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Scallop potting with lights: A novel, low impact method for catching European king scallop (*Pecten maximus*)

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ABSTRACT

This paper describes, for the first time, that scallops can be attracted into static fishing gear using LED lights. This novel finding presents an opportunity for the development of a new, low impact fishing method for scallops. Traditionally, wild caught scallops are primarily fished using dredges and trawls. Due to their penetrative nature, the interaction of this towed gear with the seabed can cause significant damage to sensitive marine habitats and species. Diver caught scallops have been a low impact alternative source, however, this sector can only supply limited quantities due to logistical constraints. In this study, we investigate the potential for scallops to be fished using illuminated standard commercial crustacean pots. We assessed the effect of using light in a range of pot designs on scallop, brown crab, lobster and crawfish, and spider crab catches in Cornwall between December 2020 and February 2021. A total of 77 strings were shot, deploying 1886 pots of six treatment types. The fishing grounds used in the trial are traditionally potted for crustacea and are not renowned scallop beds. Despite this, all treatments with lights retained scallops and of the 518 scallops recorded, 99.6% (n = 516) were caught in pots with lights. A modified parlour pot with lights (treatment F) caught scallops most effectively, with a maximum catch rate of 19 scallops per string (23–24 pots per string) per 24-, and the maximum number of scallops recorded in a single pot was 24. We show that simple and inexpensive modifications to existing crustacean pots present fishers the opportunity to augment their existing crustacean catches with a low environmental impact, premium scallop product. Further refinement to pot design and the lights are needed to enhance scallop and crustacean retention before a commercially viable fishery can be established. We discuss the opportunities that these new findings present to the fishing industry and marine managers.

1. Introduction

Sea scallops (*Pectinidae*) are wild caught globally, with the top five catching countries (in order by landed weight; USA, France, Canada, Argentina, and the United Kingdom) contributing > 85% of global scallop landings (FAO, 2021). These fisheries are often high value, with operators attracted to the sector by lucrative prices and relatively low operating expenditure compared to other fishing methods (Stewart and Howarth, 2016).

Wild caught scallops are primarily fished using mobile gears (dredges and trawls) but are also hand collected by SCUBA divers in smaller quantities. Dredges are the most common fishing method used to extract high value, relatively low mobility species of scallops (e.g. European king scallops; *Pecten maximus,* Atlantic sea scallops*; Placopecten magellanicus,* and Australian southern scallops; *Pecten fumatus;* Duncan et al., 2016; Roman and Rudders, 2019). Although dredge designs vary among fisheries, they typically feature metal and mesh collecting bags, towed singularly or in gangs of up to 22 dredges aside (Cappell et al., 2018). The Newhaven dredges used in the UK possess a spring-loaded bar of teeth designed to penetrate the substrate and lift the scallops up

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into the collecting bags (Stewart and Howarth, 2016). In comparison, the New Bedford and Turtle deflector dredges used in the USA have depressor and cutting bars across the front which are designed to travel on or just above the substrate to generate a hydrodynamic flow that flips the scallops into the collecting bag (Roman and Rudders, 2019). Alternatively, although Atlantic sea scallops are also be taken by otter trawls (Stokesbury et al., 2016) this method is more commonly used for the more mobile species of scallops (e.g. European queen scallops; *Aequipecten opercularis,* tropical saucer scallops; *Amusium balloti*, and Patagonian scallops; *Zygochlamys patagonica* (Duncan et al., 2016; Stewart and Howarth, 2016). Unlike mobile gears, extracting scallops by hand-diving has little to no impact on the seabed, but landings are limited by physical constraints such as water depth, weather, ground coverage, and dive time / decompression restrictions. To this end, hand-dived scallops constitute a very small proportion of global take – for example, the UK hand-dived scallop fishery represents < 2% of total landed weight, nationally (Cappell et al., 2018).

In the UK, dredge caught European king scallops (herein referred to as scallops) account for 95% of scallop landings (Cappell et al., 2018). The “Newhaven” dredge (metal frame with spring loaded teeth) used by the UK scallop fishery is likely to be one of the most damaging types of scallop dredge due to the effect of the spring loaded teeth penetrating 3–10 cm into the seabed (Hinz et al., 2012; Stewart and Howarth, 2016). Due to this penetrative nature, the dredges can cause substantial physical disruption to the seafloor, particularly in sensitive habitats. The interaction between the dredge and the seabed has been widely documented with evidence of physical disturbance of the upper layers of the seabed, direct removal, damage, displacement or death of the associated benthic flora and fauna, short-term attraction of scavengers, alteration of habitat structure, and remineralisation of sedimentary carbon to CO_2 (Gubbay and Knapman, 1999; Kaiser et al., 2001; Sala et al., 2021; Sewell and Hiscock, 2005).

Aside from management intervention via effort reduction or redistribution (e.g. gear restrictions, spatial and temporal closures), attempts to mitigate dredging impacts on the seabed are limited and often centred around modifications associated with the design of the dredge. One example of this is the “hydrodredge”, which uses water movement instead of tooth bars to lift scallops from the seabed. Whilst this reduces the contact the dredge has with the seabed, it was shown to be considerably less efficient (60–90%) at catching scallops compared to the standard “Newhaven” dredge (Shephard et al., 2009). More recently, the manufacturers of another variant of dredge, the “N-Virodredge” (a modified dredge design that uses wire tines instead of tooth bars) claimed their method “reduces seabed damage”, “improves fuel efficiency”, and “maintains or improves catch levels”. However, independent diver observation did not detect a reduced impact of the N-Virodredge on the seabed (ICES, 2016). Alterations to dredge design tailored at reducing the impact on the seabed are welcomed, however, it is unlikely that a towed array of modified dredges will sufficiently alleviate the concerns of marine managers responsible for protecting sensitive marine species and habitats.

Adapting fishing gear by adding illumination has been demonstrated elsewhere to enhance catch rates and is rapidly becoming a growing area of innovation. A number of studies have revealed that the introduction of light sources to static gear significantly increase the catch rates of target species. For example, Nguyen et al. (2017) demonstrated a 77% increase in the valuable snow crab (*Chionoecetes opilio*) catch rates in illuminated pots compared to pots without lights. Moreover, the catch per unit of effort (CPUE) of snow crab in unbaited illuminated pots was similar to the baited pots (Nguyen et al., 2017). In Sweden, it was discovered that illuminating cod traps with green LED lights increased the landed weight of legal sized cod (*Gadus morhua*) by 80% compared to traps without LED lights (Bryhn et al., 2014).

The knowledge base describing gear illumination effects on fish and shellfish catch rates is increasing (Marchesan et al., 2005), however, to date, there has been a lack of formal research assessing the potential of an illuminated pot fishery for bivalves such as scallops, despite previous studies describing phototaxis in scallops (Howell, 1989). Scallops possess numerous eyes along the margin of their mantle, with short focal length relative to pupil size, resulting in high light-gathering power (Colicchia et al., 2009; Warrant and Locket, 2004). Light is known to have both inhibitory and excitatory effects causing scallops to move and orientate themselves, or close their shell in response to shadows or movement (Speiser and Johnsen, 2008; Wilkens, 2006). SCUBA divers seeking scallops will often shine their torches over the ground to find the scallops who respond by closing their shell rapidly, revealing their positions. Most species of scallop are considered to be sessile but their swimming escape response has been well documented (Brand, 2006; Caddy, 1968; Wilkens, 2006) and their ability to swim to a preferred habitat using sight has also been described (Hamilton and Koch, 1996).

In 2019, a commercial crab fisherman from Cornwall, UK was asked to note any effects on catch resulting from the attachment of a single, constant white light (Fishtek Marine PotLight) to the inside of a standard commercial pot during standard fishing operations. Whilst no notable increase (or decrease) in crustacean catch was observed in the illuminated pots compared to the non-illuminated pots, the fisherman recorded an unexpected outcome. Over the one-month trial, the illuminated pots consistently caught scallops in quantities not previously seen by the fisherman. For context, the fisherman anecdotally reported catching approximately five scallops per year in his standard non-illuminated gear (from ca. 35,000 pots), whereas in the illuminated pots, ten scallops per 50 pots were observed, an approximately 1400 fold increase. This anecdotal evidence formed the basis of this current study which aims to further investigate the potential for using light to attract scallops into pots by trialling varying illuminated pot designs to investigate whether (1) scallops can be caught using static gear; (2) light attracts scallops; and (3) if scallops could potentially augment the catch value of existing crustacean fisheries.

2. Method

2.1. Experimental trials

Strings of pots were deployed and hauled from a commercial fishing vessel operating from Newlyn port in the south west of the UK. Hauls were made between December 2020 and February 2021 in areas where the vessel would normally fish for shellfish. Strings of pots were hauled and randomly re-laid within a 1.5 km x 1.5 km area of seabed off Lands-End, Cornwall not regularly fished by vessels towing mobile gears. At the request of the fishing skipper, a map showing haul locations is not presented to protect the commercial sensitivity of the fishing ground.

