LED Light Trap Fishing as Alternative for Harvesting American Crayfish

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American crayfish or red swamp crayfish (*Procambarus clarkii*, Cambaridae) is one of the most prominent species of crayfish that supports in one way, the aquaculture industry with remarkable commercial success, *e.g.* in Louisiana, USA (Romaire, 1995), Kenya (Olouch, 1990), China (Huner, 1998), and in Spain (Ackefors, 1999) because of its rapid growth and ecological tolerance (Huner and Lindqvist, 1995). Farmers in Louisiana produce soft-shell crayfish not only for fish bait but also for the seafood industry (Culley and Duobinis-Gray, 1989), as well as egg-bearing females for breeding purposes (Richards *et al*., 1995). On the other hand, many countries have been regulating the introduction of this invasive species due to their adverse impacts on the native species and the ecosystems (Bernardo *et al*., 1997; Usio *et al*., 2001; Nakata *et al*., 2006), including damages to substrates, especially to rice paddies due to their burrowing habit, and interference with fishing operations and consumption of eggs of other fishes (Maitland *et al*., 2001). Collecting crayfish from the wild and ponds makes use of conventional gears (*e.g.* baited traps, fyke nets) but since these had been found to be ineffective due to their impacts on the natural resources, the use of lights in trapping the crayfish is therefore being promoted to improve the harvesting procedures and address the need to reduce the population of the invasive crayfish while minimizing the impacts of the fishery on the environment.

The use of light emitting diode (LED) in fishing has been introduced in many countries to optimize fish catch considering that fish and other aquatic species have color receptions in their eyes that could recognize various intensities of light that lead to their aggregation in lighted areas. The use of LED lights is one of the most recent advances in light fishing being promoted in fisheries, instead of using incandescent, halogen, and metal halide illuminations. In order to adapt the use of LED lights in harvesting the American crayfish (*Procambarus clarkii*), their phototactic responses were tested using incandescent and LED lights in laboratory experiments as well as in pond trials. Four incandescent lights with intensities ranging from 215 to 2050 lx and four standardized LED colors (blue, green, yellow and red) were used as light sources.

In the laboratory experiment with no shelters, positive group responses of the crayfish were more pronounced in lower light intensities as well as in green, blue and yellow colors, and were significantly different with the control. Subsequent fishing trials conducted in a pond using four box-shaped traps (same shape and material) with particular lamp and repeatedly used every night indicated that both incandescent light and LED light traps can be used to harvest crayfish from ponds. However, the use of LED light traps provides a considerable advantage over incandescent lights because of high energy efficiency of LEDs with greater variability of available LED colors, and greater durability. Results of these trials supported observations from other studies that *P. clarkii* has true color vision and are able to alter independently their behavioral responses to different colors. The method of trapping fish and other aquatic species with lights could be replicated for other fishing gears, habitats and target species.

Light Trap Fishing Trials

The trials in collecting crayfish using light through laboratory and pond experiments, has established the magnitude of group responses of crayfish towards different intensity of incandescent lights or different color of LED lights. Specifically, the pond trials were considered crucial in addressing the essential requirements for commercializing the culture or developing environmental control measures of the species.

Laboratory Experiment

Conducted at the Laboratory of Fishing Technology, Faculty of Fisheries, Kagoshima University, Japan in August 2007, the laboratory experiments were done in PVC tank (190×42×40 cm) using 26 adult crayfish (109–151 mm total length) at 1:1 male to female sex ratio, and kept in tank with tap water at 23-26.5°C during 12 h light:12 h dark. The tank had sand substrate at the bottom with an under-gravel filter system. The animals were fed twice a week with crayfish pellets at 0.5 % body weight. Dissolved Oxygen (DO) concentration was 4.8 mg L^{-1} while turbidity of the water was 10 FTU. In order to examine the phototactic responses of *P. clarkii* towards different intensities of incandescent lights in the PVC tank, four incandescent lamps with different intensities were used as light sources (**Fig. 1**). Light intensity of each lamp was 215 lx (SIL-1), 398 lx (SIL-2), 1010 lx (DIM) and 2050 lx (LIGHT) where SIL-1 = 0.45 W and SIL-2 = 1.5 W. For DIM and LIGHT, 4.5 W lamp was placed inside a waterproof acrylic box (14×8×15 cm), the walls of which were lined with white-paper, and 1 to 4 1.5 V batteries. Meanwhile, four selected colors of LEDs were used as light sources (**Fig. 1D**) with

