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Effects of gear type, entrance size and soak time on trap efficiency for freshwater crayfish *Cherax destructor* and *C. albidus*

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Abstract. Freshwater crayfish support significant commercial and recreational fisheries worldwide. The genus *Cherax* is fished in Australia with a variety of fishing gears, yet little is known of the relative efficiency of the different fishing gears and methods. Additionally, freshwater-crayfish traps can pose a risk to air breathing by-catch such as aquatic mammals, reptiles and birds, so by-catch mitigation is important. We sought to understand whether freshwater-crayfish fishing can be undertaken efficiently, using passive traps and nets, without undue risk to air-breathing by-catch species. In field-experiments, we compared the efficiency of six gear types and tested the effect of five exclusion rings on catch performance over three soak times. The efficiency of gear types varied significantly by soak times. In productive locations, catch can be maximised by repeatedly deploying open-topped gear for short soak times. Opera-house traps fitted with fixed entrance rings (45–85-mm diameter) were not size-selective for yabbies. Encouragingly, open-topped gear and opera-house traps fitted with fixed ring entrances much smaller than many commercially available (45-mm diameter) still fish effectively for yabbies. We believe that smaller fixed ring-entrance size is likely to be correlated with a reduced risk of by-catch for air-breathing fauna.

Additional keywords: by-catch exclusion, crawfish, fishing-gear efficiency, yabby trap.

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Introduction

Fisheries for freshwater crayfish are economically important in several states in the USA and Australia, and in Europe, for human consumption and also as fishing bait (FAO 2012). USA industries rely on *Procambarus* spp., whereas in Australasia, it is several species within the endemic genus *Cherax*, across much of the Australian states of Western Australia, South Australia, Victoria, New South Wales and Queensland that support significant commercial and recreational fisheries. An Australian national recreational and indigenous fish survey estimated an annual catch in 2000–2001 of almost 7.5 million freshwater crayfish (Henry and Lyle 2003). The genus *Cherax* (Family: Parastacidae) comprises 26 species of freshwater crayfish, with four others under investigation (McCormack 2012). Commercial and recreational catches of freshwater crayfish vary strongly, for example between 1974 and 1984, commercial harvest in New South Wales varied from 30 to 170 t, with population abundance strongly linked to hydrologic conditions (Rankin 2000). A boom in freshwater-crayfish stocks after drought-breaking rains (van Dijk *et al.* 2013) across Victoria and the rest of southern Australia brought an increase in the popularity and productivity of recreational fishing for freshwater crayfish, both for bait and for the table (ABC 2011). The Victorian fishery is mainly for two similar species, *Cherax destructor* and *C. albidus*; both were encountered in the present study. Genetic and morphological studies indicated that *C. albidus* may merit subspecific classification (Campbell *et al.* 1994).

A range of innovative new ‘pyramid’ trap designs are now commercially available and have become widespread in the community alongside lift nets and opera-house traps. Although the legality of use of these designs varies across different state jurisdictions and waterways, most state recreational fishing regulations allow for the more traditional approach of using lift nets (in public waters) and opera-house traps (see Fig. 1; at least in private waterways) (DEPI 2013). Lift nets require an active approach to fishing, with fishers regularly attending the nets, whereas traps enable a more passive approach so that freshwater crayfish can be harvested over long soak times.

