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Green lamps as visual stimuli affect the catch efficiency of floating cod (*Gadus morhua*) pots in the Baltic Sea

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ABSTRACT

This study compared catches in numbers (catch per unit effort, CPUE) and biomass (weight per unit effort, WPUE) of Atlantic cod (*Gadus morhua*) in two-chambered floating cod pots equipped with and without a green lamp as a form of visual stimuli in two areas. A green lamp inside the pot increased the CPUE and WPUE of cod above the maximum legal size (>38 cm) by 74 and 80%, respectively. There were no differences in CPUE and WPUE of small (<38 cm) cod caught in pots with and without a green lamp. By increasing the catch efficiency of cod green lamps could consequently be highly beneficial for the Baltic commercial cod pot fishery.

1. Introduction

Seal-inflicted damage to fishing gear and catch losses have increased rapidly in many types of small-scale coastal fisheries along the Baltic Sea coast and have severely affected the inshore fishery (Westerberg et al., 2008; Hemmingsson et al., 2008; Bruckmeier and Höj Larsen, 2008). The gillnet fishery for Atlantic cod (*Gadus morhua*; hereafter simply referred to as cod) has, for instance, experienced an extensive surge in damage caused by grey seal (*Halichoerus grypus*) since year 2005 (Königson et al., 2009). In response to the conflict between the increasing seal population and a continued viable coastal fishery alternative, seal-safe gear, such as baited cod pots, is now under development. Pots may serve as an alternative fishing method with less seal damage and fish loss than gillnets and longlines (Königson, 2011).

The Common Fisheries Policy (CFP) as well as the Helcom Baltic Sea Action Plan promote the development of an ecosystem-based management of coastal fisheries. The use of pots in the cod fishery would contribute towards this development. In comparison to trawls and other active fishing gears, pots cause limited harm to the marine environment (Jennings et al., 2001; Thomsen et al., 2010). Suuronen et al. (2012) included pots in a compilation of LIFE (Low Impact and Fuel Efficient) fishing gear due to their low energy use, effective species selectivity, better protection against marine mammals, and low bycatch of marine mammals and seabirds, in addition to low gear construction costs. Another advantage with pots is that they can be designed to capture cod above a certain length (Königson, 2011; Ovegård et al., 2011). Another equally important reason for developing alternative fishing gear, such as pots, is that the small-scale coastal fisheries suffer from low profitability and scant addition of young fishers. A positive development such as using alternative fishing gear could include ecolabelling fish or marketing the fish as locally caught which in turn could give the fishers a higher catch value. Comparable or higher catches from an equal amount of effort provides incentives for changing from a traditional to an alternative fishery. Generally, the catch efficiency of pots has been far lower than that of other fishing gear, such as trawls (Suuronen et al., 2012). Presently there is no commercial pot fishery in the Baltic. However, experimental fishing conducted in cooperation with commercial fishermen has showed that during certain time periods pots can be as efficient as gillnet and hook fisheries in the same area (Königson and Lunneryd, 2013). The fishing efficiency of the pots is usually maintained by attracting fish to the pot using bait (Furevik and Løkkeborg, 1994; Løkkeborg, 1998), but discussions about how to further improve fishing efficiency are ongoing.

The fishing efficiency of pots is to a great extent related to fish behaviour when compared to other types of fishing gear. Pots must have the right characteristics to lure the fish to enter the pot. Cod generally approach pots slowly (Furevik, 1994) and fish sometimes

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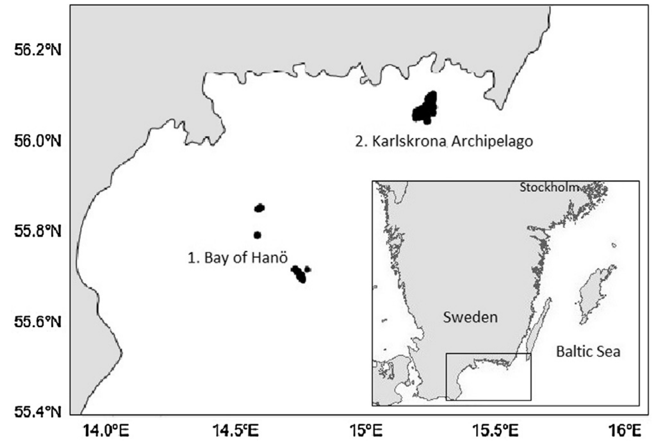

Fig. 1. Location of test fishing concerning green lamps as visual stimuli. (1) Bay of Hanö. (2) Karlskrona Archipelago. The inset map shows the location of the test sites in southern Sweden.

swim into pots for other reasons than foraging, e.g., curiosity, movement of other fish inside the pot, or protection (High and Ellis, 1973; Furevik, 1994).