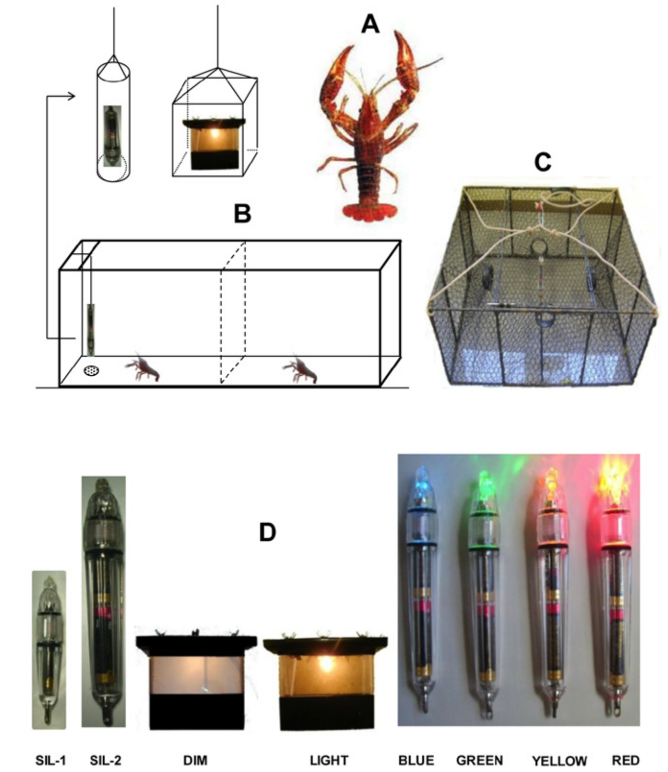

Fig. 1: A: American crayfish (*Procambarus clarkii*); B: laboratory tank experiment; C: typical trap used in the pond; and D: typical lamps used in laboratory and pond experiments

each color placed inside a lamp case of SIL-2 which was generated by 3 V dry-cell battery (0.06 W). The light intensity of LEDs was set at equal quanta intensities by placing a grey fiberglass window screen inside each lamp, and the spectral irradiance for each color was determined using a spectroradiometer.

Recapture experiments were carried out at night before and after setting the lamps under ambient light environment. While the LED lamp was placed downright to the bottom anchored with a weight with the other tip tied to a stationary rod, the incandescent lamps had weights placed on top of the lamp to hold them in upward pressure. Lights were stabilized by caging the lamps with a piece of PVC pipe (15 cm long and 4.8 cm dia) for LED lights and a plastic mesh box (18×18×20 cm) for the incandescent lamps for 30 sec before exposing the animals to the lights.

Trapping Experiment

Trapping experiments were conducted at night in a concrete pond (10.0×5.8×0.7 m, 55 cm deep) using 197 adult crayfish (68-111 mm TL) with 1:1 male to female sex ratio and kept in 3200 L tap water at 16-28°C. The animals were fed twice a week with commercial prawn feed at feeding ratio of 0.5-1.0% body weight. Shelters made of PVC pipes (approx. 15 cm long and 6 cm dia) were distributed at the bottom, and aeration was applied for 24 h; DO concentration was 6.65 mg L^{-1} while turbidity of water ranged from 1 to 14.6 FTU.

Four box-shaped traps were constructed with 6-mm iron frames (60 cm x 50 cm x 25 cm) and black 3/5 inch hexagonal mesh wire (16 gauge PVC-coated wire). The traps had four large entry funnels on each side with 6 cm inside ring entrance, with a trap door on top (48×25 cm) to release the animals (**Fig. 1C**). The light sources were the same as those used in laboratory experiments and were repeatedly used every night in two pond experiments to test light intensity and light color preference.