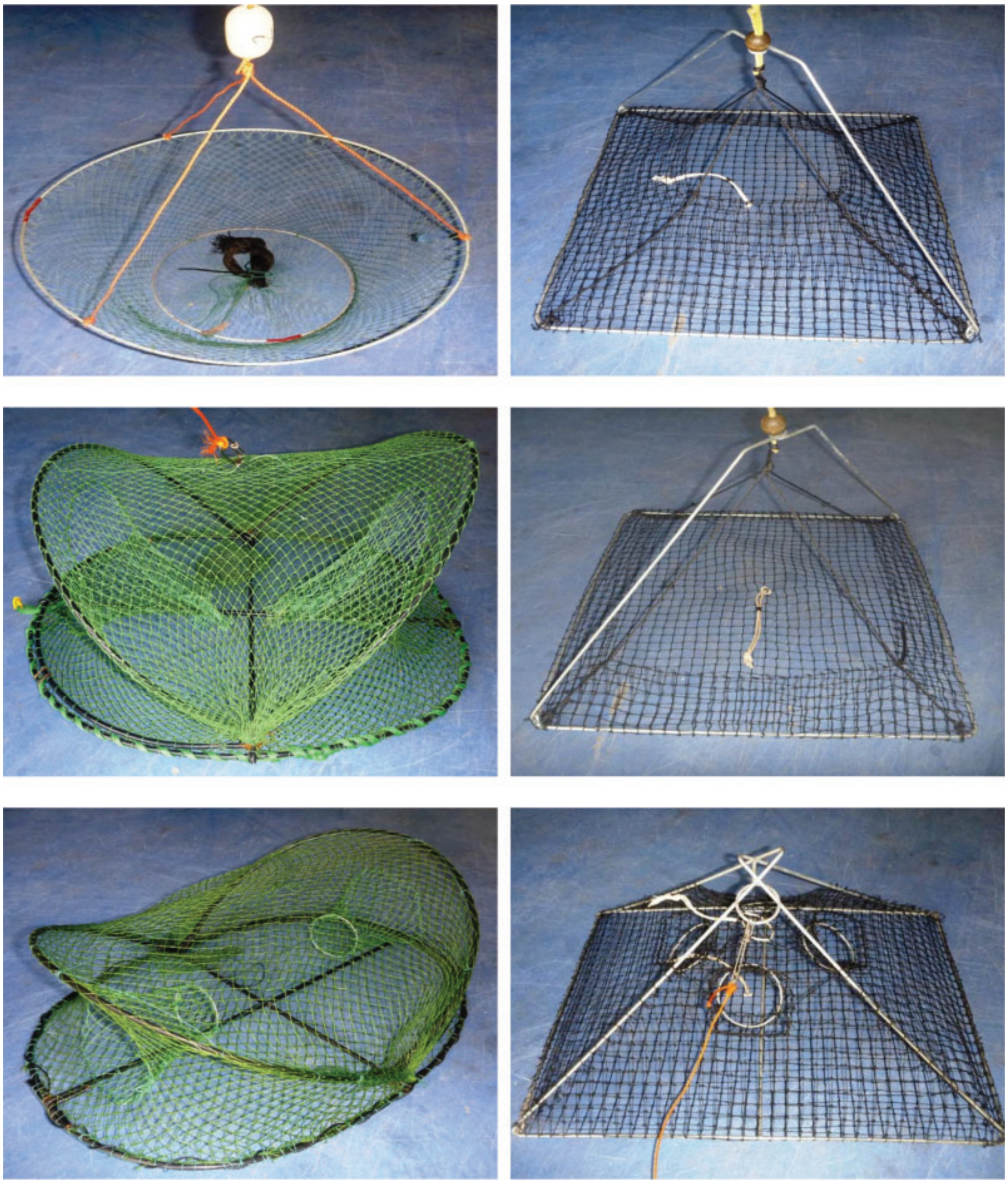

Fig. 1. Clockwise from top left: lift net (LN), pyramid trap long side (PTLS), pyramid trap short side (PTSS), pyramid trap ringed funnel (PTRF), opera-house net ringed funnel (OHRF) and opera-house net collapsible funnel (OHCF).

Some recreational and commercial freshwater-crayfish fishers are concerned about the potentially high efficiency of new trap designs on the market compared with lift nets (Charas 2010; Vic DPI 2011). Little scientific data were available on the relative efficiency of the different fishing gears and methods (Campbell and Whisson 2001), and published data were insufficient to support the substantial interstate variation in permitted types and quantities of recreational fishing gear.

Compared with lift nets, traps pose a risk to air-breathing by-catch such as aquatic birds, mammals and reptiles (Limpus *et al.* 2006; Serena and Williams 2010). Some of the available traps have entrance holes lined with a metal ring to exclude large by-catch such as turtles and to hold the entrance open to enable air-breathing fauna to escape more easily (NSW DPI 2011). Entrance rings are of benefit because they prevent the entry of by-catch above a threshold size-range. As a general principle, the smaller entrance the rings have, the less by-catch is expected. Small-entrance rings may also reduce the freshwater-crayfish catch rate (M. Allanson and S. Thurstan, NSW DPI, pers. comm.). However, more information is required to clarify the relationship between exclusion-ring diameter and freshwater-crayfish trap performance and whether longer soak times can compensate for this.

Exclusion of by-catch from freshwater-crayfish traps by restricting entry is a more appropriate by-catch mitigation practice than is provision of escape vents. Freshwater-crayfish traps are passive capture devices that pose a risk to species such as platypus (*Ornithorhynchus anatinus*), water rats (*Hydromys* *chrysogaster*) and turtles (*Chelodina* spp. and *Emydura* spp.). Once inside a trap, air-breathing animals undergo significant cumulative stress in the process of escaping traps, possibly resulting in death (Davis 2002; Broadhurst 2008). Exclusion of by-catch fauna avoids these risks. As freshwater-crayfish traps are inexpensive to purchase and in wide use, the development and implementation of other effective by-catch reduction methods, such as 'escape vents' for all potential by-catch species in freshwater-crayfish waters, may be unfeasible (Grant *et al.* 2004).

Using a field-experimental approach we sought to compare the efficiency of a range of freshwater-crayfish traps and to test the effect of exclusion rings on freshwater-crayfish catching performance. How can recreational fishing for freshwater crayfish be undertaken efficiently and safely, using passive gear such as traps, while limiting the risk to air-breathing by-catch species?

Materials and methods

Experimental sites

Field trials were undertaken where reasonable catch-rates of freshwater crayfish were anticipated, as determined after consultation with fisheries compliance professionals and drawing on local knowledge about recent recreational fishing activity and success rates.

For Experiment 1, the experimental sites were Charam Swamp (36°53′45″S, 141°27′32″E) and Lake Charlegrark (36°46′01″S, 141°14′17″E), in the Wimmera River catchment, and Reedy Lake (36°43′01″S, 145°06′07″E) in the Goulburn River catchment. Charam Swamp and Lake Charlegrark are shallow swamps (IWC 2012), with an average depth of ~1–3 m during March 2012 and areas of 40 and 56 ha respectively. Reedy Lake is categorised as a 300-ha deep swamp (>5 m) (IWC 2012); however, in April 2012, the average depth was 1–3 m.

For Experiment 2, the experimental sites were Miga Lake (36°55′41″S, 141°37′19″E) and Clear Lake (36°55′48″S, 141°51′58″E) in the Wimmera River Catchment. Miga Lake and Clear Lake are both open-water shallow swamps ~50 ha in extent, with maximum depths in September 2012 of ~2 m.

Water quality

At each sampling site during Experiment 1, water-quality parameters were measured (YSI meter). At the beginning and end of each day, water temperature, dissolved oxygen and pH were measured offshore and at ~0.5-m depth. During Experiment 2, water temperature was measured at midday with a spirit thermometer.

Water temperatures at Charam Swamp and Lake Charlegrark in March were between 17 and 21°C, and for Reedy Lake in May, water temperature had dropped to between 12 and 14°C.