It has been known for centuries that fish can be attracted, or otherwise affected, by artificial light (Hasegawa, 1993; Marchesan et al., 2005) and bright objects (Slack-Smith, 2001). Intensive light enables many fish species to distinguish food more clearly (Ben-Yami, 1988). Behaviour in relation to visual stimuli is, however, to some extent species dependent (Ben-Yami, 1988). Studies on cod have showed that farmed cod may grow more rapidly when stimulated by artificial light (Taranger et al., 2005) and cod in captivity use vision to a large degree to detect food in mid-water but use a more complex combination of senses to find food in bottom areas (Brawn, 1969). Moreover, cod vision reacts differently to different wavelengths of the photons; a primary sensitivity peak occurs at 490 nm (blue/green light) and a secondary peak at 550 nm (green/yellow; Anthony and Hawkins, 1983). These studies indicate that there is reason to hypothesise that it could be possible to increase fishing efficiency of pots by attracting cod into the pot chambers using green light as a visual stimulus.

The present study investigated whether green lamp mounted inside floating cod pots would increase the fishing efficiency (measured as the catch per unit effort, CPUE, and weight per unit effort, WPUE) of cod above and below the maximum legal size limit in two different areas. The catch efficiency from experimental cod pots was compared to the efficiency of control pots without lights that were deployed at the same sites. A unit effort is defined here as one soaking event including one two-chamber pot. The difference in CPUE and WPUE depending on soaking time was also studied and discussed.

2. Materials and methods

Experimental fishing was conducted at two locations (Bay of Hanö; 55°42′–56°00′ N and 14°41′–15°08′ E, and Karlskrona Archipelago; 56°03′–56°06′ N and 15°30′–15°34′ E) in the southern Baltic Sea in Swedish territorial waters between May 2008 and November 2010 (Fig. 1). Experiments were carried out in collaboration with two professional fishers using a two-chambered single-entrance floating cod pot described by Furevik et al. (2008) and Ovegård et al. (2011). In Karlskrona Archipelago, fishing was conducted close to the shore at an average depth of 20 m. Tests with control pots and pots modified with green underwater lamps were carried out from April 2009 to July 2010. During the first two months from April until May, 2009, ground lines with five control pots were set, at the same time and side by side to ground lines with five test pots, identically designed but including visual stimuli. Thereafter, pots were deployed in ground lines of four or eight pots along the same ground line. One to four ground lines were set during the same day (Table 1). Ground lines included the same number of randomly placed control pots as well as one type of test pots. In the Bay of Hanö, tests with 4 or 8 pots per ground line were carried out from June until November, 2010. At this site, the fishing was conducted at open sea at an average depth of 43 m. For an illustration of how ground lines and pots were used, see Ovegård et al. (2011). If any type of serious disturbance was noted when the pot was emptied, such as if the green lamp was not functioning, if the catch in control and test pots were mixed up, if there was a hole in the pot, or if the pot had been twisted around the ground line, the specific pot was excluded from the analysis. In 5% of the emptied pots such errors were recorded.

Green lamps (electric fishing light) were acquired from www.artisanalfish.com. Each lamp consisted of two LED green lights, with a peak wavelength of 523 nm (linewidth at $E_e/2 = 26$ nm). Measured maximum output intensity (E_e) was 124 μW. The size of each lamp was 120 mm × 43 mm with a power supply of 3V LR06 (2 AA). The lamps were placed by the bait bag in the middle of the pot. Only pots with functioning lamps at the end of the soaking period were included in the dataset for statistical analyses.