The traps were lowered on the pond before sunset and retrieved the following morning, with each trap set at a distance of roughly 4.5-8.5 m from each other following the pond shape and rotated each night, while soaking time varied from 13 to 14 h. The crayfish were counted when traps were hauled and checked for sex, carapace length, body length, chelipeds length, weight, and released back into the pond. Of the total 37 trials (148-trap hauls), 15 used incandescent light traps and 22 with LED light traps.

Results of Light Trap Fishing Trials

Laboratory Experiment

Results from the control with ambient light indicated that most of the adults seemed to remain motionless regardless of the shelters provided. Response of the control group was between 3.1±5.0 (mean%±SD) and 6.2±5.8 (**Fig. 2A**). During the trial periods, the animals showed significant photopositive responses towards SIL-1 (26.9±7.7%) at 215 lx, SIL-2 (23.1±7.7%) at 398 lx, and LIGHT (13.8±6.4%) at 2050 lx. Most of the time, the crayfish exhibited higher magnitude of group response in the absence of shelters than with shelters. Positive photo responses were more pronounced in lower than in stronger light intensities, but

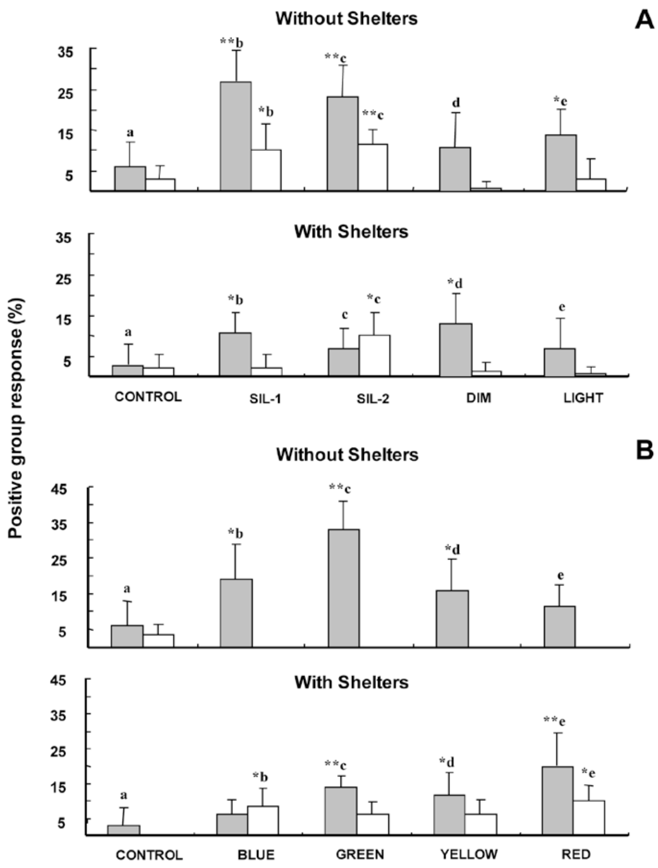

Fig. 2. Positive group responses (mean % ± SE) of crayfish when exposed to incandescent lights (A) and LED lights (B) with or without shelters. Left bars with grey area show strong response of the animals towards the lamps and right bars show weak response. There were significant differences between control (a) and tests (b, c, d, or e) at *p<0.05; **p<0.01

the magnitude of group responses declined significantly when shelters were employed (**Fig. 2A**). Some animals only responded to the DIM (13.1 ± 7.5%) at 1010 lx and SIL-1 (10.8 ± 5.0%) at 215 lx. In all trials, most animals rested in the dark area while their bodies were orienting to the light at random, *i.e.* animals hide in the shelters to be away from strong light intensity (LIGHT) or were moulting during the trials.

In the second laboratory trial, the control group response was between 3.1±5.0 (mean % ± SD) and 6.2 ± 7.0 (**Fig. 2B**). When the animals were exposed directly to color LED in the absence of shelters, the magnitude of group responses was more pronounced to green, blue and yellow lights than that of the control, but there was no significant difference between the control and red light. In the presence of shelters, phototactic responses towards green, yellow and red were significantly higher than that of the control, but no significant difference between the control and blue.