Sampling sites were well oxygenated. Dissolved oxygen in March was 7–8 mg L^{-1} and in May at Reedy Lake it varied from 7 to 10 mg L^{-1}. All sites were close to neutral pH, with the range of measurements between 6.8 and 7.5 pH units.

Experiment 1: evaluating different gear types

A 6×3 factorial randomised-block design was used to answer our research objectives. Experimental fishing was undertaken comparing six types of popular freshwater-crayfish gear at three different soak times. The six different types of freshwater-crayfish gear were lift nets (LN), opera-house traps ($2 \times$ collapsible funnels) (OHCF), opera-house traps (75-mm-diameter ring in funnels $\times 2$) (OHRF), pyramid traps (open top) long sides (PTLS), pyramid traps (open top) short sides (PTSS), pyramid trap (closed top with 90-mm ring in funnels $\times$ 4) (PTRF) (Fig. 1).

Each gear was used for the following three different soak times: a short soak (1 h), to simulate active fishing methods typical of widely used lift nets; a medium soak (6 h), to simulate the strategy of deploying and retrieving gear at the beginning and end of a day trip; and a long soak overnight typically ~12 h), to simulate fishing gear deployed on multi-day trips.

There were three replicates for each gear type at each soak time. At each day, $6 \times 3 \times 3$ (54) traps were deployed for fishing. This experimental fishing was undertaken at three different sites, and at each site, 3 consecutive days (including three overnight soak times) of fishing was carried out.

Experiment 2: evaluating effects of by-catch exclusion rings on trap performance

A 5×3 factorial randomised-block design was used with five experimental ring diameters fitted to opera-house trap entrance funnels. Three soak times were used consistent with Experiment 1 (i.e. 1 h, 6 h and 12 h). The rings used were nominally 45, 55, 65, 75 and 85 mm in diameter, with each trap being fitted with two equivalent-sized rings.

There were three replicates for each ring size at each soak time. At each day, $5 \times 3 \times 3$ (45) traps were deployed for fishing. This experimental fishing was undertaken at two different sites. At Miga Lake, 2 consecutive days (including two overnight soak times) of fishing were carried out; at Clear Lake, 1 day, including one overnight soak time, was completed.

Experimental fishing

Baits used in freshwater-crayfish gear were pieces of fish. Bait was uniform in size (~150 g) and type and held in bait bags constructed of 'mussel-mesh' (polypropylene, 10-mm mesh size). Bait bags were secured to the base of each trap or net near the centre in a uniform manner.

At all locations on each day, gear was deployed in a randomly allocated manner to remove the risk of subjective bias from operators choosing which gear went where. Each day, gear was fished in a different randomly chosen portion of the available habitat to ensure individual freshwater crayfish were encountered only once. For each soak-time treatment, gears of six different types, or the five different exclusion-ring sizes, were deployed in a randomly allocated sequence.

Three different float types were used to mark each soak-time treatment. This enabled operators to see easily what gear to haul, and what to leave, when multiple soak-time treatments overlapped.

Freshwater crayfish captured in each trap or net were all counted and the total catch from each trap or net was weighed (liveweight, ±1 g).

For Experiment 1, a subsample of up to five individuals per trap or net was randomly chosen and occipital carapace length (OCL) was measured using vernier callipers (±1 mm). During Experiment 2, all individuals were measured (OCL, mm) from each trap.

All freshwater crayfish were returned to the water immediately after counting, weighing and measuring were completed.

Statistical analyses

For Experiments 1 and 2, catch by number and catch by weight were analysed after standardising to nominal soak-times of 1, 6 and 12 h. The duration required for setting and hauling gear and processing the catch meant that actual soak times varied for individual experimental units (i.e. traps and nets). To enable standard comparisons, the catch rate for each individual experimental unit i was calculated as

$$cpue_i = \frac{c_i}{(t_{\text{haul},i} - t_{\text{set},i})}$$

where $cpue$ is catch per unit effort (catch per hour), c_i is catch in gear unit i (total number of individual freshwater crayfish, number of large freshwater crayfish or total weight of freshwater crayfish caught per haul) and t_{haul} and t_{set} are the times that unit i is hauled or set.

For each experimental unit, nominal soak times, S, are multiplied by individual-trap $cpue$, to estimate standardised catch, as follows:

$$\text{Catch} = cpue_i \times S$$

where S is 1-, 6- or 12-h soak-time treatment.

For Experiments 1 and 2, the standardised catch and weight data from all sites were analysed using general analysis of variance, as follows:

For Experiment 1,

$$\text{Treatment structure} = \text{Gear type} \times \text{Soak time} \times \text{Sites}$$

$$\text{Blocking structure} = \text{Sites} + \text{Sites} \times \text{Dates}$$

For Experiment 2,

$$\text{Treatment structure} = \text{Ring diameter} \times \text{Soak time} \times \text{Sites}$$

$$\text{Blocking structure} = \text{Sites} + \text{Sites} \times \text{Dates}$$

To reduce the skewness and stabilise the variance of residuals of the standardised data, mathematical transformations of the data were necessary for both experiments as follows:

For the catch data,

$$\text{Catch} \rightarrow \log(\text{Catch} + 5)$$

For the standardised weight data,

$$\text{Weight} \rightarrow \sqrt{\text{Weight}}$$

For Experiment 2, the standardised catch of large freshwater crayfish and the proportion of large freshwater crayfish in the catch,

$$\text{Large catch} \rightarrow \log(\text{Large catch} + 0.5)$$

$$\text{Large catch\%} \rightarrow \log(\text{Large catch\%} + 0.005)$$

One trap in Lake Charlegrark, that caught a single large freshwater crayfish, was deleted from the analysis of standardised weight in Experiment 1 as an extreme statistical outlier. Two extreme outlier traps were deleted from the analysis of standardised catch (both from Miga Lake), and the analysis of standardised weight (one from Miga Lake and one from Clear Lake).

