased in abundance and small fish abundance remained stable over time in the closed-eyed entrance

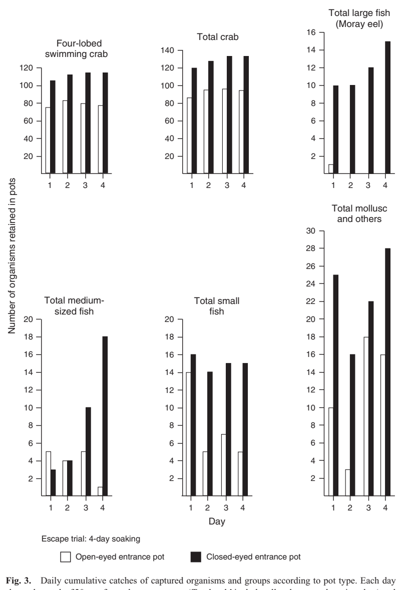

Fig. 3. Daily cumulative catches of captured organisms and groups according to pot type. Each day shows the catch of 20 pots for each entrance type. 'Total crab' includes all crabs except hermit crabs, 'total large fish' refers to morays, 'total medium-sized fish' refers to marbled rockfish and catfish, 'total small fish' comprises neon damselfish, cardinal fish and gobies and 'total mollusc and others' comprises snails, sea hares and sea cucumbers.

pots. The initial and final numbers of the main organisms and groups found in the pots with the different entrance types, as well as those of their escapees, are represented in Figure 4. In the escape trials, each organism was tagged in the day of its capture (days 1 – 3) and subsequently identified and counted in each of the following days until the end of the experiment (see ‘Day 4’ in Table S2 in the Supplementary material). Each individual was logged and registered as survivor, death or as escapee, and the totals were calculated (‘Sum’ in Table S2). Analysis of residual variances in the mixed escape models showed that there were strong day-to-day variations in catch and escape, and even that some individual pots retained some organisms better than others. However, the unexplained variance brought about by the individual escape ability of the organisms was larger than that accounted for by replication, irrespective of species..

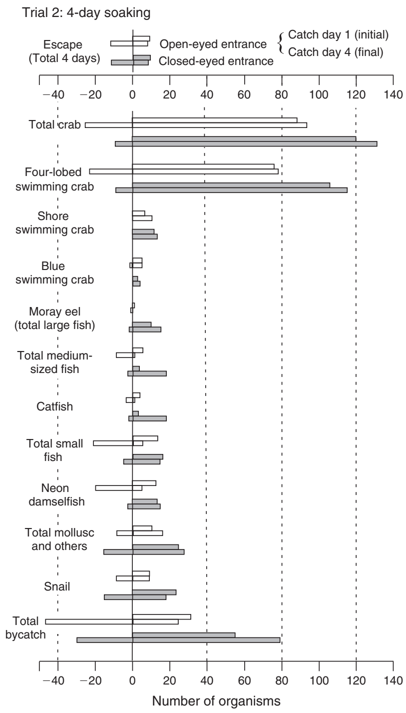

Fig. 4. Abundance of main organisms and groups found in open-eyed and closed-eyed entrance pots after 1- and 4-day deployments, and escapees. ‘Total crab’ includes all crabs except hermit crabs, ‘total large fish’ refers to morays, ‘total medium-sized fish’ refers to marbled rockfish and catfish, ‘total small fish’ comprises neon damselfish, cardinal fish and gobies and ‘total mollusc and others’ comprises snails, sea hares and sea cucumbers.

The most represented target species, the four-lobed swimming crab, clearly spent a longer time in the pot, with less than half of the number of escapees in the closed-eyed entrance pots than in the open-eyed ones (Fig. 4). Inclusion of the pot type in the retention model of the four-lobed swimming crab resulted in highly significant effects (ΔAIC=153; AoD, $P < 0.001$; Table 2, ‘Escape trials’). Nevertheless, this species showed a slow escape from both open and closed-eyed entrance pots, with half-residence times (R50%) longer than three days in both cases (Fig. 5). Even after one day in the pot about 90% of the crabs still remained inside the open-eyed entrance pots, while nearly 100% were still in the pot in the closed-eyed ones.