Data on both retained and discarded catch were recorded by a trained observer. For each trip, physical conditions (depth, position, haul duration, and gear properties), and biological composition of the retained and discarded catch were recorded. Data on predated scallops (empty shells) within pots were recorded with only right valves (domed shell) counted to prevent double counting. Shell length for scallops, carapace length for lobsters (*Homarus gammarus*) and crawfish (*Palinurus elephas*), carapace width for brown crab (*Cancer pagurus*) and carapace length for European spider crab (*Maja squinado*) were measured to the nearest millimetre, and total length of fish and mantle length of cephalopods were measured to the nearest centimetre, with individuals of each species sexed where possible. Retained catch exceeded the Minimum Landing Size (MLS) for a given species and are as follows; Scallops > 100 mm, male brown crab > 160 mm, female brown crab > 155 mm (and not berried), spider crabs > 130 mm, crawfish > 110 mm and lobster > 90 mm.

2.2. Pot design

Static fishing methods used to catch swimming bivalves have no prior art, therefore pot treatments trialled in these experiments were designed to maximise scallop retention based on two criteria: 1) the behavioural swimming characteristics of *Pecten maximus* and 2) the operational needs of the fishing vessels deploying the pots. To this end, all pot treatments were based around modifications to existing, readily available commercial pot frames.

The "scallop ramps" (herein ramps) used in treatments C, D and F (Fig. 1) mimic the swimming take off angles for scallops described by Minchin and Mathers (1982). The 40-degree sloping ramp, facing upwards into the pot was therefore considered unlikely to inhibit scallop swimming activity into the pot, and would be a difficult barrier for scallops wishing to take off once inside the pot. To further enhance scallop retention, each treatment with a ramp had a "scallop retainer" (herein retainer) fitted in the pot. The scallop retainer was a piece of nylon sheet running the length of the pot and hanging vertically down from the centre of the pot roof and to a level in line with the top of the inward facing ramps (Fig. 1). The design intent of the retainer was to prevent scallops taking off and exiting the pot. Treatments C and D use one ramp and one retainer (along the full length of one side of the pot), and treatment F uses two ramps, one retainer (along 2/3 of the length of both sides of the pot).

2.3. Experiment 1: Effects of light and or pot modification on scallop catch

Four treatments of pot (based on commercially available 64 cm × 46 cm × 38 cm pots) were compared across two strings of 50 pots. Treatments consisted of an unmodified pot (control; treatment A); a pot with lights (treatment B); a pot with a ramp, comprising of a single perforated nylon sheet (500 mm × 150 mm × 3 mm) fixed at 40 degrees sloping upwards into the pot and inserted by removing the netting from the lower half of one side of the pot and fixed into place with nylon cable ties, (treatment C); and a pot with lights and a ramp (treatment D; Fig. 1). All treatments with ramps had a retainer fitted to the roof of the pot (Fig. 1). Each string was shot between 12 and 13 times (Table 1) with alternating treatments, comprising 25 of two treatments in combination (A + B, string 1; C + D, string 2). Pots were spaced 22 m apart, the quantity of 50 pots per string and spacing of pots are representative of commercial fishing practices for this size of pot and fishing vessel.

2.4. Experiment 2: Augmenting crustacean fisheries with scallops using modified parlour pots

In this experiment (run concurrently with experiment 1), two treatments of parlour pot, (based on commercially available 86 cm × 56 cm × 38 cm pots) were compared across two strings. Parlour pot treatments consisted of an unmodified parlour pot (control; treatment E), and a parlour pot with lights and ramp (treatment F). Scallop ramps comprised two pieces of perforated nylon sheet (300 mm × 150 mm × 3 mm) fixed at 40° sloping upwards into the pot, inserted by removing the netting forward of the parlour pot compartment from the lower half of both sides of the pot, and fixed in place with nylon cable ties. All treatments with ramps had a retainer fitted to the roof of the pot (Fig. 1). These treatments were shot between 12 and 15 times (Table 1) in strings of 23 or 24 pots of one treatment per string and spaced 44 m apart, the quantity and spacing of pots representative of commercial fishing practices for this size of parlour pot and fishing vessel.

However, due to the work space on the boat, we were limited in how many pots could be deployed in the experiments. We also wanted to

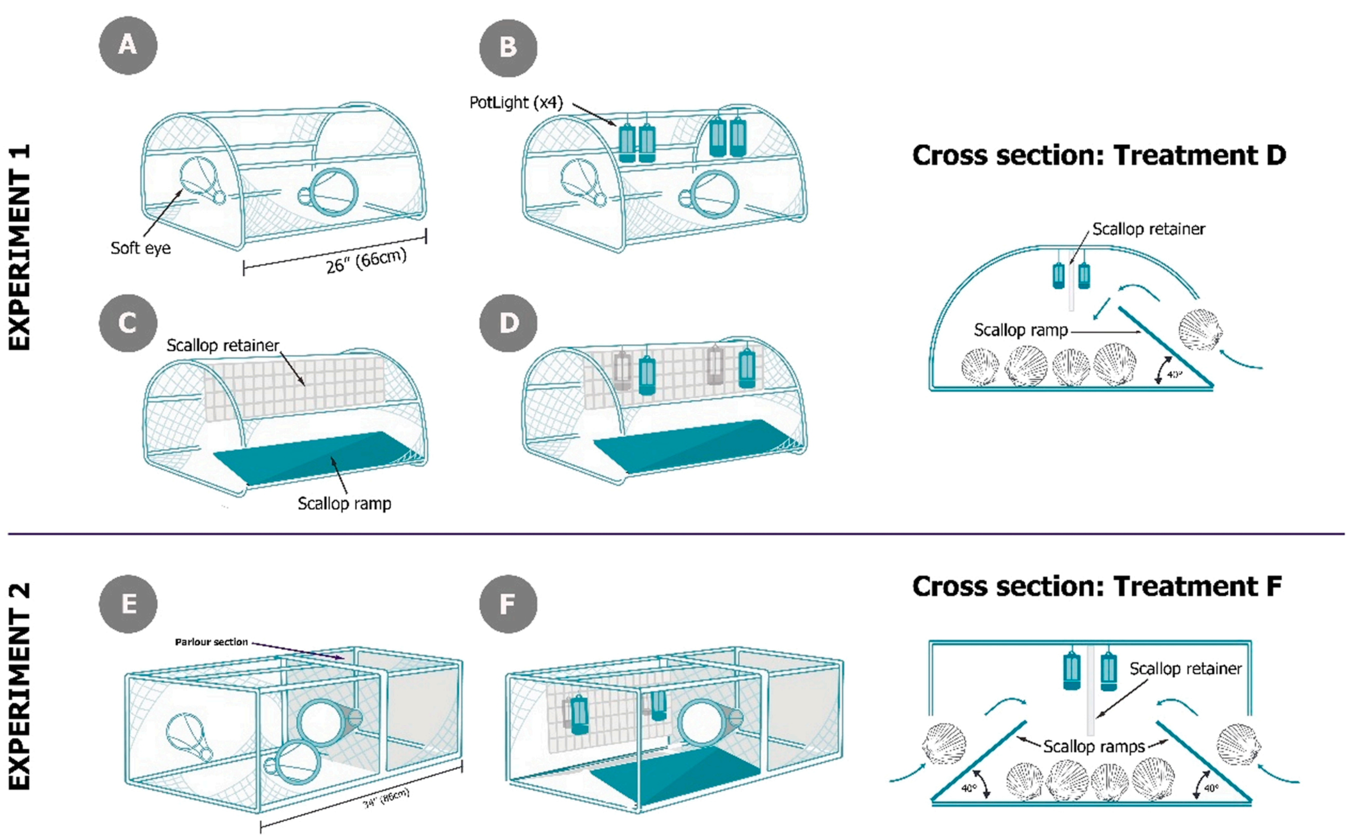

Fig. 1. Schematic diagrams of pot configurations. Experiment 1: Effects of light and or pot modification on scallop catch (A; unmodified pot (control), B; pot with lights, C; pot with ramp comprised of a single perforated nylon sheet (500 mm × 150 mm × 3 mm) fixed at 40 degrees sloping upwards into the pot and inserted by removing the netting from the lower half of one side of the pot and fixed into place with nylon cable ties, and D; pot with lights and a ramp), and Experiment 2: Augmenting crustacean fisheries with scallops using modified parlour pots (E; unmodified parlour pot and F; parlour pot with lights and ramps). All treatments with a ramp (C, D and F) had a retainer fitted, a piece of nylon sheet running the length of the pot and hanging vertically down from the centre of the pot roof.

Table 1
Summary data of deployments, number of pots deployed, soak time, and depth for each pot configuration.