The difference between predicted means is judged significant if its magnitude is greater than the least significant difference.

Size analysis

The proportion of large freshwater crayfish in the measured sample was compared for each gear type. There is no minimum legal size for freshwater crayfish (*Cherax* spp.) in Victoria (DEPI 2013). Therefore, to determine an appropriate benchmark size for 'large' freshwater crayfish for human consumption, we conducted a brief survey of the commercial retail market.

A review of market size among commercial freshwater-crayfish growers suggested that individual freshwater crayfish larger than 60 g would be an acceptable 'benchmark' for harvest for human consumption. Length data from sampled freshwater crayfish allowed us to classify them as 'large' or 'small' on the basis of whether they were larger than 45-mm carapace length equating to a liveweight of ~60 g.

To compare the distribution of the catch of large freshwater crayfish across sites and gear types the proportion and standard error of large freshwater crayfish (≥45-mm OCL) in the catch at each site, and for each gear type, were calculated and the confidence limits on this proportion were determined as follows:

$$s_p = \sqrt{\frac{p(1-p)}{n-1}}$$

where s_p is the standard error of the sample proportion p from the sample n, and the 95% confidence interval of the proportion p with the normal approximation is $[p - s_p \times 1.96, p + s_p \times 1.96]$. Proportions with non-overlapping confidence intervals were considered significantly different.

Results

Experiment 1: evaluating different gear types

The total catch was 3826 freshwater crayfish, weighing 112 kg. Analyses of the length subsample indicated that ~26% of the catch was of generally acceptable harvest size (i.e. 45 mm, OCL and ~60 g).

General analysis of variance of the freshwater-crayfish catch data showed that catch efficiency among locations depended on soak times ($F = 38.8$, $P < 0.001$). Under the assumption that catch rate broadly indicated population density, the optimum soak time to maximise the catch depended on the density of freshwater crayfish at the fishing location. With lower-density populations such as Lake Charlegrark and Reedy Lake, the catch continued to accumulate over longer soak times. Long overnight soak times yielded the highest catches using all gears. With higher-density lakes such as Charam Swamp, the catches generally peaked after 6 h and declined for longer overnight soaks.

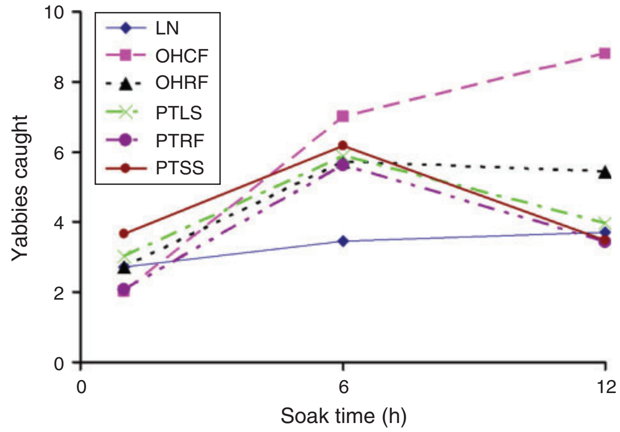

Fig. 2. Mean (back-transformed) standardised catch per trap (number of freshwater crayfish) for each of six types of gear fished over soak times of 1, 6 and 12 h at Charam Swamp, Lake Charlegrark and Reedy Lake. LN, lift net; OHCF, opera-house trap with collapsible funnel; OHRF, opera-house trap with ring funnel; PTRF, pyramid trap with closed top and ring funnels; PTLS, pyramid trap with open top and original long sides; PTSS, pyramid trap with open top and modified short sides.

Table 1. Mean (back-transformed) standardised catch of freshwater crayfish per trap for each of the six types of gear (see Fig. 1 for gear type key) at the three soak times trialled

Soak time	Gear type					
	LN	OHCF	OHRF	PTLS	PTRF	PTSS
1	2.7	2.0	2.7	3.0	2.1	3.7
6	3.5	7.0	5.7	5.9	5.6	6.2
12	3.7	8.8	5.4	4.0	3.4	3.5
6×1 h[A]	16.3	12.2	16.3	18.1	12.4	22.0
12×1 h[A]	32.6	24.4	32.5	36.2	24.8	44.0

[A]Simulated catches for active fishing in 1-h soaks over 6- and 12-h periods included for comparison.

The catch efficiency among gear types depended on soak times ($F = 9.1$, $P < 0.001$) (Fig. 2, Table 1).

The catch using the PTSS was similar to that using PTLS. However, the catch using PTSS was significantly higher than those with the other gears over the short (1 h) soak time (Fig. 2). Generally, gear types with constrained entrances, for example, opera-house traps and pyramid trap with funnel entrances, had the lowest catch efficiency over short soak times. In the simulation of active fishing with 1-h soak times, with the exception of the open-topped PTSS, all gears had similar catches (Table 1).

Over medium soak times, traditional LNs had the lowest catch efficiency and catches were significantly lower than those obtained with all other gear types (Fig. 2). All pyramid-trap variants (PTSS, PTLS and PTRF) had similar catches and performed similarly to opera-house variants with rings in the funnels (OHRF) or collapsible funnels (OHCF). The OHCF was clearly the most efficient during medium soak times at almost twice the catch of LNs. Lift nets were no more effective than during short soak treatments, whereas all other gear types were more effective than during short soak treatments.