In both areas, each pot was baited with about 250 g of cut fresh herring. Pot soaking time was on average 3.9 days, varying from one day to nineteen days, depending on factors such as location, weather conditions, and fishing routines. Cod above and below 38 cm (minimum legal size for Baltic Sea cod) were analysed separately. From March, 2010, all pots were fitted with a 45 mm square mesh panel in order to test the difference in catch of undersized cod (results from tests using panels are presented in Ovegård et al., 2011, although tests concerning green lamps in pots were not analysed in that study). CPUE and WPUE (catch and weight per unit effort in number and kg cod per pot) of <38 cm and >38 cm cod from pots without selection panels (328 pots in Karlskrona Archipelago) were separated into two datasets (small cod and large cod). From pots which were equipped with a selection panel (all pots deployed in the Bay of Hanö and 261 of the pots in Karlskrona Archipelago), CPUE and WPUE of cod above 38 cm were added to the large cod dataset while <38 cm cod were not used in the analysis due to the low number of small cod caught in such pots.

The two fishers reported catches, types of visual stimuli applied to each pot, location, and soaking time using standardised protocols. In the Bay of Hanö, the fisher reported data from each pot in every ground line. In Karlskrona Archipelago, data were recorded for every ground line with either control or test pots as well as for each pot in each ground line (Table 1). On 40% of the fishing trips in Bay of Hanö, on-board observers joined the fishers to measure the length and weight of fish and to ensure maintained data quality by comparing the recordings by the fishermen to those taken by the observers. There were no deviations between the reports taken by fishermen and observers. In Karlskrona Archipelago, observers were present less frequently, although regular contact was maintained between researchers, observers and fishers in order to ensure high data quality.

According to Furevik (1994), it is the duration of the odour plume of the bait which attracts the fish to the pot and influences the fishing time of a pot. Since the bait is either consumed or ceases to emit a sufficient amount of olfactory stimulus after one or two days (Furevik, 1994), pots with soaking time of one to two days were analysed separately as a subset of the total dataset. The fishing depth and date were recorded for each trip/effort. Associations between catch and water depth, season (months) and lunar cycle were subsequently examined.

Table 1
Details about green lamp tests. Location 1: Bay of Hanö. Location 2: Karlskrona Archipelago. Selection panels sharply decrease the catch of cod <38 cm (Ovegård et al., 2011).

Location	Fishing period	Data reported	Ground lines per trial	Pots per ground line	Selection panel	Number of emptied pots	
						Test	Control
1	22/06/2010–07/11/2010	Per pot	1–4	8	Yes	219	219
2	23/04/2009–21/07/2010	Per ground line/per pot	1–3	4–8	Yes/no	296	293

Non-parametric Mann–Whitney *U* tests were used to compare CPUE and WPUE between control and experimental pots. As parts of the data were recorded per ground line of pots (instead of individual pots) in the Karlskrona Archipelago, CPUE and WPUE were calculated as the average catch per pot in a ground line. The non-parametric Mann–Whitney *U* analysis was selected as none of the comparable samples displayed a normal distribution. Furthermore, a forward stepwise multiple regression was performed to investigate multiple determinants of CPUE and WPUE. These regressions were used as a basis to construct non-parametric generalised linear models (GLMs) with Poisson distributions. Only significant ($p < 0.05$) explanatory variables were kept in the GLMs, and the software used was Brodgar (www.brodgar.com). In regressions and models, CPUE and WPUE were Box%3Fndash;Cox transformed into $(\text{CPUE})^{0.25}$ and $(\text{WPUE})^{0.25}$ in order to attain normal distributions. The 95% confidence level was used throughout the study.

3. Results

Fig. 2 shows the CPUE of >38 cm cod in pots with and without green lamps, and for different soaking times. No optimal soaking time could be observed in the data and it should be noted that pots in both categories (lamp and no lamp) continued to retain cod long after the olfactory effect from the herring bait had vanished (after approximately 1–2 days, Fig. 2). The two areas were fished during different months and the catch was particularly high in August-November (Fig. 3), although data were only collected from the Bay of Hanö (site 1) during these months. Differences in CPUE and WPUE between site 1 and site 2 are displayed in Fig. 4 while differences in CPUE and WPUE between control pots and test pots are displayed in Fig. 5.

