Estimating area of attraction in a Brown crab (*Cancer pagurus*) fishery using experimental potting

Dr Matthew Coleman, Dr Isobel Bloor, Prof Jan Hiddink, Prof Stuart Jenkins

School of Ocean Sciences, College of Natural Sciences, Bangor University

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Contact. M.Coleman@Bangor.ac.uk

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Introduction

In the case of data deficient fisheries the use of fishery dependant data is the primary source of information from which local and national stock assessments are undertaken. In the case of brown crab *Cancer pagurus*, the species remains a socio- economic keystone for inshore fisheries across the North East Atlantic. However, the relationship between fishing pressure and perceived changes in stock abundance in this fishery is poorly understood and provides an ongoing challenge for fisheries managers in ensuring long term sustainability of the fishery.

Standardised landing per unit effort (LPUE) data is commonly used to provide a metric of fishery health and overall stock abundance. There are however numerous biotic and abiotic factors that can affect catchability in crustaceans and hence the relationship between LPUE and stock abundance. These include temperature/season (Lizárraga-Cubedo et al., 2015), moulting (Ziegler et al., 2004), reproduction and the effect of conspecifics ; Emmerson *et al*, 2022). An additional factor to consider in the interpretation of LPUE as a function of population density is understanding the area over which pots attract the target species. This process can be split into 3 parts as described by Bell *et al*., (2001); (Figure 1):

Area of Influence – described as the distance at which bait is detected, with a measurable response exhibited by the target species

Trapping area – Described as the area in which the probability of capture of individuals during deployment of the trap is greater than zero, or the total area from which the catch is drawn. This area can be directly influenced by deployment length, environmental factors and target species behaviour making it potentially larger than the area of influence in some cases.

Effective area fished – a notional area of the seabed containing as many animals as were trapped

In the case of commercial crustaceans, estimates of area of influence and trapping area have primarily been undertaken using telemetry, with these estimates derived through the recording of behavioural responses pre and post baited pot deployment (*Homarus americanus* - Watson III et al. (2009); *Homarus gammarus* - Lees et al. (2018); *Cancer pagurus - Skajaa et al. (1998);* Table 1). The use of such technology, though useful, requires: a) a significant number of individuals to be tracked; b) a suitable sized sampling area to encompass home ranges; and c) significant financial cost. Furthermore, studies are heavily reliant on subjective assessment of behavioural responses to bait. In this regard there is an overall lack of standardisation in describing bait detection behaviours. For example , Watson III et al. (2009) and Lees et al. (2018) used change in angle of movement to infer bait detection while (Skajaa et al., 1998) used changes in walking speed.

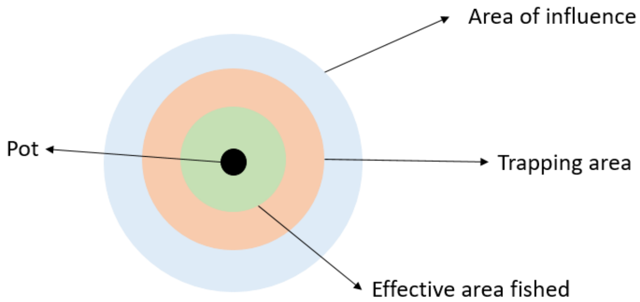

Figure 1 Conceptual representation of three types of attraction areas around a trap as defined by Bell *et al*., (2001)

Table 1 Existing estimates of area of influence and trapping area in commercial static gear fisheries derived using a variety of techniques and target species.