After long overnight soak times, the OHCF traps were the most effective, catching significantly more than the OHRF, which in turn caught significantly more than all other gears (Fig. 2). The slight increased catches in LN were not significantly different from LN catches at medium or at short soak treatments.

OHCF traps had significantly increased catches after longer soak times (Fig. 2). There was no significant change in catch between medium and long soak times for LN and OHRF. Catches significantly declined in all pyramid-trap variants fished for the long soak times.

General analysis of variance of the freshwater-crayfish catch (weight) data showed that results varied by site and gear type broadly mirror the previously reported results for numbers of freshwater crayfish caught. At short soak times, both open-topped pyramid traps (PTSS and PTLS) had significantly heavier catches of freshwater crayfish than did other gears. At medium and long soak times, results were equivalent to catch-by-numbers and will not be reported further.

The size distribution of the catch varied depending on the site sampled (Fig. 3). The catch from Charam Swamp and Reedy Lake had a similar size distribution with a single identifiable size class of 25–55-mm OCL. The catch from Lake Charlegrark had two distinct size classes, including freshwater crayfish larger than 60-mm OCL (Fig. 4).

The mean size of freshwater crayfish caught varied among location by gear type ($F = 5.0$, $P < 0.001$) and by soak time ($F = 2.8$, $P = 0.026$). Whereas mean size of freshwater crayfish did not differ by gear type at Charam Swamp and Reedy Lake, at Lake Charlegrark, where the size range of freshwater crayfish included larger individuals, different gear types caught different sizes of freshwater crayfish. At Lake Charlegrark, mean length of all freshwater crayfish caught by pyramid traps with short sides was the highest at 54-mm OCL. The mean length of all freshwater crayfish caught by the LNs and pyramid traps with rings and funnels was the lowest at 41-mm OCL.

Although the proportion of large freshwater crayfish (≥45-mm OCL) in the catch varied among sites (24–32%), there was no indication that any gear type was better at catching large freshwater crayfish overall (Fig. 5). The differences in mean size of freshwater crayfish caught among gear types were largely driven by the catches at Lake Charlegrark. At Lake Charlegrark, the greatest proportion of large freshwater crayfish was caught by open-topped pyramid traps (PTSS and PTLS); and the lowest proportion of large freshwater crayfish was caught by the LN; however, sample size was small ($n < 20$) and confidence intervals overlapped for all gear types, indicating no statistically significant difference.

Experiment 2: evaluating effects of by-catch exclusion rings on trap performance

Opera-house traps with exclusion rings in the entrance funnels (OHRF) of five different nominal diameters were deployed in two waterways over 3 days and three different soak times for 135 individual trap lifts. The total catch was 2699 freshwater crayfish, weighing 89 kg. The whole catch from each trap lift was counted, weighed (g) and sampled for individual lengths. For most trap lifts, all the freshwater crayfish caught were

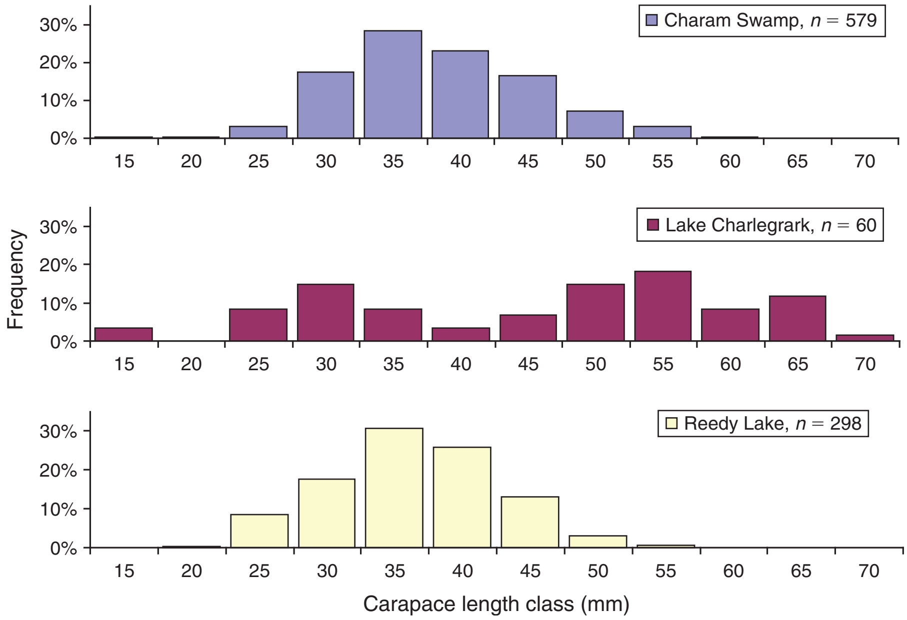

Fig. 3. Percentage frequency distribution of freshwater crayfish size (carapace length) caught from three locations in Victoria during March and May 2012, using multiple gear types in Experiment 1. End points of 5-mm length classes are shown as *x*-axis labels.