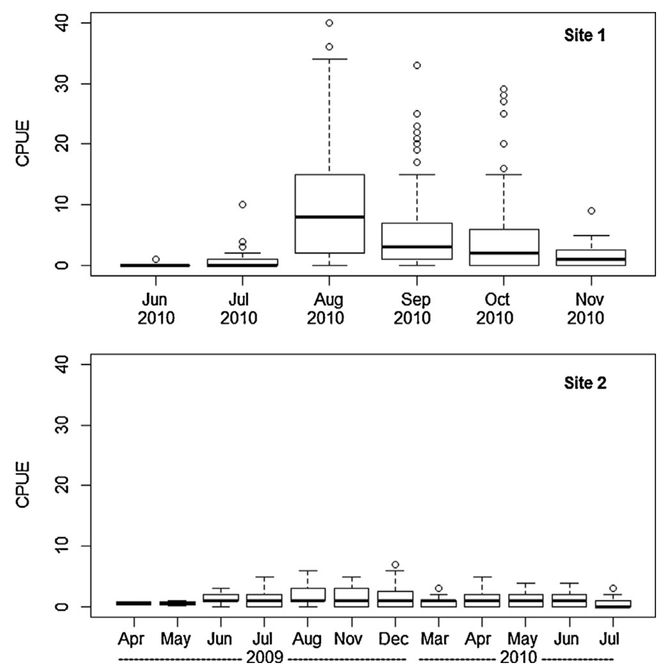

Fig. 3. CPUE of cod >38 cm during different months. Upper panel: site 1 (Bay of Hanö). Lower panel: site 2 (Karlskrona Archipelago).

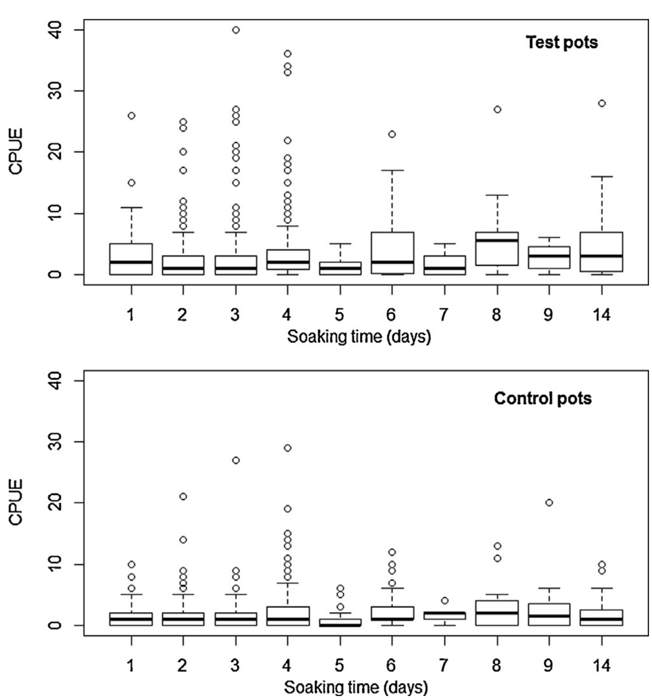

Fig. 2. Soaking time (days) and CPUE of cod >38 cm in pots deployed in the Bay of Hanö and the Karlskrona Archipelago. Upper panel: test pots ($N = 512$) with green lamps. Lower panel: control pots ($N = 515$) without lamps.

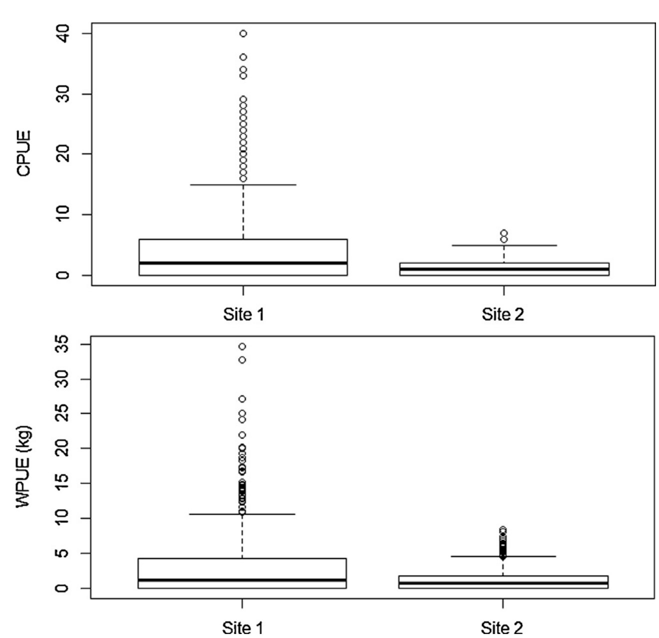

Fig. 4. CPUE and WPUE of cod >38 cm at site 1 (Bay of Hanö) and 2 (Karlskrona Archipelago).