Experiment	Treatment	Treatment description	Total number of deployments	Total number of pots	Soak duration (mean ± sd (range); h)	Depth (mean ± sd (range); m)
1	A	Pot	12	300	104.00 ± 96.72 (24.00–336)	65.00 ± 1.04 (64.00–66.00)
	B	Pot + light	12	300	104.00 ± 96.72 (24.00–336)	65.00 ± 1.04 (64.00–66.00)
	C	Pot + ramp	13	325	116.31 ± 107.26 (24.00–336)	64.92 ± 1.04 (64.00–66.00)
	D	Pot + light + ramp	13	325	116.31 ± 107.26 (24.00–336)	64.92 ± 1.04 (64.00–66.00)
2	E	Parlour pot	12	276	104.00 ± 96.72 (24.00–336)	65.00 ± 1.04 (64.00–66.00)
	F	Parlour pot + light + ramp	15	360	124.80 ± 109.68 (24.00–336)	64.60 ± 0.91 (64.00–66.00)

minimise the impact on the fishers and their commercial activities.

2.5. Pot illumination and bait

Illuminated pots (treatments B, D, and F) were each equipped with four constant white PotLights (Fishtek Marine) attached to the inside roof of the pots (Fig. 1, Supplementary Plate S1). PotLight batteries were replaced every 500 h (or ~20 days) in line with the manufacturer's recommendations. Any lost or damaged lights were replaced. All treatments (A-F) were baited with equal quantities of mixed-fish comprising gurnard (*Triglidae)*, "ray backs" (*Batoidea*), and lesser-spotted dogfish (*Scyliorhinus canicula*).

2.6. Data analysis

Data from all pot configurations for Experiment 1 deployed in alternating treatments (A-D) were combined for a four-level treatment comparison of catch levels of scallops, brown crabs, European lobsters and crawfish, and European spider crabs. Each species was considered separately with a metric of effort created to standardise catch levels for soak time and number of pots for both experiments. The metric created was "pot days" generated by using the equation: ((soak time in hours/ number of pots in a string) * number of pots deployed) to create a measure of catch per pot per 24-h.

Four models per experiment were considered to test whether pot configuration (treatment) influenced the number of individuals of each species caught (response variable = number of individuals). All models included the fixed effect of pot configuration and an offset of logged pot days to model the rate of individuals per pot per 24-h. Due to overdispersion, negative binomial generalised linear models (GLMs) were fitted using the glmmTMB package in R v4.0.2 (Brooks et al., 2017; R Core Team, 2020). Where partial or complete separation occurred - when the outcome variable separates a predictor variable or a combination of predictor variables (scallop catch data, due to some levels of treatment only containing zeros) a Bayesian generalised linear model was fitted via the *BhGLM* package (Yi et al., 2019). Bayesian generalised linear models were applied due to evidence for weakly informative default prior distributions overcoming this issue in regression models (Gelman et al., 2008), and resulted in a global models for each species group being created with the following structures:

Generalised linear model:

glmmTMB(Number of individuals ~ treatment + offset(log(pot days), data = data, family = nbiom2).

Bayesian generalised linear model:

bglm(Number of individuals ~ treatment + offset(log(pot days)), data = data, family = NegBin, prior = Student(mean = 0, scale = 0.5, df = 1, autoscale = TRUE)).

Spatial autocorrelation was examined via a Moran's I test for distance based autocorrelation, calculated on simulated residuals from each model using the *testSpatialAutocorrelation* function in the *DHARMa* package (Hartig, 2020), where unique latitudes and longitudes of deployments were used to calculate distances. Temporal autocorrelation was tested using a Durbin-Watson test on the scaled residuals from each model against time, where unique decimal dates of string deployment used as times implemented through the *testTemporalAutocorrelation* function in the *DHARMa* package (Hartig, 2020). A comparison of the observed number of zeros and the expected number of zeros were tested from simulated residuals from each model to detect zero-inflation using the *testZeroInflation* function in the *DHARMa* package (Hartig, 2020). Diagnostic checks of model residuals were conducted inspecting dispersion using a nonparametric dispersion test of residuals fitted vs. simulated residuals via the *testDispersion* function in the *DHARMa* package (Hartig, 2020), and uniformity via visually inspecting QQ plots of model residuals via the *testUniformity* function in the *DHARMa* package (Hartig, 2020). To generate the top model set, the dredge function from the *MuMIn* package was used (Barton, 2018), with all combinations of terms (i.e. with and without the fixed effect of treatment) examined and ranked by small sample size Akaike information criterion (AICc) or Quasi-Akaike information criterion values when overdispersion remained (QAICc; Burnham and Anderson, 2002; Harrison et al., 2018). Top ranked models were defined as models $\Delta AIC \leq 6$ units of the best supported model, after excluding further models where a simpler model attained stronger weighting ("nesting rule"; Richards et al., 2011), with weights renormalised after this subsetting to equal a sum of one. Cohen's *d* effect sizes of pairwise comparisons were obtained for the categorical fixed effect of treatment using the *eff_size* function in the *emmeans* package (Lenth, 2021). To visualise results, predictions of means and standard errors were calculated from the top models using the *predict* function from the *stats* package (R Core Team, 2020).

3. Results

Between December 2020 and January 2021, a total of 77 hauls were carried out, deploying 1886 pots of six treatment types (A; n = 300, B; n = 300, C; n = 325, D; n = 325, E; n = 276, and F; n = 360). Pot deployment depth remained relatively constant throughout the study at 65 m (+/- 1 m) and mean soak times across treatments ranged between 4.3 and 5.2 days (Table 1). All treatments with lights (B, D, and F) caught scallops, and of the 518 scallops recorded, 99.6% (n = 516) were in illuminated pots. Of the treatments with lights, 52% of scallops (n = 267) were caught by treatment F (50% above MLS), 29% (n = 149) by treatment D (52% above MLS), and 19% (n = 100) by treatment B (56% above MLS). Treatment F (adapted parlour pot with lights and double ramps) caught scallops most effectively, with a maximum rate of 19 scallops per string per 24-h (mean = 3.81), followed by treatment B (pot with lights) with a maximum catch rate of 12.75 scallops per string per 24-h (mean = 2.36), followed by treatment D (pot with lights and ramp) with a maximum catch rate of 9.50 scallops per string per 24-h (mean = 2.58; Table 2). The maximum number of scallops caught in a single pot was 24 (treatment F), and the maximum number of scallops caught in a string of 25 pots was 67 (see Supplementary Plate S2). Incidences of in-pot predation of scallops were low with 12 individuals (2.3% of scallop total) recorded across the 3 illuminated treatments (B, D and F).

In addition to scallops, 1875 brown crabs, 731 European spider crab, 66 European lobster, 3 crawfish, and 110 fish from 14 species were recorded (Table 2). Unmodified parlour pots (treatment E) had the highest catch rate (retained and discarded) of brown crab with a

Table 2
Summary results of catch rates for each experiment and species group of interest, displayed as mean ± sd (range) for catch rates per string per day.

Experiment	Treatment	Treatment description	European king scallops		Brown crab		Spider crab		Lobster & crawfish		Fish & cephalopods	
			n caught (n retained)	Rate (quantity string^{-1} 24-h^{-1})	n caught (n retained)	Rate (quantity string^{-1} 24-h^{-1})	n caught (n retained)	Rate (quantity string^{-1} 24-h^{-1})	n caught (n retained)	Rate (quantity pot^{-1} 24-h^{-1})	n caught (n retained)	Rate (quantity string^{-1} 24-h^{-1})
1	A	Pot	0 (0)	–	300 (95)	9.67 ± 11.95 (1.25–46.00)	60 (9)	1.70 ± 1.84 (0.00–6.00)	12 (6)	0.33 ± 0.49 (0.00–1.33)	5 (0)	0.07 ± 0.15 (0.00–0.50)
	B	Pot + light	100 (56)	2.36 ± 3.66 (0.00–12.75)	307 (88)	9.25 ± 10.85 (2.75–43.00)	188 (35)	5.27 ± 3.21 (0.70–12.00)	5 (3)	0.19 ± 0.34 (0.00–1.00)	22 (0)	0.56 ± 1.00 (0.00–3.50)
	C	Pot + ramp	2 (0)	–	118 (33)	3.31 ± 4.16 (0.00–12.75)	20 (2)	0.74 ± 1.21 (0.00–4.00)	5 (0)	0.12 ± 0.19 (0.00–0.50)	4 (0)	0.03 ± 0.11 (0.00–0.40)
	D	Pot + light + ramp	149 (77)	2.58 ± 2.70 (0.00–9.50)	194 (50)	5.84 ± 6.05 (0.29–19.00)	41 (20)	1.08 ± 1.18 (0.00–3.00)	2 (1)	–	8 (0)	0.29 ± 0.59 (0.00–2.00)
2	E	Parlour pot	0 (0)	–	560 (134)	20.70 ± 26.94 (3.76–97.04)	296 (126)	11.87 ± 10.92 (0.73–39.65)	34 (17)	0.99 ± 0.84 (0.00–2.61)	56 (0)	1.65 ± 1.27 (0.00–4.17)
	F	Parlour pot + light + ramp	267 (134)	3.81 ± 4.90 (0.00–19.00)	396 (117)	8.01 ± 9.80 (0.00–40.00)	126 (70)	2.94 ± 3.03 (0.00–11.00)	11 (7)	0.16 ± 0.25 (0.00–0.67)	15 (0)	0.27 ± 0.31 (0.00–1.00)

maximum of 97.04 crabs per string per 24-h (mean = 20.70). This was followed by the unmodified pots (treatment A) which had a maximum catch rate of 46 brown crabs per string per 24-h (mean = 9.67).