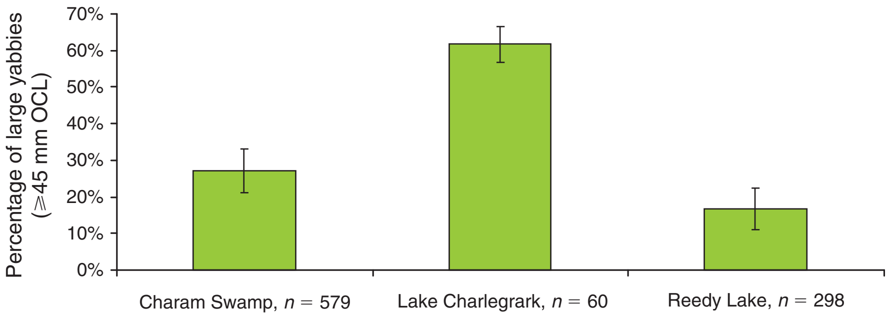

Fig. 4. The proportion (±95% CI) of large freshwater crayfish in the combined catch from all gears at three sites in Victoria. (OCL, occipital carapace length.)

individually measured. Analyses of the lengths indicated that ~3% of the catch was of generally acceptable harvest size (i.e. ≥45-mm OCL and ~60 g). Actual ring diameters varied, although average actual size was within ±3 mm of nominal size in each case (Table 2).

General analysis of variance of the freshwater-crayfish catch data showed that catch efficiency for opera-house traps was not dependent on the exclusion-ring diameter during Experiment 2. None of the two-way interactions or the three-way interaction was statistically significant. Consistent with the results of Experiment 1, the numbers of freshwater crayfish caught varied only by soak times ($F = 101$, $P < 0.001$), not by ring diameters. The mean numbers of freshwater crayfish caught at 6- and 12-h soak times were approximately five times higher than that at the 1-h soak time (Fig. 6).

The catch data for large freshwater crayfish (≥45 mm, OCL) showed that catch efficiency for opera-house traps was not dependent on the exclusion-ring diameter during Experiment 2. None of the two-way interactions or the three-way interaction was statistically significant. The number of large freshwater crayfish caught varied only by soak times ($F = 8.6$, $P < 0.001$), not by ring diameter. As with the total number of freshwater crayfish, the mean numbers of large freshwater crayfish caught at 6- and 12-h soak times were approximately five times higher than that caught at the 1-h soak time (Fig. 6).

The data for weight of freshwater crayfish (g) caught indicated that catch efficiency for opera-house traps was not dependent on the exclusion-ring diameter during Experiment 2. None of the two-way interactions or the three-way interaction was statistically significant. The weight of freshwater crayfish caught varied only by soak times not by ring diameters. The weights of freshwater crayfish caught at 6- and 12-h soak times were approximately six times higher than that caught at the 1-h soak time.

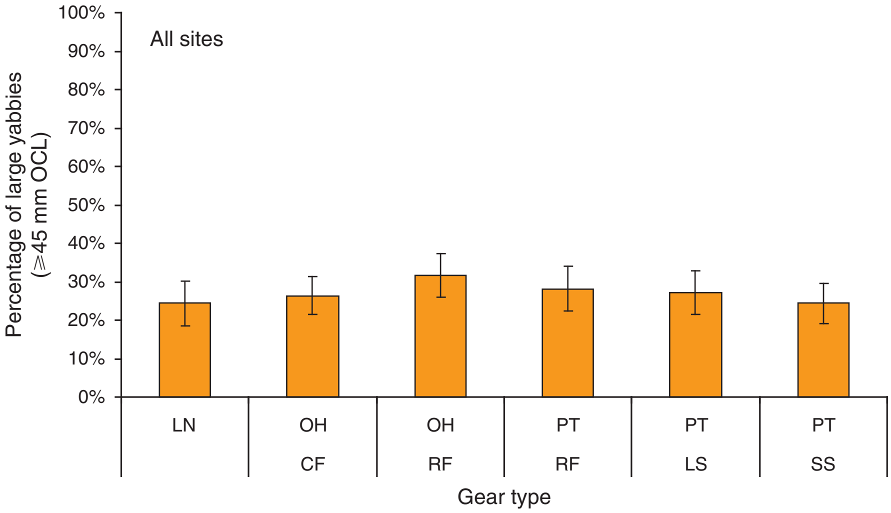

Fig. 5. The proportion (±95% CI) of large freshwater crayfish in the catch from each gear type. LN, lift net; OH, opera-house trap with closed funnel (CF), or fixed ring in funnel (RF); PT, pyramid trap with fixed ring funnel (RF), open top and original long sides (LS) or open top and modified short sides (SS). (OCL, occipital carapace length.)

Table 2. Summary of actual measurements of exclusion-ring treatments for Experiment 2

Parameter	Nominal inside-diameter of exclusion rings (mm)				
	'45'	'55'	'65'	'75'	'85'
Minimum	45	53	65	71	85
Mean	46	54	66	73	88
Maximum	48	55	67	75	90

Mean length (mm, OCL) of freshwater crayfish caught did not vary according to the exclusion-ring diameter or soak-time during Experiment 2. Miga Lake generally had bigger freshwater crayfish; however, mean size was not significantly different from that in Clear Lake.

The proportion of large freshwater crayfish (≥45-mm OCL) caught indicated that this proportion varied only by soak times and did not vary by exclusion-ring diameter during Experiment 2. The proportion of large freshwater crayfish caught at 6- and 12-h soak times were approximately four times higher than that caught at the 1-h soak time.