Table 2
Results from green lamp tests. *p*-Values describe statistical difference uncertainty according to Mann–Whitney U tests. Location 1: Bay of Hanö. Location 2: Karlskrona Archipelago. N.A.: data not available.

Soaking time (days)	Location	Size of cod (cm)	Pot category	Number of pots	Mean CPUE (number)	*p*-Value of difference	Mean WPUE (kg)	*p*-Value of difference
1–14	1 + 2	>38	Test	512	3.4	<0.001	2.8	<0.001
			Control	515	2.0		1.6	
	1	>38	Test	219	6.2	<0.001	4.8	<0.001
			Control	219	3.2		2.3	
	2	>38	Test	293	1.3	0.024	1.4	0.030
			Control	296	1.1		1.0	
	2	<38	Test	164	1.6	0.61	N.A.	N.A.
			Control	164	1.3		N.A.	
1–2	1 + 2	>38	Test	154	3.1	0.009	2.6	0.014
			Control	154	1.7		1.4	
	1	>38	Test	87	4.4	0.021	3.4	0.033
			Control	87	2.3		1.7	
	2	>38	Test	67	1.3	0.11	1.4	0.17
			Control	67	1.0		1.0	
	2	<38	Test	39	2.2	0.28	N.A.	N.A.
			Control	40	2.6		N.A.	

Results from the experiment with green lamps and with different soaking time are displayed in Table 2. Pots equipped with a green lamp contained an average CPUE of 3.4 (standard deviation, SD: 5.8) concerning cod >38 cm and the average WPUE of such cod was 2.8 kg (SD: 4.8 kg). These values were significantly ($p < 0.001$) higher than those of the control pots which had an average CPUE of 2.0 (SD: 3.4), and a WPUE of 1.6 kg (SD: 2.8 kg).

When test data were analysed per area, significant differences in >38 cm cod CPUE and WPUE remained (Table 2). Among the Bay of Hanö data, the average CPUE in pots with green lamps was 6.2 individuals >38 cm and the average WPUE of >38 cm cod was 4.8 kg, compared to the average control pot with a CPUE of 3.2 and a WPUE of 2.3 kg concerning large cod (number of pots: 98). Mann–Whitney *U* tests on these Bay of Hanö data indicated differences in CPUE and WPUE at $p < 0.001$. In Karlskrona Archipelago, mean CPUE and WPUE in test pots were 1.3 and 1.4 kg, respectively, compared to control pots with a mean CPUE of 1.1 and a mean WPUE of 1.0 kg (difference at $p = 0.024$ for CPUE and $p = 0.030$ for WPUE).

Green lamps made no significant difference ($p = 0.61$) to the CPUE of small cod (<38 cm) in the Karlskrona Archipelago when test and control pots without size selection panels were used (Table 2). The average CPUE of <38 cm cod was 1.4 (SD: 1.4).

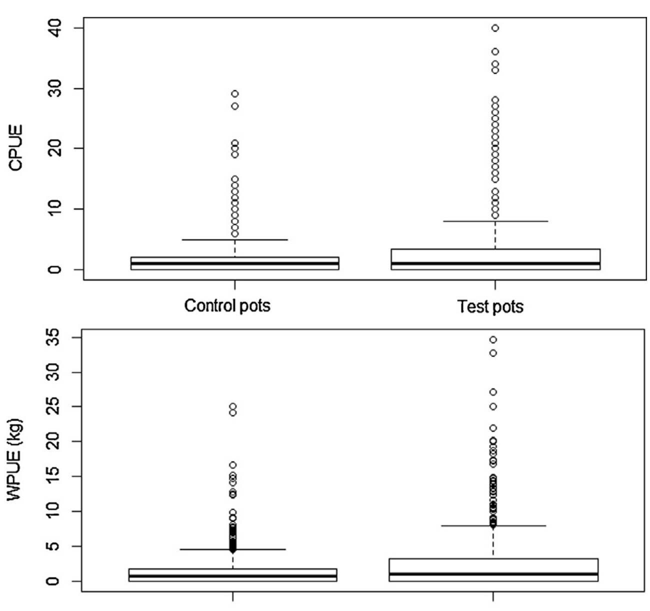

Fig. 5. CPUE and WPUE of cod >38 cm in control pots and test pots.