Unmodified parlour pots (treatment E) had the highest catch rates (retained and discarded) for spider crab with a maximum of 39.65 crabs per string per 24-h (mean = 11.87). This was followed by pots with lights (treatment B) which had a maximum catch rate of 12 spider crabs per string per 24-h (mean = 5.27; Table 2). Catch rates of lobster and crawfish, and fish and cephalopods were very low (Table 2).

Mean scallop shell length was 97 ± 19 mm (range: 53–137 mm), with 52% larger than MLS. Mean carapace width of brown crab was 142 ± 24 mm (range: 53–230 mm), with 28% larger than MLS. Mean spider crab carapace length was 126 ± 13 mm (range: 80–186 mm) with 36% larger that MLS. Mean lobster carapace length was 103 ± 16 mm (range: 67–151 mm), with 52% larger than MLS (Fig. 2).

No evidence of spatial autocorrelation, temporal correlation, or zero-inflation was detected from diagnostic tests ($p = >0.05$; Table S1).

3.1. Experiment 1: Effects of light and or pot modification on scallop catch

The number of scallops caught was shown to be influenced by pot configuration in Experiment 1 (Table 3), with large effect sizes between treatments B and D when compared to other configurations (Fig. 3). Both pots with lights (treatment B), and pots with lights and ramps (treatment D) caught increased numbers of scallops (Fig. 3), with unmodified pots (treatment A) not catching any scallops across all deployments, and pots with just ramps (treatment C) only catching two scallops across all deployments (Fig. 3). Pot configuration was also shown to influence the catch rate of spider crabs, with pots with lights (treatment B) catching individuals at a greater rate (Fig. 3). Whilst pot configuration was not retained in the top model in Experiment 1, effect sizes showed larger catch rates for unmodified pots (treatment A) and pots with lights (treatment B) when compared to other treatments for both brown crabs, and unmodified pots (treatment A) compared to lights and ramps (treatment D) for lobster and crawfish (Fig. 3).

3.2. Experiment 2: Augmenting crustacean fisheries with scallops using modified parlour pots

Parlour pot configuration was shown to influence catch rates of scallops, lobster and crawfish, and spider crabs (Table 3; Fig. 4). Effect sizes between treatments of parlour pots with lights and ramps (treatment F) compared to parlour pots, with lights and ramps (treatment E) were extremely large for scallop catch, with unmodified parlour pots (treatment E) not catching any scallops across all deployments (Fig. 4). Spider crabs, and lobster and crawfish were shown to be caught more frequently in unmodified parlour pots (treatment E; Fig. 4). Parlour pot configuration was not retained in the top model for brown crab in Experiment 2, although effect sizes between treatments show evidence of increased catch rates in unmodified parlour pots (treatment E; Fig. 4).

4. Discussion

The results from this study have shown, for the first time, that scallops can be attracted and caught in illuminated crustacean pots. This is the first study of its kind to investigate and demonstrate that the previously described phototaxis in scallops provides an opportunity to develop a new capture method. We reveal that when light is used alongside bait, scallops can augment crab and lobster catches without costly modifications to existing gear, although with the current pot designs, slightly fewer commercially important crustacean species were retained, highlighting the need for further work to improve pot design. These novel findings present fishers and marine managers with an exciting opportunity for the development of a new, low impact scallop fishery.

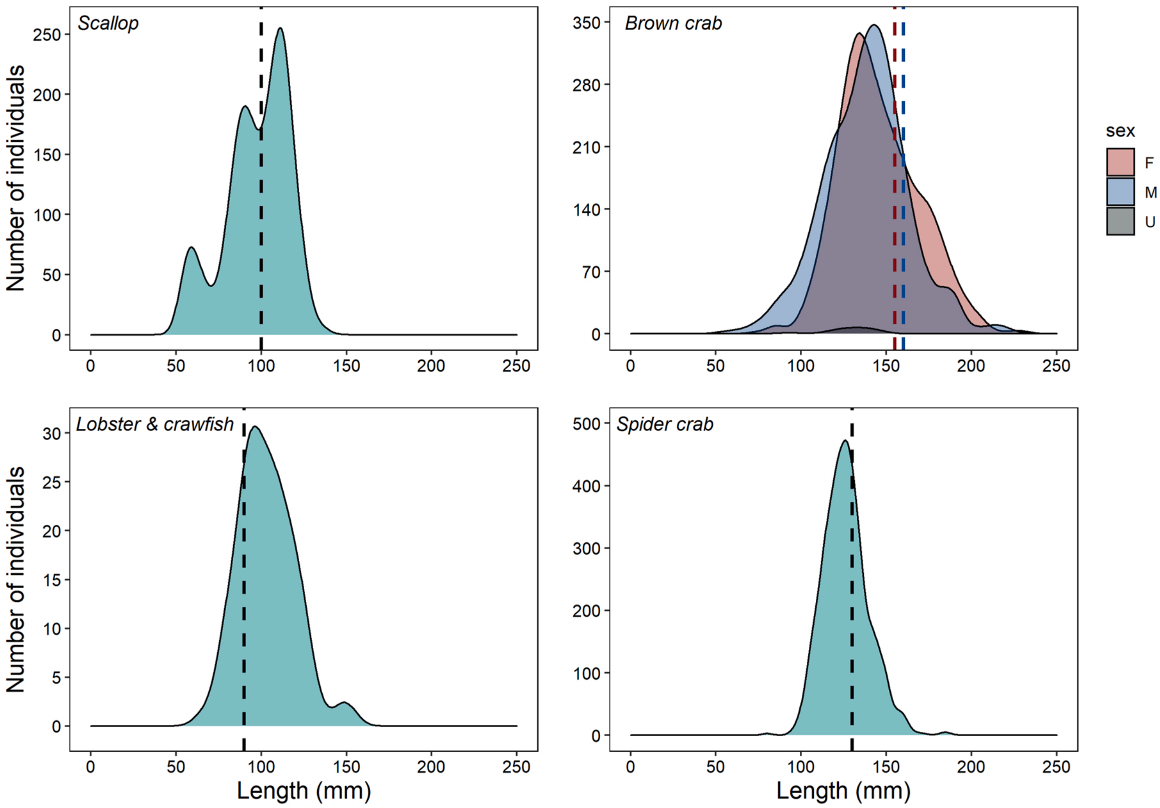

Fig. 2. Distribution of lengths (mm) for individuals caught for each species. Minimum landing sizes (MLS) for each species denoted by the dashed black line; for brown crab sex specific MLS exist denoted by coloured density plots and corresponding dashed lines. M=Male, F=Female and U=unsexed.

Table 3
Summary results of negative binomial generalised linear models (GLMs) for each experiment and species group of interest. Top ranked models and adjusted weights (Adj. Weight) after selection for ΔAIC ≤ 6 and applying the nesting rule are shown.

Treatments	Response	Fixed effects	Intercept	d.f	logLik	AICc	Adj. Weight
Experiment 1: A + B + C + D	*Total number of scallops*	~ treatment + log(offset(number of pots day^{-1}))	-6.92	5	-84.32	180.01	1.00
	Total number of brown crab	~ log(offset(number of pots day^{-1}))	-1.31	2	-205.65	415.56	1.00
	Total number of lobster and crawfish	~ log(offset(number of pots day^{-1}))	-5.19	2	-49.71	103.68	1.00
	Total number of spidercrab	~ treatment + log(offset(number of pots day^{-1}))	-2.70	5	-136.65	284.66	1.00
Experiment 2: E+F	*Total number of scallops*	~ treatment + log(offset(number of pots day^{-1}))	-8.18	3	-55.56	118.15	1.00
	Total number of brown crab	~ log(offset(number of pots day^{-1}))	-0.58	2	-130.28	31.67	1.00
	Total number of lobster and crawfish	~ treatment + log(offset(number of pots day^{-1}))	-3.27	3	-43.76	94.56	1.00
	Total number of spidercrab	~ treatment + log(offset(number of pots day^{-1}))	-0.72	3	-105.91	218.86	1.00

4.1. Experiment 1: Effects of light and or pot modification on scallop catch

Pots without lights (treatments A and C) caught only two scallops throughout the entire study, whereas pots with lights (treatments B and D) caught 249 scallops (100 and 149 scallops respectively). These findings highlight the potential for using LED lights to attract and retain scallops in commercial pot fisheries.