Discussion

A review of marine crustacean trap fisheries considered many factors important in regulating the catch of crabs and lobsters, including trap size, bait quantity and quality, soak time and prevention of escape through the entrance; however, the largest potential for increasing trap catches was by increasing ease of entry and reducing the effect of gear saturation (animals inside traps preventing those outside from entering; Miller 1990). Our results suggest that this is also the case for freshwater-crayfish trap catches, with the effectiveness of new open-topped pyramid traps enhanced by modifying the traps to cut down the length of the sides, making it easier for freshwater crayfish to enter. Although lift nets lying flat on the substrate should also be easy to enter, they are equally easy for freshwater crayfish to leave, and this may be the difference between their effectiveness and that of the open-topped pyramid designs. Short soak times are one way to minimise gear saturation. In our experiments, an active approach yielded greater catches of freshwater crayfish than did a passive one (see Table 1). An active fisher repeatedly sets and resets each trap while moving to new locations in between each set. At medium and long soak treatments, none of the gears achieved the catch equivalent to those at short soaks over the same period. Studies of freshwater crawfish (*Procambarus clarkii*) in the USA have shown that the highest catch rates are achieved with empty traps, as opposed to traps with live crawfish already inside (Hardee 2009). The presence of live crawfish in traps inhibited the entry of additional crayfish because of their aggressive, agonistic behaviour. Active fishing for freshwater crayfish may capitalise on similar behaviour, and improvements in catch size can be 200–300% higher than those achieved by passive approach.

The present findings are that passive rather than active fishing produces best results, which is opposite to current regulation trends in Victoria. Indeed, a global trend in recreational fisheries management is to regulate fishing activity towards active methods rather than passive ones such as reducing the number of fishing rods used (FAO 2012). Examples include prohibition of recreational mesh nets, and more recently of baited set lines in Victorian inland waters (Victorian Government 2014). The common view of this trend is that it provides a more conservative approach and limited harvesting for recreation rather than subsistence; however, paradoxically, the present study suggests that active fishing and trends for regulating against gears that promote passive fishing are likely to maximise catches of freshwater crayfish in many circumstances. There is presently no assessment of possible impacts of such trends on the sustainability of freshwater crayfish stocks. The driving need for recreational freshwater crayfish fishing regulations in

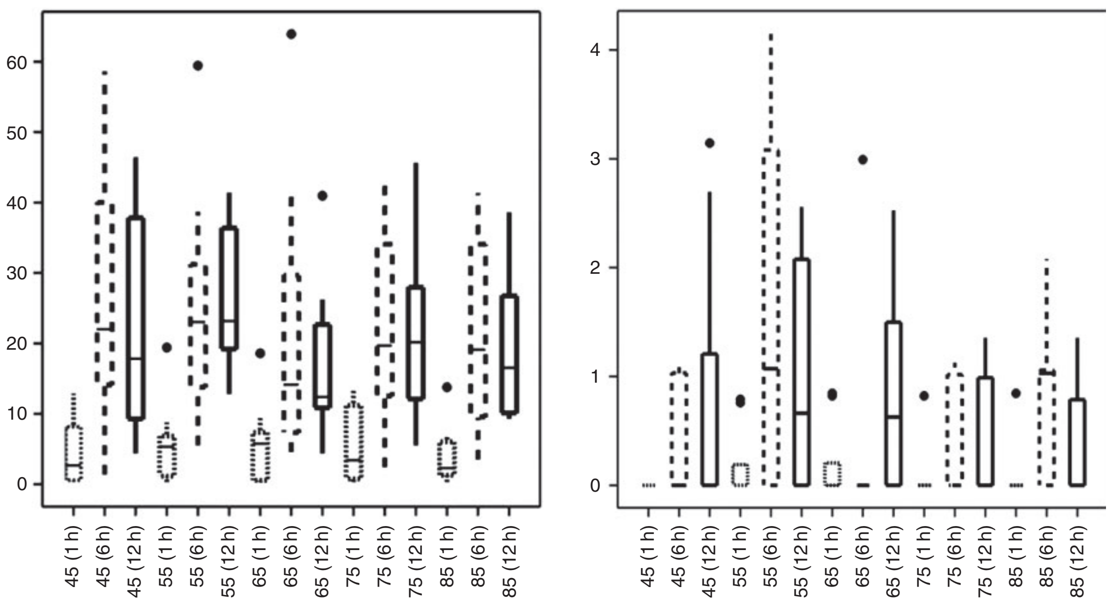

Fig. 6. Box plots showing a summary of catch data from Experiment 2. The total catch (left) and the catch of large freshwater crayfish (≥45-mm occipital carapace length) (right) in opera-house traps with five different diameter entrance rings (45 mm, 55 mm, 65 mm, 75 mm and 85 mm) standardised to three different soak times of 1 h (dotted), 6 h (dashed) and 12 h (solid). Boxes describe inter-quartile range (Q3–Q1), with the median indicated within the box. Bars indicate range of data, with points indicating outliers.

Australia has been to minimise by-catch mortality of non-target, air-breathing aquatic fauna (Serena and Williams 2010).

We examined the role of fixed-diameter entrance rings as by-catch exclusion devices on the freshwater-crayfish catch performance and size-structure of the catch. Our assumption was that the most effective by-catch exclusion-ring size in the present study was the smallest-diameter ring studied (45-mm diameter). There was no statistical difference between catches using this diameter entrance and catches from traps of any of the larger entrances. The only previous study of catches in opera-house traps modified with entrance rings of various sizes was inconclusive; however, it indicated that catch variability was high and no statistical difference in numbers of freshwater crayfish caught was found among traps with variable entrance-ring size (M. Allanson and S. Thurstan, NSW DPI, pers. comm.).

Recreational fishers generally catch freshwater crayfish either to eat (i.e. large freshwater crayfish) or to use as bait for finfish (i.e. small freshwater crayfish). The popularity of a by-catch reduction device will likely depend on its ability to catch both sizes. The size distribution of freshwater-crayfish populations sampled in our Experiment 2 showed no evidence of relative size-selectivity in catches of traps with any particular entrance size. Large and small freshwater crayfish, typical of those harvested by recreational fishers, were adequately captured in traps with small (45-mm diameter) entrances. A study of eight trap designs used to catch red-swamp crayfish (*P. clarkii*) in France was carried out in a population with a size distribution comparable to that of the present study (Paillisson *et al.* 2011). These authors also showed that traps with small (40-mm diameter) entrances caught good numbers of large crayfish (>45-mm OCL) in comparison with other trap types with larger entrances. Also, the standard inside diameter of entrances to traps preferred in the Louisiana commercial crawfish fishery for crawfish (*Procambarus* sp.) (McClain *et al.* 2007) of a preferred size similar to that of *Cherax* sp. in the present study is 44–51 mm, on the basis of published length–weight relationships (Dörr *et al.* 2006).