The yield in pots with 1–2 days of soaking time was generally lower than the average yield in the total dataset concerning cod >38 cm (Table 2). Small cod (<38 cm) were, however, particularly numerous in pots with a soaking time of 1–2 days. The reduced dataset with 1–2 days of soaking time largely corroborated patterns in the total dataset, although the number of pots was, as expected, lower and *p* values were in many cases higher.

Differences in CPUE and WPUE of cod >38 cm between test pots and control pots remained significant in the reduced dataset (with soaking time: 1–2 days) when data from both areas were analysed ($p = 0.009$ and $p = 0.014$, respectively; Table 2). CPUE and WPUE of >38 cm cod were also significantly higher in test pots deployed for 1–2 days in the Bay of Hanö (at $p = 0.021$ and $p = 0.033$, respectively) compared to control pots. In the Karlskrona Archipelago, the difference in >38 cm cod CPUE and WPUE between pots used for 1–2 days was not significant ($p = 0.11$ and 0.17, respectively). No significant difference ($p = 0.28$) in CPUE could be distinguished between test pots and control pots concerning cod <38 cm caught in pots without size selection panels when the soaking time was 1–2 days.

There was no significant correlation between CPUE or WPUE and soaking time, panel use in pots, water depth, season (month of the year) or lunar cycle. However, there were significant correlations between CPUE and consecutive month (as Fig. 3 suggests), between WPUE and consecutive month, between CPUE and site, WPUE and site, CPUE and treatment and, finally, WPUE and treatment. Forward stepwise multiple regressions (Tables 3 and 4) excluded consecutive month as a significant explanatory variable concerning CPUE and WPUE as dependent variables. GLMs with Poisson distributions confirmed that site and treatment were significant determinants of CPUE and WPUE but could not support the use of the interaction product between site and treatment as determinants (Table 5).

4. Discussion

This study shows that the Atlantic cod resembles many other pelagic fish species (e.g., herring, anchovies and mackerel; Ben-Yami, 1988) in that it is attracted to light and that the cod catch efficiency of pots equipped with a green lamp was significantly higher than those lacking a lamp in two areas on the east coast of Sweden. Results suggested that the cod catch rate in terms of weight per pot could increase by on average 80% (and by 108% in the Bay of Hanö) when using green lamps in two-chamber pots.

Table 3
Forward stepwise multiple regression concerning CPUE. Site: 1 for Bay of Hanö and 2 for Karlskrona Archipelago. Treatment: 1 for green lamp and 0 for no lamp. $Y = \text{CPUE}^{0.25}$.

Step and n in X_n	X_n	Equation	R^2	p
1	(Site − 1)	$Y = 1.00 - 0.286 \cdot X_1$	0.045	<0.001 for all coefficients
2	Treatment	$Y = 0.924 - 0.285 \cdot X_1 + 0.162 \cdot X_2$	0.059	<0.001 for all coefficients
3	(Site − 1) · Treatment	$Y = 0.864 - 0.181 \cdot X_1 + 0.282 \cdot X_2 - 0.209 \cdot X_3$	0.065	0.018 for coefficient regarding X_1; 0.011 for coefficient regarding X_3; <0.001 for remaining coefficients

Table 4
Forward stepwise multiple regression concerning WPUE (in kg). Site: 1 for Bay of Hanö and 2 for Karlskrona Archipelago. Treatment: 1 for green lamp and 0 for no lamp. $Y = \text{WPUE}^{0.25}$.

Step and n in X_n	X_n	Equation	R^2	p
1	(Site − 1)	$Y = 0.918 - 0.206 \cdot X_1$	0.025	<0.001 for all coefficients
2	Treatment	$Y = 0.838 - 0.206 \cdot X_1 + 0.161 \cdot X_2$	0.041	<0.001 for all coefficients
3	(Site − 1) · Treatment	$Y = 0.784 - 0.112 \cdot X_1 + 0.269 \cdot X_2 - 0.188 \cdot X_3$	0.047	0.045 for coefficient regarding X_1; 0.018 for coefficient regarding X_3; <0.001 for remaining coefficients

Table 5
Statistics from generalised linear models (GLMs) for $\text{CPUE}^{0.25}$ and $\text{WPUE}^{0.25}$; WPUE in kg. Site: 1 for Bay of Hanö and 2 for Karlskrona Archipelago. Treatment: 1 for green lamp and 0 for no lamp. Interactions between Site and Treatment were insignificant ($p > 0.05$).