Species	Technique	Effective area fished (m^2)	Trapping area (m^2)	Area of Influence (m^2)	Density (m^2)	Reference
Cancer pagurus	Mark Recapture	7,776	-	-	0.0014	Bell et al. (2003)
	Mark Recapture	7,022	-	-	0.0038	Ungfors, 2008
	Telemetry	-	2,461	7,238	-	Skajaa et al. (1998)
Cancer porteri	Experimental Potting	-	9,348	-	-	Aedo and Arancibia (2003)
Panulirus cygnus	Telemetry	-	45,239	-	-	Jernakoff & Phillips (1988)
H. gammarus 24hrs	Telemetry	-	-	2,289	-	Lees et al. (2018)
H. gammarus average	Telemetry	-	-	3,090	-	
H. gammarus against current	Telemetry	-	-	10,908	-	
H. americanus	Telemetry	-	382	2,604	-	Watson III et al. (2009)

Other methods to estimate the components of trapping attraction areas have been based on different experimental fishing approaches. Eggers et al. (1982) developed a methodology that was further refined by Arena et al. (1994), to estimate abundance utilising traps/hooks at different spacing. With the trapping area process simplified to be circular with a fixed radius, removing complications and assumptions surrounding bait plume dispersal. Aedo and Arancibia (2003) measured capture per unit effort (CPUE) in the *Cancer porteri* fishery under different pot spacing's (Table 1). The point of inflection in the curve relating pot spacing and CPUE was considered the distance at which baited pots stopped interfering with neighbouring pots' capture rates (Figure 2). This distance may be used to calculate an area which equates to the definition of trapping area of Bell (under the conditions imposed i.e. the areas of influence of different traps overlapping). Aedo and Arancibia (2003) estimated the trapping area in the *Cancer porteri* fishery to be 9,348m^2 (Table 1). In the case of *C. pagurus* estimates of effective area fishing area and subsequent density have been estimated Bell et al. 2003 in Norfolk, England and by Ungfor, (2008) in Sweden (Table 1). The approach of Bell et al. (2003) used a traditonal mark recapture technique utilising commercial pot fishing, which led to an estimate of effective fishing area in *Cancer pagurus* of 7,776 m^2 and a density of 0.0014 crab/m^2 in the England East coast fishery. In comparison Ungfor, (2008) used an experimental design in which crabs were marked and released at five difference distances from two central pots, with recapture rates from each distance used to estimate an effective fishing area of 7, 002 m2 and a density of 0.004 crab/m^2.

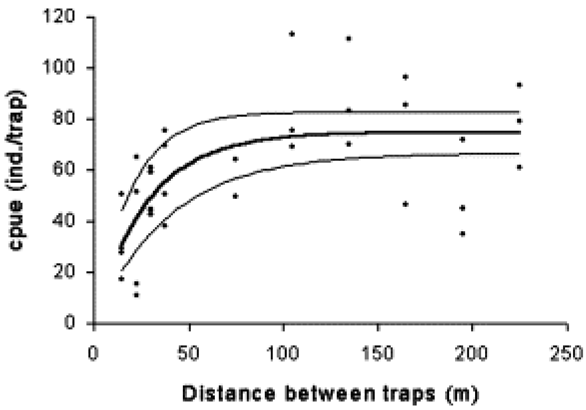

Figure 2 Recorded trend between CPUE and distance between traps by Aedo and Arancibia (2003) used to determine total potential attraction area (TPAA) in *Cancer porteri*.

Based on a review of previous approaches we adopted a similar methodology to that Aedo and Arancibia (2003) to estimate the trapping area for crab pot fisheries in the Isle of Man's territorial sea. Using this approach we address two overall aims: 1) inform pot spacing to maximise capture efficiency; 2) enhance our ability to provide estimates of stock abundance.

Methods

Experimental Design

Eight different pot spacing treatments were established ranging from 15 metres (m) to 225m (Table *2*). Each treatment was established on a single string with 5 pots, and fished over 3 separate 24 hour periods (ie using a 24 hour soak time between each haul event). When hauled the number of individuals per species per pot was recorded. Individuals were sexed and measured (Brown Crab - carapace width (CW) (mm); European lobster – carapace length (CL)) using Vernier callipers. All sublegal (Brown Crab CW <140mm; European lobster <88mm CL), soft and black spot individuals were returned to the sea after processing. Individuals of commercial size (Brown crab CW >140mm; European lobster >88mm CL) were retained and landed by the participating vessel.