Evidence for the impact of lights on crustacean catch rates was mixed, with spider crabs being caught more frequently in illuminated pots (treatment B), which is consistent with studies of snow crab, a species from the same family as European spider crabs, showing increased catch using LED lights (Nguyen et al., 2017).

There was a trend for increased catch in the unmodified pots (treatment A), and pots with lights (treatment B) for brown crab, and in unmodified pots (treatment A) for lobster and crawfish. Pots with lights and a ramp (treatment D), designed specifically to enhance scallop retention (and not to retain crustacean), performed only marginally better with respect to scallop catch rates than the standard pot with light (treatment B) with observed catch rates of 2.58 (± 2.70) and 2.36 (± 3.66) scallops per string per 24-h respectively. Results indicate that the "ramp and retainer" design adds little value over a standard illuminated pot (with respect to scallop retention) but also, as expected, reduced catch rates of other commercial species.

4.2. Experiment 2: Augmenting crustacean fisheries with scallops using modified parlour pots

Observations during the fishing scenario (Experiment 2) met our predictions that the unmodified parlour pots (treatment E) would not catch any scallops but performed as usual for catching targeted commercial species. Parlour pots with lights and ramps (treatment F) had the highest scallop catch rate (19 scallops per string per 24-h) but also showed the largest decline in catch rates for brown crab, spider crabs, and lobster and crawfish. This shows modifications to operational fishing gear under normal fishing activities can increase catch of scallops, but, if the trap is not designed appropriately (as in this experiment), there will be a trade off with other commercially important species to consider such as the ability for mobile crustaceans to exit the pots once caught due to the addition of ramps.

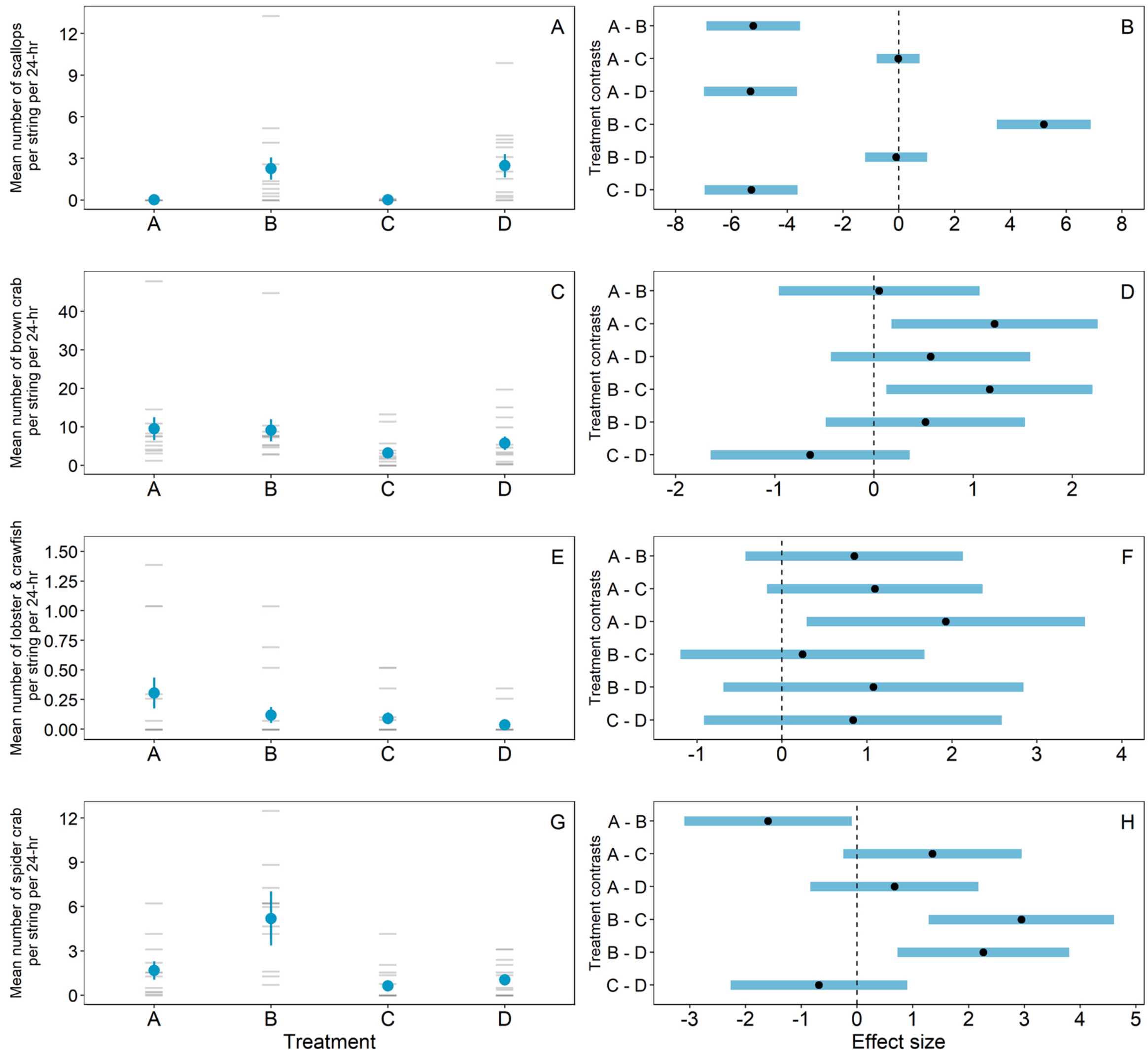

Fig. 3. Mean number of individuals caught per 24-h (multiplied from single pot up to mean number of pots per string; n = 25 pots) for treatments of pot configuration in Experiment 1. Treatment configuration labels; A = unmodified pot (control), B = pot with lights, C = pot with ramp, and D = pot with lights and ramps. Predicted mean estimates (filled blue circles), and standard error (se; solid blue lines) from GLM presented for each model of species catch with grey dashes denoting raw catch rates for each species (panels A, C, E, and G). Standardised effect sizes (Cohen's *d*; black filled circles) and 95% confidence intervals (blue bars) for all combinations of treatment types for each species (panels B, D, F, and H). Note panels are on different scales.

4.3. Scallop behaviour

The mechanism by which scallops are attracted to illuminated pots is not fully understood, however, it is likely that the stimulus is visual. Scallops have between a dozen to several hundred image-forming eyes located on the mantle margins of their valves (Speiser and Wilkens, 2016). These eyes are sensitive to both motion (to enhance feeding opportunities; Speiser and Johnsen, 2008) and light intensity (to detect approaching predators; Land (1966) and/or enable location of preferred forms of shelter; Von Buddenbrock and Moller-Racke (1953)). As such, we hypothesise that their movement into the illuminated pots is to move to preferential feeding habitat due to increased biotic life at the light source. Anecdotally, in support of a visual hypothesis, it was noted by the fisherman conducting the experiment that, following winter storm events when water was more turbid, reducing visibility, scallop catches were lower, suggesting that light attenuation from the pots could have been inhibited by the water turbidity. Meteorological conditions and turbidity should be measured in situ for future trials to determine any effect of these factors on catch rates. It was also noted that in illuminated pots there was an increase in pistol shrimps (*Alpheus glaber*) when hauled. Sensitivity to sound waves is described in scallops (Helm et al., 2004), and although unlikely, there is potential for sound waves created from pistol shrimps (190–210 dB; Versluis et al., 2000) stunning their zooplankton prey (also attracted to the illuminated pots Humborstad et al., 2018; Utne-Palm et al., 2018) that could have enticed the scallops in to the pots.