Explanatory variable	Coefficient signs	p-Value in GLM with $\text{CPUE}^{0.25}$	p-Value in GLM with $\text{WPUE}^{0.25}$
(Site − 1)	Negative	<0.001	<0.001
Treatment	Positive	0.0069	0.0075

Light attraction among cod has not been tested before in experiments using control groups. However, some significant results in this study can be supported by earlier findings in the literature, e.g., that cod can use vision when locating food (Brawn, 1969) and that cod are receptive to green light (Anthony and Hawkins, 1983).

The olfactory stimulus from herring bait in pots is effective for 1–2 days (Furevik, 1994). However, the propensity to retain cod persisted in the pots for much more than two days, whether there was a green lamp inside or not (Fig. 2). Königson et al. (2014) used a larger dataset of pots from the Bay of Hanö and the Karlskrona Archipelago to investigate the optimal soaking time for pots in the area. They distinguished a peak in cod yield after approximately 6 days of soaking time. Presumably, the herring bait is important during the first two days and after that, the fish either tend to stay in pots and cannot find their way out or are accompanied by new individuals who are attracted by cod aggregating inside.

The only inconsistency in the test results between the full dataset (soaking time: 1–14 days) and the reduced dataset (soaking time: 1–2 days) concerned cod >38 cm in the Karlskrona Archipelago. p-values from the full dataset indicated a significant difference in CPUE and WPUE while p-values from the reduced dataset pointed at a lack of significant difference (Table 2). However, differences were marginal in absolute numbers (CPUE = 1.3 and WPUE = 1.4 kg in test pots and CPUE = 1.0–1.1 and WPUE = 1.0 kg in control pots; Table 2).

The near-field and ingress behaviour is important for the fishing efficiency of the pots. Along Norway's Atlantic coast, Furevik (1994) found that a large proportion of cod being attracted to the pot did not actually enter when approaching the entrance of the pot. The increase in the number of cod in pots with green lamps inside indicates that visual stimuli inside the pot may indeed affect the propensity for cod to enter the pot and thereby affect the ingress behaviour of the fish. However, light could, alternatively, indirectly lure cod to enter the pots by attracting potential cod prey species such as smaller fish or crustaceans. The potential differences in prey species could explain the marked difference in catch between the two areas. The Bay of Hanö has a slightly higher salinity than Karlskrona Archipelago, which may point to a higher number of crustaceans. The density of invertebrates increases in the Baltic Sea along an increasing salinity gradient (Bonsdorff, 2006). Another factor that can influence the effect from visual stimuli which might differ in the two areas is the visibility in the water. In Karlskrona Archipelago, experiments were conducted closer to the shore where water might have been more turbid compared to the Bay of Hanö where fishing was carried out further away from the shore. Multiple regression and GLMs showed that depth, panel use in pots, season and consecutive month were redundant as determinants of CPUE and WPUE of cod >38 cm when site was used as an explanatory variable (Tables 3–5).

Standard deviations of CPUE and WPUE were similar to mean values, indicating a large difference between catches in different pots. Many pots were equipped with selection panels (Table 1). According to Ovegård et al. (2011), selection panels significantly decreased catches of undersized cod (<38 cm) in the two investigated areas. If panels would not have been used in the present study, catches of undersized cod would probably have been higher and these catches could have been analysed in more detail.

Future studies on the optimal luminous intensity and an optimal photon wavelength in lamps deployed for attracting cod into pots are recommended, in combination with studies on how potential prey for cod (small fish and crustaceans) may be attracted to light in a pot and thereby influences the catch rate of cod.

To conclude, this study shows that the propensity of cod to be caught in cod pots may be affected by visual stimuli. A green lamp inside the pot increased the number and weight of large (>38 cm) cod. Results showed that green lamps may be used in the commercial pot fishery as the lamp increased the mean catch weight of legal sized cod by 80%.

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