Regarding the non-target species, all (n = 10) the medium-sized fish, which consisted of marbled rockfish *Sebasticus marmoratus* and catfish *Plotosus lineatus* (Table S2), and 83% of the small fish (cardinal fish *Apogonichthyoides niger*, gobies *Chasmichthys gulosus* and neon damselfish) captured in the open-eyed entrance pots managed to escape and had relatively short residence times. In contrast, only 10% of the medium-sized fish and 29% of the small fish managed to escape from the closed-eyed entrance pots. The half-residence time in these two fish groups increased from about 0.5 day in the open-eyed entrance pots to 1.5 – 2.5 days in the closed-eyed entrance ones, which was a highly significant effect (ΔAIC=12 to 73; AoD, $P <$ 0.001, Table 2, ‘Escape trials’; Fig. 5). In the escape trials, the only large fish captured was the moray, and it was only retained in large numbers in closed-eyed entrance pots. Only one individual was observed in an open-eyed entrance pot, and it had escaped after one day. Molluscs and other catches comprised mostly snails, followed by sea hares

Table 2. Analysis of deviance of the mixed models used for comparison of the catch (retention trials) and escape (escape trials) in the two types of pot
The main variables tested were pot and time (escape trials) and the blocking factors were date, individual pot and organism (escape trials). LLn, log-likelihood of the null model (two parameters); LLs, log-likelihood of the saturated model (four parameters, including pot and day)

Organism caught	LLn	LLs	Deviance	*P*-value (χ^2)
Retention trials				
Four-lobed swimming crab	−131.55	130.00	3.09	0.08
Total crabs (five spp.)	−382.93	−382.81	0.24	0.63
Total non-target crustaceans (three spp.)	−84.65	−83.06	2.84	0.09
Total large fish (two spp.)	−62.91	−52.80	20.21	<0.001
Total medium fish (two spp.)	−37.62	−37.59	0.07	0.8
Total small fish (three spp.)	−148.71	−148.42	0.56	0.45
Total molluscs and others (six spp.)	−228.61	−227.97	1.24	0.27
Escape trials				
Four-lobed swimming crab	245.67	64.77	285.45	<0.001
Total medium fish (three spp.)	41.35	6.20	11.39	<0.001
Total small fish (four spp.)	111.87	29.75	13.83	<0.001
Snails	144.17	90.68	1.73	0.19

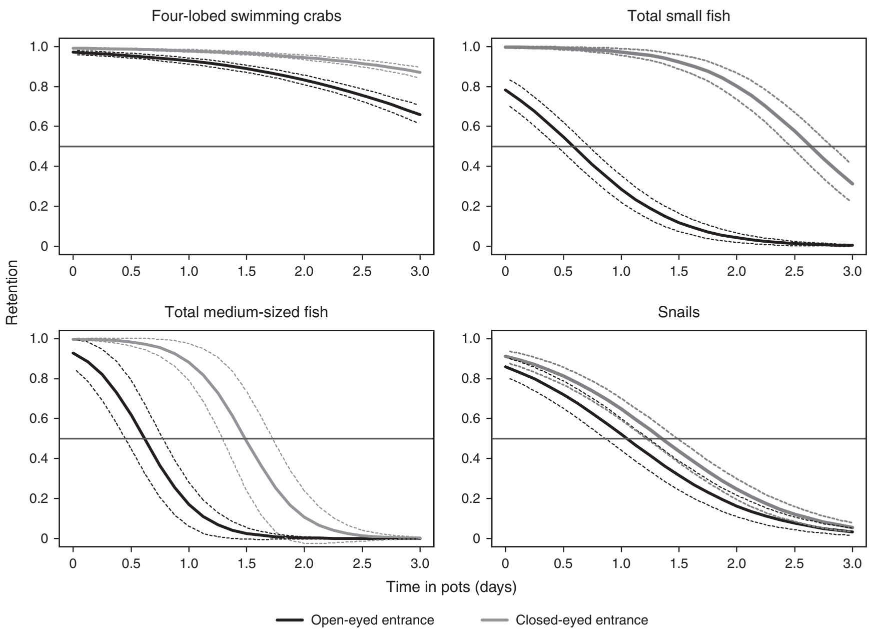

Fig. 5. Estimated probability of retention (±s.e. of the estimate, stippled lines) of four frequent species or groups as a function of time after first detection (t_0) and pot type. The logistic model was fitted to the observations made with individually tagged organisms over a 4-day trial. ‘Total medium-sized fish’ refers to marbled rockfish and catfish, whereas ‘total small fish’ comprises neon damselfish, cardinal fish and gobies.

and sea cucumbers. Both sea hares and sea cucumbers were effectively retained in both pot types, with the exception of one sea hare escapee in a closed-eyed pot (Table S2). Only the snails, which appeared in large numbers, showed a clear escape behaviour. In contrast with the other organisms, these snails were not delayed by the presence of the closing sleeve of the closed-eyed entrance pot (ΔAIC=0.9; AoD, $P > 0.05$; Table 2, 'Escape trials'). Their R50% was about 1.5 days, on average for both pots (Fig. 5), a little less for open-eyed entrance pots than for the closed-eyed ones.