Pots were baited with two haddock frames in the bait sock and an additional haddock frame loose in the pot. This was in keeping with commercial practises. Bait was replenished at each hauling event. All escape gaps on pots were closed prior to deployment using two cable ties to ensure the retention of both legal and sublegal *C. pagurus*.

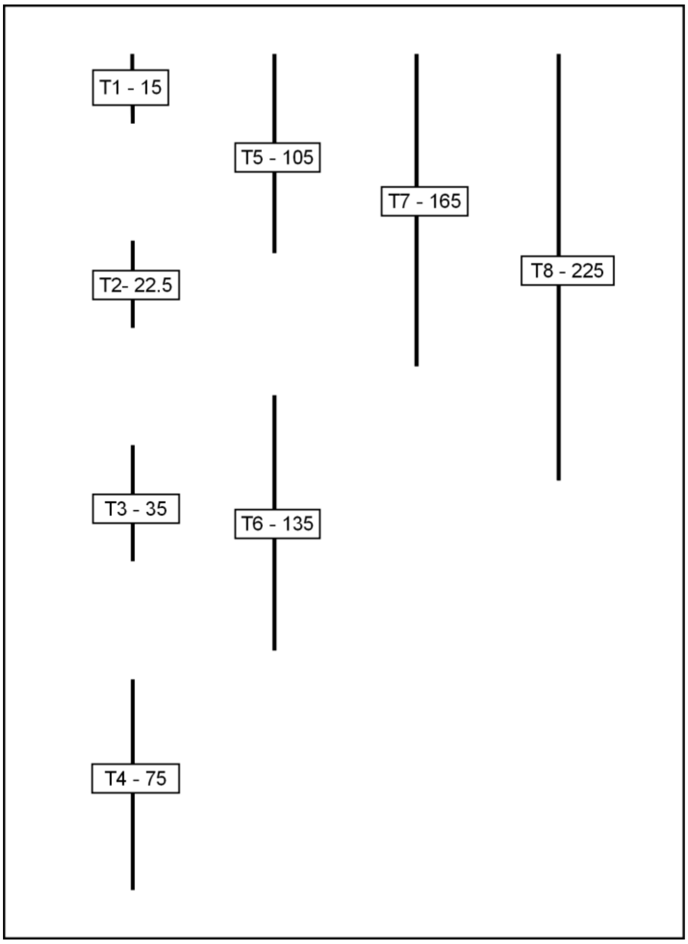

Figure 3 Treatment arrangement inside the survey box and associated pot spacing.

Table 2 Experimental pot arrangement per treatment and the number of pots replicates per treatment/spacing. ^{C} denotes commercial spacing

Treatment	No. Pots	Pot Spacing (Metres/Fathom)	Number of fishing events
T1	5	15/8	3
T2	5	22.5/12	3
T3	5	35/20^{C}	3
T4	5	75/41	3
T5	5	105/57	3
T6	5	135/73	3
T7	5	165/90	3
T8	5	225/123	3

Statistical Analysis

To determine the relationship between CPUE and pot spacing a non-linear least squares regression model was used. Following model fitting the inflection of the curve, where the relationship changed from a positive relationship to an asymptote was estimated. The asymptote indicated the point at which the theoretical trapping area of pot no longer overlaps with neighbouring pots, providing insight to when a pot is fishing independently (Figure 4).

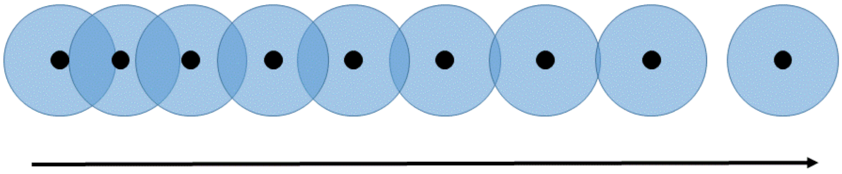

Figure 4 Graphical representation of how location of pot increased the degree of overlap between pots and how increased spacing results in reduced trapping area until pots no longer overlap and fish independently

Trapping area

In order to estimate trapping area three components where needed to be calculated. The first being the footprint of the pot. In this case an assumption that the probability of capture was equal in all directions i.e. the area of attraction and hence trapping area were circular. Therefore the volume of a cone was used as the starting point to estimate this (Equation 1):.