4.4. Environmental opportunities

Static fishing gear is often considered lower impact with respect to marine benthic habitats (Coleman et al., 2013; Eno, 2001; Stephenson et al., 2017) and far less damaging than mobile demersal gears (Sewell and Hiscock, 2005). Blyth et al. (2004) compared the impact of towed and static fishing gear on benthic communities in a zoned commercial fishery management area also off the south coast of England (an area which spatially separates towed and static gears to avoid conflict). Benthic communities in the area open only to static gears were richer and hosted greater biomass than those in areas that were subjected to towed fishing gears during the same period. A qualitative assessment of different gear types with the aim of identifying "responsible fishing methods" described potting as "more responsible" compared to (i) dredging for impact on habitat, (ii) energy cost per/kg fish caught, and

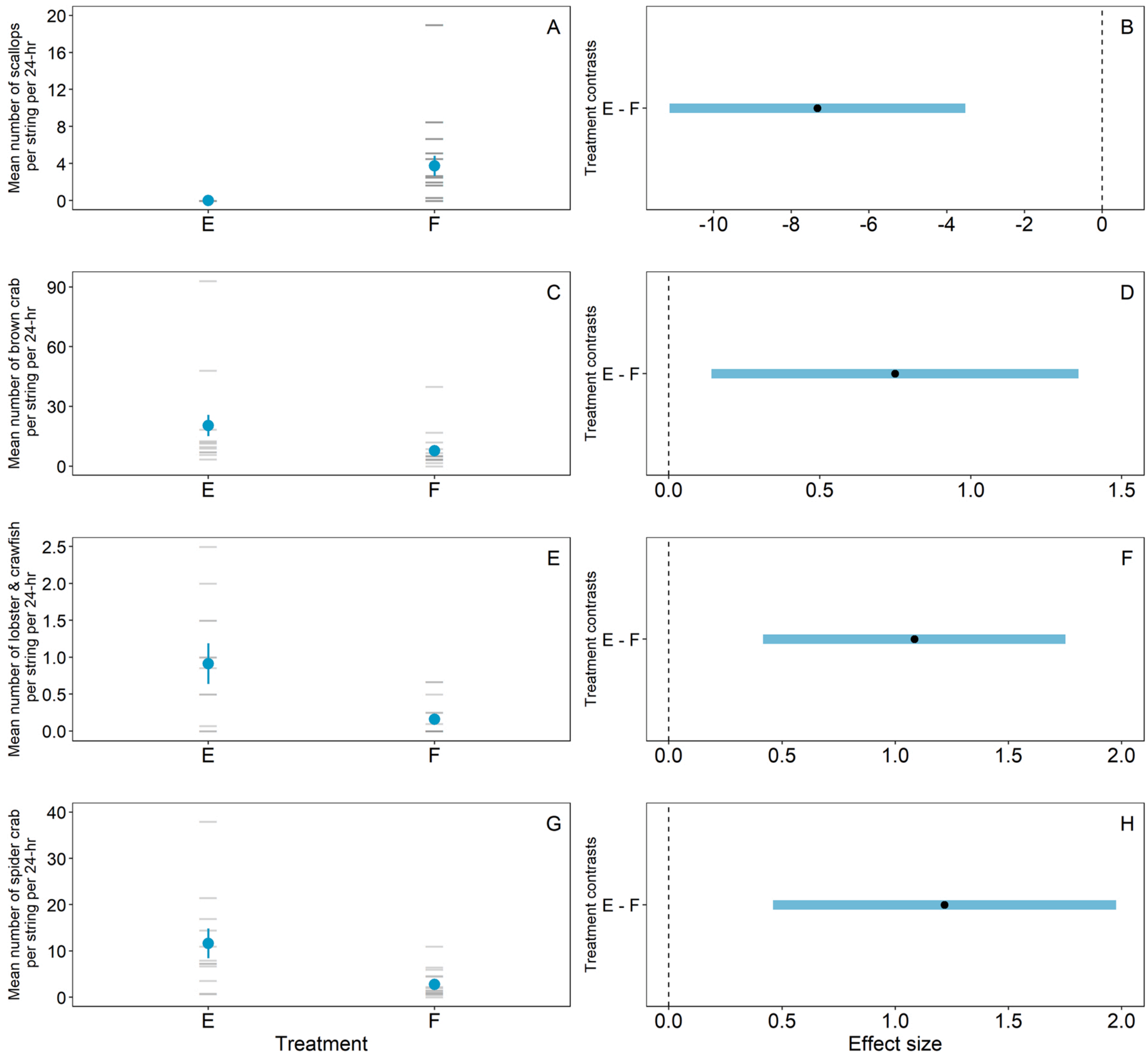

Fig. 4. Mean number of individuals caught per 24-h (multiplied from single pot up to mean number of pots per string; n = 24 pots) for treatments of pot configuration in Experiment 2. Treatment configuration labels; E = unmodified parlour pot (control), and F = parlour pot with lights and ramp. Predicted mean estimates (filled blue circles), and standard error (se; solid blue lines) from GLM presented for each model of species catch with grey dashes denoting raw catch rates for each species (panels A, C, E, and G). Standardised effect sizes (Cohen's *d*; black filled circles) and 95% confidence intervals (blue bars) for all combinations of treatment types for each species (panels B, D, F, and H). Note panels are on different scales.

(iii) levels of non-commercial bycatch (ICES, 2006). However, if scallop potting develops into a commercial proposition for fishers, it should be developed carefully. Gall et al. (2020) raised concern over potting impacts on the marine environment, and a recent study by Rees et al. (2021) highlighted, in the absence of effort-based management for commercial potting, the importance of managing potting density and reported that high levels of pot fishing effort had negative effects on reef building epibiota and commercially targeted species. Likewise, it will be important to consider other potential issues such as ghost fishing by lost pots (Bullimore et al., 2001) and any risk of entanglement with marine mammals (Stevens, 2021). Furthermore, it may also be appropriate to consider controls or limits on any potential scallop pot fishery when setting current or future harvest levels.

Initially, it is likely that fishers will seek to augment their existing crustacean catches with scallop, rather than targeting scallops with pots as an entirely new stand-alone fishery. This will be an important feature in achieving a sustainable, low-impact scallop fishery. If scallop potting is to have a lower environmental footprint than dredge-caught scallops, any development of the fishery following this work must ensure management measures are in place to prevent uncontrolled growth in static fishing effort and that scallop catch rates are within sustainable limits. This could be particularly important in Marine Protected Areas which have developed substantial scallop populations and which allow potting, but are off limits to dredges (e.g. Stewart et al., 2020).

With appropriate management and enforcement, a scallop augmented crustacean fishery has the potential to reduce impacts on marine habitats relative to traditional dredge-caught scallops. Where possible, opportunities to shift to gear types that reduce the penetrative impacts of fishing on the seabed will facilitate governments in meeting a number of the United Nations Sustainable Development Goals; in particular, goals 12 (Responsible consumption and production), 13 (Climate action), and 14 (Life below water; FAO, 2011, 1995).

4.5. Industry opportunities

To date, there have been considerable barriers for inshore fishers to access scallop fisheries in the UK. Notwithstanding the significant outlay costs (e.g. new gear, increased engine size, increased winch power, etc.), the nomadic nature of the larger offshore scallop dredgers, present inshore vessel operators with an investment risk. Fishing opportunities for inshore vessels are limited due to weather and, more importantly, by their range, with grounds close to home ports forming the basis of income. However, unless prevented by regulation, inshore scallop beds can be readily fished by nomadic vessels from distant ports, which potentially reduces economic viability of scallop fishing for inshore vessels (Cappell et al., 2018). Our findings, if developed appropriately, offer inshore fishers the opportunity to engage in scallop fisheries with little financial outlay or risk. The methods presented here are scalable and relatively easy for current fishers to adapt their existing gear. As this new fishing method develops over time (e.g. light design, pot design, shooting method) from its current embryonic baseline, improvements to scallop catch rates are likely to manifest which will facilitate fishers' Return On Investment e.g. outlay (lights and modified traps) and running costs (batteries). Moreover, pot-caught scallops are likely to have 2–2.5 times greater price premium compared to dredge-caught scallops (Holmyard, 2015) and the value of pot-caught scallops should be comparable in price to hand-dived scallops because of their similar environmental and quality credentials. Operationally, in comparison to dive-caught scallops, scallop pots will be able to be deployed in deeper waters and in more inclement weather conditions that would be dangerous or impossible for divers.

With 38% of UK waters designated within Marine Protected Areas and the rapid growth of Offshore Wind Farms (OWF), fishers (towed gear in particular) are facing a cumulative spatial encroachment on traditional fishing grounds (Gray et al., 2016). However, based on our findings, illuminated pots could offer fishers an opportunity to catch scallops inside some Marine Protected Areas and around OWFs where mobile gears are no longer permitted or unable to fish (Cappell et al., 2018; Gray et al., 2016).

Increasingly, consumers, retailers and their supply chains demand lower impact methods of fishing. Since March 2021, European corporations have been incentivised to report strong Environmental, Social and Corporate Governance (ESG) credentials in their annual accounts to prevent divestment from fund managers under the EU Sustainable Finance Disclosure Regulations (European Commission, 2019). "Sustainable use and protection of water and marine resources", a mandatory indicator of the Environmental Objective states that (under article 12.1d of EU supplementing regulation 2020/852) corporates must contribute to the Good Environmental Status (GES) of European marine waters. The UK Government highlighted shellfish fishing using trawls as one of the main pressures preventing the achievement of GES (DEFRA, 2019). For retail corporations in Europe intent on achieving high ESG scores (and thus investment), it is likely that seafood procurement will shift away from damaging fishing methods and gravitate towards lower impact forms of fishing, such as the potential scallop potting method outlined here.