Under light stimulation, the animals behaved similarly to each type of lamp, *i.e.* spontaneously changed their positions by crawling forward along sidewall of the tank while waving their chelipeds and antenna whips pausing near a lamp, moving for short distances, or remaining motionless while facing the light. Some animals failed to reach the lighted area when larger animals ambushed them, but the shelters appeared to be helpful for the egg-bearing females. There were no significant differences in the attractability of males and females in the tank experiments. Moreover, the duration of animals' concentration near a lamp seemed to be longer when the light was obscured conforming to the lack of visual field of the animals.

Trapping Experiments

Crayfish in the pond were exposed to SIL-1, SIL-2, Lighted and Dimmed light traps simultaneously. The animals crawled slowly towards the lighted traps with or without waving their chelipeds while searching for the funnel entrances. Inside the trap, the animals crawled around while holding on to the netting or elevating their postures in front of a lamp. Outside the traps, some animals moved around or crawled along the sidewall of the pond for some distances, but most remained motionless while facing the lamps. Movement of the animals during each trial in the pond was directly observed by ocular inspection. The average catch per trap per night ranged between 1.3 ± 0.5 and 7.5 ± 2.4. Results of the test showed no significant differences in the total catch or in terms of average sizes between males and females. Despite the original 1:1 male to female sex ratio in the pond, many more males were caught than females (sex ratio of 1.6:1.0).

In the second pond experiment, the performance of blue, green, yellow and red LED light traps were investigated simultaneously. While the animals behaved almost the same as described in the above findings, behavior was difficult to observe during the last 22 trials because of low water clarity. The average catch per trap per night ranged between 1.0 ±

0.8 and 7.0 ± 0.8 and there were no significant differences in the total catch or in the average sizes between males and females. As in the first pond experiment, more males were significantly caught in all LED light traps with sex ratio of 2:1 male to female. In addition, 15 egg-bearing females were also observed although there were no indications that they behaved differently than females without eggs.

Before each trial, the animals were confined to one end of the tank using a black PVC partition, providing them with enough space to crawl freely. At the start of each trial, ambient light was applied for 10 min (control), partition removed and the animals allowed to move freely. When the partition was returned to its original place confining the animals again, it was observed that putting and removing the partition did not affect the behavior of crayfish. The trials consisted of submerging the lamp, removing the partition, applying the lamp for 10 min, and capturing crayfish with a scoop net. Shelters made from PVC pipe were distributed at the bottom. Out of 20 trials, 10 were with shelters and the other 10 without shelters, and incandescent or LED lamps were applied in rotation, with each lamp repeatedly used for 5 trials including the reverse of a lamp from one side of tank to the other. The animals were given 10 min to rest after each trial. Movement of the animals during each trial was recorded with a digital video camera while the animals' behavior in ambient light (control) was observed by eyes. The animals' directional crawling towards the light within the 10 min test period was considered a *positive response*, where a strong positive response is defined when animals approach a lamp within 2 min and remain at least 75 cm from the lamp's radius. A weak positive response is considered when animals crawl slowly towards a lamp within 10 min per trial, while crawling away from the lamp and remaining in dark area for a long period of time (within 50 min) is defined as a *negative response*. After statistically comparing the percent values for the 5 trials at each lamp with the percent value for the control (Conover, 1980), results showed that the test values for the trials were significantly higher than that of the control, therefore the group response was considered *positive*.

Discussion

Results from the pond experiments seem not to support the findings from the laboratory experiments indicating the possible effect of the size of the tank. The difference between the light intensity in small tank and large tank may be significant to the animal. Moreover, although the light intensity of LED was set at equal quanta intensities in air, the intensity may not be the same in water because of the waters' different levels of absorption of light wavelengths (colors). Therefore, it could not be established whether the color or light intensity of LED affects the difference in "*attraction*", which is still arguable as with the findings of Marchetti *et al*. (2004) in using chemical light sticks for collecting fish larvae.