Volume of cone= 1/3 * pi * r^2 * h

Where r is the radius of the circle and h the height of the cone.

Equation 1

The degree of overlap and its effect on subsequent catch is then needed to be estimated. This is due to degree of overlap being dependent on the position of the pot on a string (string position) (Figure 4) Pots were therefore assigned to one of two groups: middle (n=3 per string) and end (n=2 per string). In order to calculate the degree of overlap a function of overlapping cones was used (Equation 2).

Volume overlap=(h/(3*r))*{r^3 * acos(x/r) -2*r*x*sqrt(r^2-x^2) + x^3*log({r+sqrt(r^2-x^2)}/x) }

Equation 2

A non-linear least square regression was finally used to estimate trapping area, with the model incorporating both pot area and degree of overlap of adjacent pot dependant on location on the experimental string to estimate the CPUE asymptote distance and density of catchable crabs (Model).

Catch~ Volume of Cone – String Position*Volume overlap

Model 1 Non-linear least square equation incorporating both volume of cones (pot trapping area), string position and degree of volume overlap.

Results

Size frequency

A total of 298 *C. pagurus* were caught during the trial and ranged in size from 100 to 200 mm CW. Of these 244 were female and 54 were male. Size distribution centred on the minimum landing size (140mm), with greatest abundance observed in size classes 140 – 160mm (Figure 5), and with this trend observed across all three hauling events.

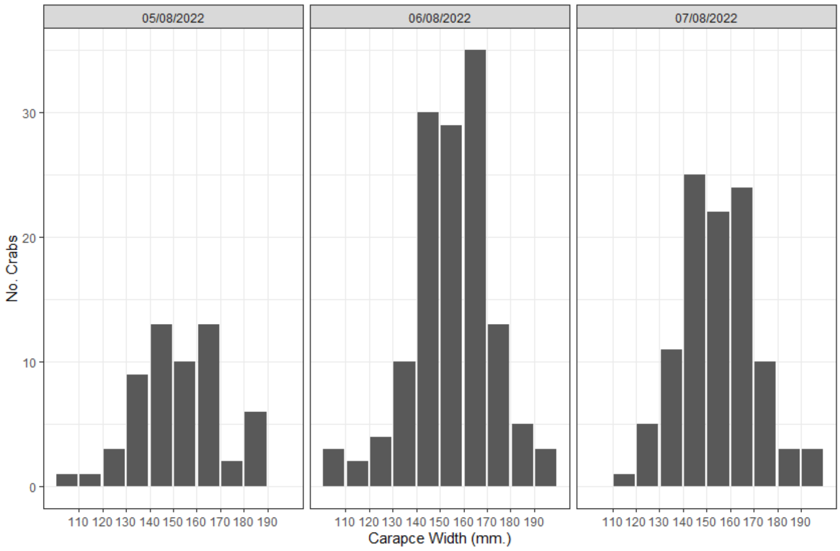

Figure 5 Size distribution of all Brown crab caught in the experimental potting trial per haul event.

Catch Rates

Catch rates ranged from 0 – 11 individuals per pot across all pot spacing's, with mean catch per unit effort (CPUE) (no. crabs/pot) ranging from 1.2 (±1.2) crabs at 15m pot spacing to a high of 5 (± 2.8) crabs at 165m spacing (Table *3*). Percentage change per pot spacing was calculated compared to commercial spacing (35m). Treatments with reduced spacing (15m and 22.5m) resulted in 31% decrease in CPUE whilst increased spacing (75m – 225m) yielded increases in CPUE, ranging from ~40% to ~66%.

Table 3 Mean catch rates and standard deviation of number of brown crab (*Cancer* pagurus) caught per experimental pot spacing.