4.6. Further work

The findings in this work give rise to the potential to augment current crustacean pot fisheries with additional scallop catch, and to develop new scallop pot fisheries with a relatively low environmental impact. Despite conducting these experiments on grounds not known for their scallops, and at a time of year when the crustacean season was ending, illuminated parlour pots demonstrated the highest catch rates of scallop. Whilst the catch rates of commercial crustaceans were slightly lower in this pot design than the unmodified parlour pot, there are some simple modifications to the design that would likely achieve similar retention levels of commercial crustaceans to the unmodified parlour pot, but also enable augmentation of the catch with high value scallops. Any attempt to analyse scallop catch rates or undertake any economic comparisons with respect to other scallop fishing methods (dredges, trawls and diving) would be too premature for this manuscript. Priority for further work must be placed on optimising the pot design to better retain crustaceans and developing a bespoke pot light for this fishing method.

A white light was chosen in these experiments simply on the basis that this colour was used when the initial anecdotal observation was recorded. Speiser et al. (2011) documented that the photoreceptors of scallops are most sensitive to greener wavelengths and that environmental conditions may influence the wavelengths to which scallops are sensitive (Speiser and Wilkens, 2016). Additional insight is needed to establish whether other light colours can further increase the attraction of scallops into the pots. Further work will be needed to establish how different wavelengths of light in the illuminated pots impact catch rates of the other commercially important species. For example, Nguyen et al. (2019) showed that purple wavelengths of light increased snow crab CPUE in a Barents Sea pot fishery whereas white wavelengths had no notable effect on snow crab CPUE. Operationally, it would be highly advantageous to attract scallops using a flashing light as this would increase battery life (proportionally to the reduction in duty cycle) and thus running costs (and time-consuming battery changes). Further work is required to investigate the impacts that varying duty cycles (flash rates) would have on scallop and target catch retention.

Light intensity is likely to be important factor, as is turbidity. To this end, further work is required to understand the viability of scallop potting in different regions with varying turbidity. We also recommend that trials are undertaken in different geographical areas with different environmental conditions (e.g. depth, temperature, substrate, currents), including areas where scallops are known to exist in high density.

Pot illumination may also reduce landing value in certain fisheries. For example, a UK crustacean fisherman of 30 years mentioned that pots containing spider crab (low value), will not harvest lobster (high value; *pers. comm.* Chris Martin). This has important economic implications for illuminated pots designed to retain scallop but that have been shown to increase spider crab retention by up to 200%. Further work is required to investigate these relationships and if necessary, limit trap illumination for scallops to seasons/areas where spider crabs are absent. Similarly, research in Scotland found inverse relationships between catch rates of lobsters and other crustacean species (Howarth et al., 2016).

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: RE, PD & PK are employees of Fishtek Marine Ltd who manufacture the PotLights used in this study.

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CRediT authorship contribution statement

Robert Enever: Conceptualization, Methodology, Validation, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Jon Ashworth:** Conceptualization, Methodology, Investigation, Data curation. **Brendan J. Godley:** Methodology, Writing – review & editing, Supervision. **Philip D. Doherty:** Methodology, Software, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Melanie Parker:** Writing – original draft. **Mark Duffy:** Writing – review & editing. **Bryce D. Stewart:** Writing – review & editing. **Pete Kibel:** Writing – review & editing.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.fishres.2022.106334.

References

Barton, K., 2018. MuMIn: Multi-Model Inference. R Package version 1.42.1: ⟨https://CRAN.R-project.org/package=MuMIn⟩.

Blyth, R.E., Kaiser, M.J., Edwards-Jones, G., Hart, P.J.B., 2004. Implications of a zoned fishery management system for marine benthic communities. J. Appl. Ecol. 41, 951–961. https://doi.org/10.1111/j.0021-8901.2004.00945.x.

Brand, A.R., 2006. Chapter 12 Scallop ecology: distributions and behaviour. Dev. Aquac. Fish. Sci. 35, 651–744. https://doi.org/10.1016/S0167-9309(06)80039-6.

Brooks, M.E., Kristensen, K., van Benthem, K.J., Magnusson, A., Berg, C.W., Nielsen, A., Skaug, H.J., Mächler, M., Bolker, B.M., 2017. glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. R. J. 9, 378–400. https://doi.org/10.32614/rj-2017-066.

Bryhn, A.C., Königson, S.J., Lunneryd, S.G., Bergenius, M.A.J., 2014. Green lamps as visual stimuli affect the catch efficiency of floating cod (Gadus morhua) pots in the Baltic Sea. Fish. Res. 157, 187–192. https://doi.org/10.1016/j.fishres.2014.04.012.

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

Burnham, K.P., Anderson, D.R., 2002. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach, 2nd ed. Springer.

Caddy, J.F., 1968. Underwater observations on scallops (placopecten magellanicus) behaviour and drag efficiency. J. Fish. Res. Board Can. 25, 2123–2141. https://doi.org/10.1139/f68-189.

Cappell, R., Huntington, T., Nimmo, F., MacNab, S., 2018. The UK Scallop Fishery Current trends, future management options and recommendations Final report.

Coleman, R.A., Hoskin, M.G., von Carlshausen, E., Davis, C.M., 2013. Using a no-take zone to assess the impacts of fishing: sessile epifauna appear insensitive to environmental disturbances from commercial potting. J. Exp. Mar. Biol. Ecol. 440, 100–107. https://doi.org/10.1016/j.jembe.2012.12.005.

Colicchia, G., Waltner, C., Hopf, M., Wiesner, H., 2009. The scallop's eye - a concave mirror in the context of biology. Phys. Educ. 44, 175–179. https://doi.org/10.1088/0031-9120/44/2/009.

DEFRA, 2019. Marine strategy part one: UK updated assessment and Good Environmental Status, Marine Monitoring and Assessment Strategy (UKMMAS).

Duncan, P.F., Brand, A.R., Strand, Ø., Foucher, E., 2016. The European Scallop Fisheries for Pecten maximus, Aequipecten opercularis, Chlamys islandica, and MimaChlamys varia. In: Developments in Aquaculture and Fisheries Science. Elsevier, pp. 781–858. https://doi.org/10.1016/B978-0-444-62710-0.00019-5.

Eno, N., 2001. Effects of crustacean traps on benthic fauna. ICES J. Mar. Sci. 58, 11–20. https://doi.org/10.1006/jmsc.2000.0984.

European Commission, 2019. Regulation (EU) 2019/2088 of the European Parliament and of the Council of 27 November 2019 on sustainability-related disclosures in the financial services sector (Text with EEA relevance). . J. Eur. Union.

, 2021FAO, 2021. FishStat Plus - Universal sorftware for fisheries statistical time series.

FAO, 2011. International Guidelines on Bycatch Management and Reduction of Discards. Rome, Italy.

FAO, 1995. Code of Conduct for Responsible Fisheries, Review of the State of World Fishery Resources: Marine Fisheries. Rome: Food and Agriculture Organization, Rome, Italy.

Gall, S.C., Rodwell, L.D., Clark, S., Robbins, T., Attrill, M.J., Holmes, L.A., Sheehan, E.V., 2020. The impact of potting for crustaceans on temperate rocky reef habitats: implications for management. Mar. Environ. Res. 162, 105134 https://doi.org/10.1016/j.marenvres.2020.105134.

Gelman, A., Jakulin, A.,Pittau, M.G., Su, Y.S., 2008. A weakly informative default prior distributionfor logistic and other regression models. 2,1360–1383. ⟨https://doi.org/10.1214/08-AOAS191⟩.

Gray, M., Stromberg, P.-L., Rodmell, D., 2016. Changes to fishing practices around the UK as a result of the development of offshore windfarms-Phase 1.

Gubbay, S., Knapman, P.A., 1999. A review of the effects of fishing within UK European marine sites. UK Mar. SACs Proj.

Hamilton, P.V., Koch, K.M., 1996. Orientation toward natural and artificial grassbeds by swimming bay scallops, *Argopecten irradians* (Lamarck, 1819). J. Exp. Mar. Biol. Ecol. 199, 79–88. https://doi.org/10.1016/0022-0981(95)00191-3.

Harrison, X.A., Donaldson, L., Correa-Cano, M.E., Evans, J., Fisher, D.N., Goodwin, C.E.D., Robinson, B.S., Hodgson, D.J., Inger, R., 2018. A brief introduction to mixed effects modelling and multi-model inference in ecology. PeerJ 6, e4794.

Hartig, F., 2020. DHARMa: Residual Diagnostics for Hierarchical (Multi-Level/Mixed) Regression Models. R. Package Version 0.3.3 0. ⟨https://CRAN.R-project.org/package=DHARMa⟩.

Helm, M.M., Bourne, N., Lovetail, A., 2004. The hatchery culture of bivalves: a practical manual. Mar. Biol. 15, 350–355.

Hinz, H., Murray, L.G., Malcolm, F.R., Kaiser, M.J., 2012. The environmental impacts of three different queen scallop (Aequipecten opercularis) fishing gears. Mar. Environ. Res. 73, 85–95. https://doi.org/10.1016/j.marenvres.2011.11.009.

Holmyard, N., 2015. Ranching in Scotland brings hope for scallops future [WWW Document]. URL ⟨https://www.seafoodsource.com/features/ranching-in-scotland-brings-hope-for-scallops-future⟩.