Discussion

Recent swimming crab invasions of the species tested here have required sampling surveys and eradication trials in New Zealand and Western Australia (MAF Biosecurity New Zealand technical paper 2008; Hourston *et al.* 2015). Several studies on eradication of swimming crabs have shown a preference for collapsible pots over hoop traps or hourglass traps (Gust and Inglis 2006; Hourston *et al.* 2015). Earlier surveys used collapsible box-shaped pots fitted with slit entrances (Gust and Inglis 2006; Miller et al. 2006), while more recent ones have employed dome-shaped pots with open-eyed entrances (MAF Biosecurity New Zealand technical paper 2008; Fowler *et al.* 2013, 2011; Hourston *et al.* 2015). The soaking times applied during these studies have ranged from a few hours to two days; but a 24 – hour soaking was preferred, which is typical for trapping these crabs commercially (Vazquez Archdale *et al.* 2006b).

Initially, we conducted retention trials setting both open and closed-eyed entrance pots overnight, under the typical 24 – hour soaking. Our findings showed that under such a short time there was no difference in swimming crab numbers between the two entrance types. Similar results were obtained with the non-target catch, and only large fish (congers and morays) showed highly significant differences in escape behaviours. In addition, closed-eyed entrances did not seem to deter ingress into the pots.

The sizes of the captured organisms did not differ between pot designs because their meshes were the same size (2.3 cm). Eradication trapping is different from commercial fishing in that it targets crabs of all sizes, not only large ones. Previous research investigating crab size selectivity depending on mesh size recommended smaller mesh sizes for eradication, rather than the 6 cm meshes commonly applied to swimming crab pots (Vazquez Archdale *et al.* 2006b).

To assess the possible negative impact ('ghost fishing') of lost fishing gear on target species and co-occurring species, we conducted a second set of escape trials by observing both types of pots for four days and examining the catch fluctuations. Under such a short 4 – day period the swimming crabs caught tended to stay in both pots. Only after three days in the pot were significant differences between entrance types detected in four-lobed swimming crabs, and while 90% retention was still maintained in closed-eyed pots only 70% remained in open-eyed ones. Previous research examining swimming crab escape from collapsible pots (Vazquez Archdale *et al.* 2007) determined that entrance design could greatly affect escape. Captive swimming crabs could easily exit pots fitted with open-eyed entrances, and 100% of the blue swimming crabs and 78% of the shore swimming crabs could escape within a week. However, no crabs could escape from box-shaped pots fitted with slit entrances, which acted as one-way valves and resemble the closed-eyed entrances used in the present study. Studies on escape prevention devices applied to pots targeting other crab species have shown that when triggers (wire or plastic bars fixed at entrances that only open inwards) were installed at the pot's entrances they significantly prevented escape. Blue crabs *Callinectes sapidus* showed longer retentions in pots fitted with triggers, and only 60% of those caught could escape after 28 days in the pot (Muir *et al.* 1984). In addition, only 45% of the Dungeness crabs *Cancer magister* retained in triggered pots could escape after 12 days, while 74% escaped from pots lacking them within 24 hours (High 1976). In Korea, placing doors called "flappers" at the pot's entrances retained more *C. japonica* than pots without them (Kim and Ko 1990, 1987). However, while these devices can increase the retention of the animals in the pots, they can also contribute to ghost fishing when pots are lost at sea, posing a danger to local fauna, and should be used with caution.

Considering the non-target catch, both medium-sized and small fish had shorter residence times in open-eyed entrance pots during the escape trials. Half-residence times were approximately 0.5 days in the latter, while those in closed-eyed entrance pots were 1.5 and 2.5 days for medium-sized and small fish, respectively. The half-residence times estimated for medium-sized and small fish cannot be directly extrapolated to large ones, but the observations in the retention trials suggest that congers and morays will be effectively retained. Snails, on the other hand, showed similar retention curves for both entrance types, with average half-residence times of 1.5 days. These small animals crawled along the seafloor and entered the pots through the meshes near their base, and only those large enough were retained after hauling. For this reason, rather than entrance type, it was the same mesh size that caused the similar results.