Pot spacing (metres)	CPUE (No. Crab/Pot)	Standard Deviation	Percentage Change from Commercial Spacing
15	1.26	1.2	-31%
22.5	1.26	1.5	-31%
35^{c}	1.73	1.2	-
75	2.86	1.6	+39.5%
105	3.93	2.1	+55.9%
135	3.26	1.9	+46.9%
165	5.06	2.8	+65.8%
225	3.26	2.6	+46.9%

Trapping Area

The trapping area was estimated using mean CPUE∞ for both end pots and mid pots, with CPUE∞ calculated to be at a pot spacing of 134.3 metres/~73 fathom (Figure 6). Using this information we can estimate trapping area of a pot to be 14,187 m^2 with a density of 0.00073m^2, scaled to a density of 750 crabs/Km^2

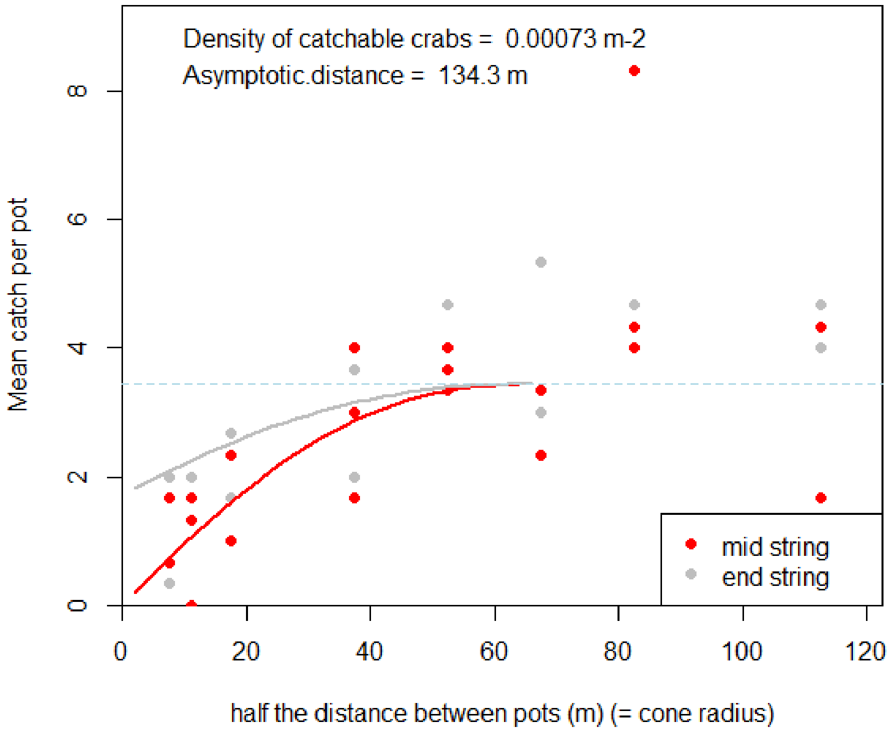

Figure 6 Nonlinear least square regression trend between CPUE and pot spacing's in the *Cancer pagurus* experimental potting trial.

Discussion

The survey successfully demonstrated the potential to estimate trapping area from experimental pot spacing in the Isle of Man fishery.

The estimation of trap area for baited pots remains a key area of research and is necessary to understand the interaction of the commercial fishery with target species. In this instance preliminary estimates showed the pot spacing which led to no interference among neighbouring pots for *C. pagurus* was 134m. This leads to an estimate of trapping area of 14,166m^2, which is double that of Bell et al. (2003): 7,776 m^2 and Ungfors, (2008): 7,007 m^2 these estimates are however based on the smaller effective fishing area compared to trapping area in this study. Therefore estimates of density of crabs are far larger in both studies compared to those estimated here due to this difference. This study does however provide the first estimates of density of crabs in the Isle of Man fishery and northern Irish Sea.