Nevertheless, the trials strengthened the findings of a previous research that *P. clarkii* have true positive phototaxis (Ahmadi *et al*., 2008), while the form and optical characteristics of lamps used in this trials were able to attract crayfish into the traps. The total number of 362 crayfish taken from the pond using selected LED light traps was sufficient enough to support previous studies that *P. clarkii* have multicromatic visual system between blue and red (Nosaki, 1969; Cummins and Goldsmith, 1981) or have true color vision (Kong and Goldsmith, 1977), that enables the crayfish to alter independently their behavior responses to different colors, considering that true color discrimination is only possible when an animal has at least two receptor types with distinct but overlapping spectral ranges. Color discrimination requires inputs of different photoreceptor cells that are sensitive to different wavelengths of light. Anatomically, *P. clarkii* possessed two photosensitive systems, one of which is their sensitivity to blue light developed in their early life stage and the other, is sensitivity to red light which is developed later (Fanjul-Moles and Fuentes-Pardo, 1988; Fanjul-Moles *et al*., 1992), implying that the photosensitivity of crayfish changed in their different life stages. The physiology of vision of *P. clarkii* has been generally well documented, *e.g.* the formation of retina and eyestalk in *P. clarkii* was described by Hafner and Tokarski (1998), while the primary structure of their photo pigment was described further by Hariyama *et al*. (1993). Although their vision has been widely studied, their behavioral responses to different intensities or colors under field conditions (*e.g.* stream, lake, wild paddy field) are lacking, and future research on this aspect is strongly underlined.

Moreover, the movements and behaviours of *P. clarkii* in indoor tanks under light are still poorly described. While Fernández-de-Miguel and Aréchiga (1992) reported on the attraction and withdrawal responses as important adaptive mechanisms in crayfish, Fanjul-Moles *et al*. (1998) paid more attention on the effect of variation in photoperiod and light intensity towards survival and behavior in crayfish. While Kozak *et al*. (2009) devoted to the assessment of light intensity preferences, only the "*light source directional behavior*" was described in detail but not the "*exploratory behavior*", where exploratory behavior is defined as the animal directing its body towards the object surrounding it then roving around the tank at a certain distance, with or without lights, looking for '*something*'. Presumably, when refuge/shelter and certain conditions of lights were provided, the animals are likely to crawl inside/under the shelter and stop moving.

However, adding shelters did not conform to such hypothesis because the animals did not cease their explorative behavior either in light or dark conditions. In this regard, exploratory behaviour could still be considered a form of complicated and dynamic behavior as opposed to the more simple responses, either positive or negative to a light source, due to the instability of the environment and the rapid interactions between the animal and the world surrounding it. In the pond, typical exploratory behaviour includes free movement of the animals upon reacting discriminately to light intensity or color. Therefore, other behaviors such as looking around while remaining in one location or resting against any object could not be considered exploratory.

The critical conditions in exploratory behavior which could immediately shift to escape and display avoidance behaviors were identified, *i.e.* when animals were being exposed to strong light intensity, during the moult and post-moult or competitive interactions among gender/size of animals while approaching the light source. During exploration, males were more aggressive than females because they had larger chelae, with larger individuals often intimidating and out-competing the smaller ones from the shelters. This could also imply that crayfish should be harvested from ponds upon reaching marketable size to reduce aggression and provide living space and food resources for undersized animals. Understanding the way of catching, light traps could be employed for possible solutions in developing environmental control measures. Similar method of trapping with lights has been successfully replicated for other traditional fishing gear (*e.g.* "*tempirai*" or bamboo-stage trap) for collecting crustaceans and fish from Barito River of Indonesia (Ahmadi and Rizani, 2012), and thus, could most likely be adapted in the Southeast Asian region.

Conclusion

The ratio of catches to catch per unit of effort (CPUE) in all treatments could not be standardized because the soaking period of the lights during operation was variable and dependent on the type of light devices and variance in battery life. For example, a 0.45 W lamp SIL-1 (1.5 V) in the laboratory experiment would frequently turn off the four lamps, although it was established that the use of LED lights provide a considerable advantage over incandescent lights because of the higher energy efficiency of LEDs, greater variability of available LED colors, and greater durability. In the laboratory experiment with no shelters, positive group responses were more pronounced to lower light intensities than higher ones as well as green, while blue and yellow lights were significantly different with the control. The trapping experiments showed that both incandescent light and LED light traps can be used to harvest crayfish from ponds while their implications for environmental control measures were established. The results also supported findings from other studies that *P. clarkii* had true color vision and able to alter independently their behavior responses to different colors. The method of trapping with lights could be replicated for other fishing gears, habitats and target species.

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