Another possible escape route could have been the small gap found between the closing collapsible frame of the pots and their base (Fig. 1, bottom). Some animals could have squeezed out this way. The collapsible frame consists of several metal arches, and one of them is fixed to the base by a single metal clip when the pot is assembled and can be detached to easily remove the catch after hauling and store the collapsed pots on deck. In the present study we did not assess the effect of learning and repeated sampling on the pond's resident organisms, but due to its large volume and the exclusion of commercial fishing we consider that the possibility of recapture would have been small. Regarding possible stress and confounding effects while marking and returning the caught organisms back into their pots, we tried to keep handling to a minimum by working on individual pots. The effect of pot saturation (Miller 1979b), which occurs when too many crabs accumulate inside a pot and prevent others from entering, was not considered in the present study, but might have influenced catches in pots containing numerous crabs. Sampling of *C. japonica* in New Zealand (Gust and Inglis 2006) examined the effect of pot saturation at various deployment times and found that pots left for 24 hours caught twice as many *C. japonica* as those deployed for three hours and seven times more than those set for only one. In our study we did not examine the effect of sex bias because we consider it could be easily mistaken with that of size. Crab size has been documented as having an important effect on crab catches in pots (Williams and Hill 1982) as pots commonly select for the larger and more aggressive males, as reported in New Zealand for *C. japonica*, which had 90% male crab catches (Gust and Inglis 2006).

Closed-eyed entrances are an effective escape hampering device and a useful tool when applied to pots targeting morays, congers and octopus. They might have applications in surveys and eradication programs targeting swimming crabs when fishing conditions, poor weather or high labour costs require longer soaking times. However, pots installed with closed-eyed entrances should be deployed only as a last resort and fitted with ghost fishing prevention measures, such as time releases, escape gaps or biodegradable panels that render them ineffective if they are lost at sea (Eldridge *et al.* 1979; Gagnon and Boudreau 1991; Broadhurst *et al.* 2017). Considering that typically pots are soaked for about one day and that no significant differences in swimming crab abundances were detected between the tested entrance types, we recommend that open-eyed entrance pots should be used to mitigate possible ghost fishing impacts.

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Supplementary materials:

Table S1. Number of organisms and by-catch caught in open-eyed entrance pots and closed-eyed entrance pots after 24-h soaking time

Highly significant differences are shown as: ***, $P < 0.001$

	Open-eyed entrance pot			Closed-eyed entrance pot		
Catch organisms	Numbers	Proportion	Mean size (range) (cm)	Numbers	Proportion	Mean size (range) (cm)
Crab catch						
Four-lobed swimming crab	365	0.71	5.8 (3.6–7.4)	438	0.65	5.8 (3.1–8.5)
Red swimming crab	3	0.01	8.6 (7.9–9.6)	4	0.01	7.6 (6.2–8.5)
Shore swimming crab	11	0.02	9.1 (7.5–10.6)	17	0.03	8.7 (6.5–11.0)
Blue swimming crab	6	0.01	12.6 (12.0–13.0)	8	0.01	12.7 (7.2–14.3)
Xanthid crab	3	0.01	7.2 (6.7–7.4)			
Total crab	388	0.75		467	0.69	
Non-target organisms						
Hermit crab	8	0.02	2.5 (1.4–3.6)	19	0.03	2.9 (2.2–3.5)
Red shrimp	3	0.01	6.4 (3.4–8.2)	4	0.01	6.6 (5.0–8.4)
Green shrimp	1	0.00	4.6	2	0.00	4.3 (4.3–4.3)
Total non-target crustacean	12	0.03		25	0.04	
Moray eel	2	0.00	68.5 (65.0–72.0)	24	0.04	58.7 (41.5–73.5)
Conger eel				3	0.00	62.6 (58.2–69.0)
Total large fish	2	0.00		27***	0.04	
Marbled rockfish	3	0.01	18.7 (16.3–20.0)	1	0.00	19.6
Catfish	4	0.01	14.1 (10.2–19.2)	5	0.01	15.2 (10.1–23.0)
Total medium fish	7	0.02		6	0.01	
Goby				1	0.00	8.1
Cardinal fish	2	0.00	8.7 (8.2–9.2)	2	0.00	8.5 (8.0–9.0)
Neon damselfish	48	0.09	8.42 (5.8–11.5)	66	0.10	8.4 (4.9–10.1)
Total small fish	50	0.09		69	0.10	
Ivory shell	4	0.01		7	0.01	
Snail	20	0.04		48	0.07	
Octopus	20	0.04	2.3kg (0.2–4.0)	16	0.02	2.3kg (0.5–4.2)
Sea Hare	7	0.01		6	0.01	
Sea cucumber	4	0.01		2	0.00	
Jellyfish	1	0.00				
Total mollusc and others	56	0.11		79	0.11	
Total catch	515			673		
Total by-catch	127	0.25		306	0.31	
Number of pots	100			100		
By-catch per pot	1.27			2.06		