Howarth, L.M., Dubois, P., Gratton, P., Judge, M., Christie, B., Waggitt, J.J., Hawkins, J.P., Roberts, C.M., Stewart, B.D., 2016. Trade-offs in marine protection: multispecies interactions within a community-led temperate marine reserve. ICES J. Mar. Sci. 74, 263–276.

Howell, T.R.W., 1989. The response of juvenile Pecten maximus (L.) to light and water currents. Int. Counc. Explor. Sea 7, 1–10.

Humborstad, O.B., Utne-Palm, A.C., Breen, M., Løkkeborg, S., Pol, M., 2018. Artificial light in baited pots substantially increases the catch of cod (Gadus morhua) by attracting active bait, krill (Thysanoessa inermis). ICES J. Mar. Sci. 75, 2257–2264. https://doi.org/10.1093/ICESJMS/FSY099.

ICES, 2016. Report of the Scallop Assessment Working Group (WGScallop), ICES CM 2015/ACOM. Trinity, Jersey.

ICES, 2006. Report of the ICES-FAO Working Group on Fishing Technology and Fish Behaviour (WGFTFB). Izmir, Turkey.

Kaiser, M.J., Collie, J.S., Hall, S.J., Jennings, S., Poiner, I.R., 2001. Impacts of fishing gear on marine benthic habitats, in: Reykjavik Conference on Responsible Fisheries in the Marine Ecosystem. Reykjavik, Iceland.

Land, M.F., 1966. Activity in the Optic Nerve of *Pecten maximus* in Response to Changes in LightIntensity, and to Pattern and Movement in the Optical Environment. J. Exp. Biol. Co. Biol. https://doi.org/10.1242/JEB.45.1.83.

Lenth, R., 2021. emmeans: Estimated mariginal means, aka least-squares means. R package version 1.5.4. ⟨https://CRAN.R-project.org/package=emmeans⟩.

Marchesan, M., Spoto, M., Verginella, L., Ferrero, E.A., 2005. Behavioural effects of artificial light on fish species of commercial interest. Fish. Res. 73, 171–185. https://doi.org/10.1016/j.fishres.2004.12.009.

Minchin, D., Mathers, N.F., 1982. The escallop, *Pecten maximus* (L.), in Killary Harbour. Ir. Fish. Investig. Ser. B 25.

Nguyen, K.Q., Humborstad, O.B., Løkkeborg, S., Winger, P.D., Bayse, S.M., Pol, M., 2019. Effect of light-emitting diodes (LEDs) on snow crab catch rates in the Barents Sea pot fishery. ICES J. Mar. Sci. 76, 1893–1901. https://doi.org/10.1093/ICESJMS/FSZ062.

Nguyen, K.Q., Winger, P.D., Morris, C., Grant, S.M., 2017. Artificial lights improve the catchability of snow crab (Chionoecetes opilio) traps. Aquac. Fish. 2, 124–133. https://doi.org/10.1016/j.aaf.2017.05.001.

R Core Team, 2020. R: A language and environment for statistical computing. (R Foundation for Statistical Computing). ⟨www.R-project.org⟩.

Rees, A., Sheehan, E.V., Attrill, M.J., 2021. Optimal fishing effort benefits fisheries and conservation. Sci. Rep. 11, 3784. https://doi.org/10.1038/s41598-021-82847-4.

Richards, S.A., Whittingham, M.J., Stephens, P.A., 2011. Model selection and model averaging in behavioural ecology: the utility of the IT-AIC framework. Behav. Ecol. Sociobiol. 65, 77–89. https://doi.org/10.1007/s00265-010-1035-8.

Roman, S.A., Rudders, D.B., 2019. Selectivity Of Two Commercial Dredges Fished In The Northwest Atlantic Sea Scallop Fishery. J. Shellfish Res. 38, 573 https://doi.org/<p>10.2983/035.038.0308</p>.

Sala, E., Mayorga, J., Bradley, D., Cabral, R.B., Atwood, T.B., Auber, A., Cheung, W., Costello, C., Ferretti, F., Friedlander, A.M., Gaines, S.D., Garilao, C., Goodell, W., Halpern, B.S., Hinson, A., Kaschner, K., Kesner-Reyes, K., Leprieur, F., McGowan, J., Morgan, L.E., Mouillot, D., Palacios-Abrantes, J., Possingham, H.P., Rechberger, K. D., Worm, B., Lubchenco, J., 2021. Protecting the global ocean for biodiversity, food and climate. Nature 592, 397–402. https://doi.org/10.1038/s41586-021-03371-z.

Sewell, J., Hiscock, K., 2005. Effects of fishing within UK European Marine Sites: guidance for nature conservation agencies, Report to the Countryside Council for Wales, English Nature and Scottish Natural Heritage from the Marine Biological Association. Marine Biological Association. CCW Contract FC 73–03-214A. Plymouth, UK.

Shephard, S., Goudey, C.A., Read, A., Kaiser, M.J., 2009. Hydrodredge: reducing the negative impacts of scallop dredging. Fish. Res. 95, 206–209. https://doi.org/10.1016/j.fishres.2008.08.021.

Speiser, D.I., Johnsen, S., 2008. Comparative morphology of the concave mirror eyes of scallops (Pectinoidea)*. Am. Malacol. Bull. 26, 27–33. https://doi.org/10.4003/006.026.0204.

Speiser, D.I., Loew, E.R., Johnsen, S., 2011. Spectral sensitivity of the concave mirror eyes of scallops: Potential influences of habitat, self-screening and longitudinal chromatic aberration. J. Exp. Biol. 214, 422–431. https://doi.org/10.1242/jeb.048108.

Speiser, D.I., Wilkens, L.A., 2016. Neurobiology and behaviour of the scallop. In: Developments in Aquaculture and Fisheries Science. Elsevier, pp. 219–251. https://doi.org/10.1016/B978-0-444-62710-0.00005-5.

Stephenson, F., Mill, A.C., Scott, C.L., Polunin, N.V.C., Fitzsimmons, C., 2017. Experimental potting impacts on common UK reef habitats in areas of high and low fishing pressure. ICES J. Mar. Sci. 74, 1648–1659. https://doi.org/10.1093/icesjms/fsx013.

Stevens, B.G., 2021. The ups and downs of traps: environmental impacts, entanglement, mitigation, and the future of trap fishing for crustaceans and fish. ICES J. Mar. Sci. 78, 584–596. https://doi.org/10.1093/ICESJMS/FSAA135.

Stewart, B.D., Howarth, L.M., 2016. Quantifying and managing the ecosystem effects of scallop dredge fisheries. In: Developments in Aquaculture and Fisheries Science. Elsevier, pp. 585–609. https://doi.org/10.1016/B978-0-444-62710-0.00018-3.

Stewart, B.D., Howarth, L.M., Wood, H., Whiteside, K., Carney, W., Crimmins, É., O'Leary, B.C., Hawkins, J.P., Roberts, C.M., 2020. Marine Conservation Begins at Home: how a local community and protection of a small Bay sent waves of change around the UK and Beyond. Front. Mar. Sci. 7, 76. https://doi.org/10.3389/fmars.2020.00076.

Stokesbury, K.D.E., O'Keefe, C.E., Harris, B.P., 2016. Chapter 17 - fisheries sea scallop, Placopecten magellanicus. In: Shumway, S.E., Parsons, G.J. (Eds.), Scallops, Developments in Aquaculture and Fisheries Science. Elsevier, pp. 719–736. https://doi.org/10.1016/B978-0-444-62710-0.00016-X.

Utne-Palm, A.C., Breen, M., Løkkeborg, S., Humborstad, O.B., 2018. Behavioural responses of krill and cod to artificial light in laboratory experiments. PLoS One 13, e0190918. https://doi.org/10.1371/JOURNAL.PONE.0190918.
Versluis, M., Schmitz, B., Von der Heydt, A., Lohse, D., 2000. How snapping shrimp snap: Through cavitating bubbles. Sciences (80-) 289, 2114–2117. https://doi.org/10.1126/science.289.5487.2114.
Von Buddenbrock, W., Moller-Racke, I., 1953. Uber den lichtsinn von Pecten. Pubbl. Staz. Zool. Napoli 24, 217–245.
Warrant, E.J., Locket, N.A., 2004. Vision in the deep sea. Biol. Rev. Camb. Philos. Soc. https://doi.org/10.1017/S1464793103006420.
Wilkens, L.A., 2006. Chapter 5 Neurobiology and behaviour of the scallop. Dev. Aquac. Fish. Sci. 35, 317–356. https://doi.org/10.1016/S0167-9309(06)80032-3.
Yi, N., Tang, Z., Zhang, X., Guo, B., 2019. BhGLM: Bayesian hierarchical GLMs and survival models, with applications to genomics and epidemiology. Bioinformatics 35, 1419–1421. https://doi.org/10.1093/BIOINFORMATICS/BTY803.