The optimum gear for maximising a recreational fisher's catch depends on freshwater-crayfish abundance and choice of soak time. If abundance is low, catches are maximised by using either open-topped pyramid traps (PTSS or PTLS) fished in an active manner (i.e. short soaks), or opera-house nets with long, overnight soak times. If abundance is high, maximum catches are obtained by using modified open-topped pyramid traps (PTSS) in an active manner (i.e. short soaks). Where freshwater-crayfish abundance was low, such as Lake Charlegrark during the present study, greater catches were achieved by fishing in a more passive manner. Under these conditions, the use of opera-house nets with collapsible funnels (OHCF) was most effective. Campbell and Whisson (2001) found similar results using OHCF for Marron (*C. tenuimanus*) in eight waterways in Western Australia. Surprisingly, in our low-abundance populations, open-topped pyramid traps still gave greater yields when fished actively rather than passively, although the considerable effort required to achieve the small catch may make this unlikely to be a popular behaviour among recreational fishers.

When considering fishing using long soak times, such as overnight, the catch does not increase with soak time for all but one gear type (OHCF). In abundant populations, this may be because freshwater crayfish escape the gear after the bait becomes depleted, freshwater crayfish become satiated or the trap becomes overcrowded. The lowest overnight catches came from gear with open tops (LN, PTLS, PTSS) or multiple short funnels (PTRF) that may be easier to escape, whereas both opera-house net designs retained higher catches. The opera-house net with collapsible funnels (OHCF) was more effective the longer it was deployed, indicating very low, possibly zero, rates of escape.

Reduced catches at long soak times could be caused by bait depletion, satiation of freshwater crayfish or reduced bait attractiveness. Jones *et al.* (1996) showed that food consumption in C. destructor was 2–5% of bodyweight per day, declining as freshwater crayfish grew. At these consumption rates, it would take between 3 and 7.5 kg of freshwater crayfish to consume 150 g of bait on 1 day. In the present study, catches rarely exceeded 600 g per trap. It is therefore unlikely that baits were entirely depleted by consumption during experimental fishing. Satiation of freshwater crayfish attracted to the trap seems more likely. Bait was always present as the traps were hauled, although the amount remaining was not measured.

There was a reduced rate of increase in catch for OHCF between 6-h and 12-h soak times. Either because fish pieces used for bait became less attractive after 12 h than they were at 6 h, or because entry rates declined as a result of inhibition from freshwater crayfish already in the trap (Hardee 2009). Future studies to determine optimum soak times could consider weighing bait before deployment and after retrieval, and looking for statistical correlations between bait weight and catch at a range of soak times.

Two other issues were not well defined and require further study. At one location (Lake Charlegrark), we measured a significant difference in mean size caught by some gears. Neither entrance-ring size nor trap mesh size explain this as traps with larger entrance rings (PTRF) caught smaller freshwater crayfish, and gear with the larger mesh sizes did not consistently catch larger freshwater crayfish. In some trap fisheries for crustaceans, size selectivity occurs as dominant animals inhibit smaller ones from entering the trap (Miller 1979; Frusher and Hoenig 2001). Our study found evidence of size selectivity only at the site where large freshwater crayfish were abundant. Larger sample sizes are necessary to confirm which types of gear catch the largest freshwater crayfish.

No by-catch was actually encountered. Whereas non-target by-catch was not encountered during the present study, at least partially because of careful site choice, by-catch mortality is only one possible end point of interactions between fishing gear and non-target organisms. Other possibilities are encounter and avoidance, or encounter and capture followed by escape. Destructive sampling is practically flawed as a field-based evaluation method of the risk of fishing gear to aquatic fauna without parallel studies of avoidance and escape behaviour (Grant *et al.* 2004). An alternative approach is required to monitor the whole interaction of by-catch fauna with the gear (i.e. encounter, entrance and exit). Further work is required to evaluate relative by-catch risk of these gears, either in waterways with higher levels of non-target fauna, or under more controlled laboratory conditions.

The present study was carried out in freshwater crayfish stocks in five different freshwater lakes in Victoria. The findings are likely to be broadly applicable in fisheries for freshwater crayfish across similar types of habitat. However, differences in catch efficiency among traps types are likely to occur across different types of habitat (such as, for example, vegetated swamps and flowing streams). Paillisson *et al.* (2011) noted between-trap variations in standardised catch rate for different habitats and suggested that environmental factors such as vegetation cover and water level may influence the efficiency of traps. Furthermore, the likelihood of different behavioural and density-dependent factors associated with different species means that caution is advised before applying these findings to other species or genera of freshwater crayfish.

In conclusion, freshwater-crayfish catch varies by gear type and, in productive locations, could be maximised by fishing actively, repeatedly deploying open-topped gear (LN, PTSS or PTLS) for short soak times and relocating between soaks. Opera-house traps fitted with small fixed ring entrances (45-mm diameter) fish effectively for freshwater crayfish and are not size-selective. This suggests that opera-house traps could be either retro-fitted with, or legislated to have, a maximum entrance-ring diameter of 45 mm to limit the risk of by-catch, without compromising their effectiveness as freshwater-crayfish traps.

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