Table S2. Number of trapped organisms and by-catch during four consecutive days in open-eyed entrance and closed-eyed entrance pots

Catch organisms	Number of organisms in pot					Number of escapees	Number of deaths	Individuals caught	Retention index	Escape rate	Mean size (range) (cm)
	Day				Sum						
	1	2	3	4							
	Open-eyed entrance										
Crab catch											
Four-lobed swimming crab	76	83	80	78	317	24	2	102	0.24	0.08	5.7 (4.1–7.4)
Shore swimming crab	6	7	9	10	32		1	10	0.00	0.00	8.8 (7.4–10.8)
Blue swimming crab	5	4	6	5	20	1		7	0.14	0.05	13.1 (10.1–14.6)
Xanthid crab	0	1	1	1	3			1	0.00	0.00	5.4
Total crab	87	95	96	94	372	25	3	120	0.21	0.07	
Non-target organisms											
Hermit crab	2	2	2	2	8			2	0.00	0.00	3.3 (2.4–4.1)
Carpenter prawn	0	0	0	1	1			1	0.00	0.00	4.6
Total non-target crustacean	2	2	2	3	9			3	0.00	0.00	
Moray eel (Total large fish)	1	0	0	0	1	1		1	1.00	1.00	64
Marbled rockfish	1	3	2	0	6	5		5	1.00	0.83	18.7 (14.8–21.9)
Catfish	4	1	3	1	9	5	1	6	1.00	0.63	14.7 (11.2–19.8)
Total medium fish	5	4	5	1	15	10	1	11	1.00	0.71	
Cardinal fish								0			
Goby	2	0	0	0	2	2		2	1.00	1.00	11.0 (10.1–11.8)
Neon damselfish	12	5	7	5	29	22		27	0.81	0.76	8.6 (7.2–10.9)
Total small fish	14	5	7	5	31	24		29	0.83	0.77	
Snail	9	1	12	9	31	10		21	0.48	0.32	
Sea Hare	1	2	5	5	13			5	0.00	0.00	
Sea cucumber	0	0	1	2	3			2	0.00	0.00	
Total mollusc and others	10	3	18	16	47	10		28	0.36	0.21	
Total by-catch	32	14	32	25	103	45	1	72	0.63	0.44	
Total catch	119	109	128	119	475	70	4	192	0.37	0.15	
	Closed-eyed entrance										
Crab catch											
Four-lobed swimming crab	106	112	115	115	448	10	4	125	0.08	0.02	5.9 (4.2–7.4)
Shore swimming crab	11	12	13	13	49		1	13	0.00	0.00	8.4 (6.3–10.1)
Blue swimming crab	2	3	4	4	13			4	0.00	0.00	13.6 (12.4–15.6)
Xanthid crab	1	1	1	1	4			1	0.00	0.00	9
Total crab	120	128	133	133	514	10	5	143	0.07	0.02	
Non-target organisms											
Hermit crab	1	1	3	3	8			3	0.00	0.00	2.7 (2.3–3.5)
Carpenter prawn								0			
Total non-target crustacean	1	1	3	3	8			3	0.00	0.00	
Moray eel (Total large fish)	10	10	12	15	47	2		17	0.12	0.04	57.4 (38.5–67.5)
Marbled rockfish								0			
Catfish	3	4	10	18	35	2	1	21	0.10	0.06	17.5 (5.2–24.2)
Total medium fish	3	4	10	18	35	2	1	21	0.10	0.06	
Cardinal fish	1	0	0	0	1	1		1	1.00	1.00	9.7
Goby	1	0	0	0	1	1		1	1.00	1.00	7.2
Neon damselfish	14	14	15	15	58	4		19	0.21	0.07	8.8 (7.6–10.3)
Total small fish	16	14	15	15	60	6		21	0.29	0.10	
Snail	24	14	16	18	72	17		43	0.40	0.24	
Sea Hare	1	1	2	4	8	1		5	0.20	0.13	
Sea cucumber	0	1	4	6	11			6	0.00	0.00	
Total mollusc and others	25	16	22	28	91	18		54	0.33	0.20	
Total by-catch	55	45	62	79	241	28	1	116	0.24	0.12	
Total catch	175	173	195	212	755	38	6	259	0.15	0.05	