The development of this methodology and its application provides the ability to convert landing per unit effort (LPUE) to crab/m^2 providing a standardised index of abundance. This index can then be compared to the current fishery independent survey metric being trailed by Bangor University in the form of the CEFAS Northern Irish sea beam trawl survey, in which crab/km^2 is estimated. Furthermore it provides the basis from which the trapping area of baited underwater video systems (BRUV) can be assigned. These systems are currently being developed as a method to provide fishery independent estimates of abundance for areas that are not surveyed by the trawl survey or habitat types that make the use of such gears unsuitable.

It is important however to acknowledge that a number of assumptions have been made regarding the estimate using this method, principally bait plume dispersal. In this instance bait plume dispersal is assumed to be even and circular. This assumption is however known not to be the case, with dispersal influenced by tide and tidal state and therefore highly directional (McQuinn et al., 1988). The current trial also occurred over a discrete period of time, with the estimation potentially benefitting from further refinement through multiple deployments across different tidal states and times of year with capture rates known to be higher in the autumn months (September – November).

Future Considerations

The results of this survey present a number of potential considerations and areas of future wok, both in relation to how the fishery is managed and the use of this information by industry. The survey highlighted that the current commercial spacing is potentially sub-optimal, strengthening previous research that indicates that commercial spacing currently used (35m/20fathom) introduces interference between pots, thus leading to lower catch efficiency. Increasing pot spacing could therefore increase gear efficiency resulting in higher catch rates as demonstrated.

In the context of future work, increases in efficiency present the potential opportunity to reduce pot numbers whilst maintaining catch rates. This could alleviate gear conflict in certain regions and presents the opportunity to undertake gear reduction trials by developing single pot deployment zones coinciding with priority marine features or limited gear/ limited access areas. The development of increased pot spacing's however equally presents commercial implications. Technology creep is poorly understood in pot fisheries, but is recognised to significantly influence catch rates and efficiency. Research by Kleiven et al. (2022) demonstrated how slight changes in gear design in static gear can affect the catch composition available to the European lobster *Homarus gammarus* fishery. This was demonstrated by comparing the catch efficiency and catch composition of traditional wooden pots from 1928 to modern semi-synthetic pots. The study established that since 1928, pots have been fitted with incrementally larger entrance eyes, multi chambers designs and longer lasting manmade construction material. These small changes alter the catch efficiency of pots and have been highlighted as a potential contributor to the stock collapse in Norway by potential masking stock decline by keeping catches high even whilst baseline abundance decreases. The implication therefore of broad scale adoption of configurations such as increased pot spacing that increases catch rates by +50% could potentially mask the severity of population declines by artificially maintaining catch rates or increasing them. This is of concern owing to the declines recorded in both the Isle of Man *C. pagurus* fisheries (Bangor University, 2021) and those around the UK (Mesquita et al., 2021). Increased pot spacing could similarly increase gear conflict through spatial squeeze resulting from increasing the footprint of the fishery if gear reduction does not happen simultaneously. The potential for increased pot spacing adoption by the commercial fishery is however unclear, although questions surrounding the optimum spacing has been raised by the fishery due to anecdotal observation of increased catches in end pots (Bevan, pers.comm). Simultaneously rational behind currently used pot spacing is mixed, with reason behind the adoption based on personal preference, historical set-up or safety concerns (Coleman, pers. comm).

Adoption and continued use of fleets of gear such as those used in the Isle of Man therefore appears inefficient when dealing with high density, gregarious species such as C. pagurus. Reasons behind the continued use of fleets comprised of string made up of multiple pots could therefore be attributed to the historic open access nature of the fisheries and desire to maintain ownership over ground and lack of fisheries management surrounding gear limitation at a wider scale.

Further work is needed however to better understand the effect of pot spacing's on catch efficiency relative to seasonal fluctuations in catch rates and different soak times.

This work has now been published in the ICES Journal of Marine Science, for further information see:

Jan Geert Hiddink, Matthew T Coleman, Stephen Brouwer, Isobel S M Bloor, Stuart R Jenkins, Estimating the abundance of benthic invertebrates from trap-catch data, ICES Journal of Marine Science, Volume 81, Issue 1, January 2024, Pages 86–96, https://doi.org/10.1093/icesjms/fsad178

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