Journal of
Fisheries and Aquatic Science

ISSN 1816-4927

Academic
Journals Inc.

www.academicjournals.com

Journal of Fisheries and Aquatic Science 3 (6): 340-352, 2008
ISSN 1816-4927

Mechanisms of Phototaxis in American Crayfish, *Procambarus clarkii* (Girard, 1852) Following Different Methods of Trapping

[1]Ahmadi, [2]Gunzo Kawamura and [2]Miguel Vazquez Archdale
[1]United Graduate School of Agricultural Sciences, Kagoshima University,
1-21-24 Korimoto, Kagoshima 890-0065, Japan
[2]Laboratory of Fishing Technology, Faculty of Fisheries,
Kagoshima University, Shimoarata 4-50-20, Kagoshima 890-0056, Japan

Abstract: The phototactic behavior of the American crayfish *Procambarus clarkii* was investigated in aquaria and a large tank to determine their sensitivity thresholds to light and possible harvesting applications. Adult and juvenile crayfish were found to be positively phototactic and their attraction to light was highest at an intensity of 1,290 lx. Conversely, post-embryonic crayfish were negatively phototactic and moved away from the light source at intensities higher than 111 lx. Fishing trials using traps with four open funnel entrances under lighted and dimmed lamps, fish baited and non-baited treatments tested the application of trapping with lamps as an alternative harvesting method. Results showed that traps with lighted and dimmed lamps captured similar numbers of crayfish, that in some cases they catch significantly more crayfish than non-baited traps, but that their catching performance was lower than fish baited traps. Possible applications of this novel luring method are further discussed, as well as its implications in eradication programs and harvest from aquaculture ponds.

Key words: American crayfish, *Procambarus clarkii*, light intensity, threshold intensity, phototactic, lamps, traps

INTRODUCTION

The American crayfish *Procambarus clarkii* (Girard, 1852) is an important aquaculture commodity in the United States (Huner and Barr, 1991; Romaire, 1995), China (Huner, 1998), Spain (Ackefors, 1999) and other countries. They are also invasive pests in several countries where they have been introduced. In Japan, the American crayfish and signal crayfish *Pacifastacus leniusculus* (Dana, 1852) have had adverse ecological effects on the indigenous crayfish *Cambaroides japonicus* (De Haan, 1841) by competing with them for habitat, shelters and resources (Usio *et al*., 2001; Nakata and Goshima, 2003; Nakata *et al*., 2006), thus economically feasible eradication methods need to be developed.

Several active and passive fishing methods are being used to harvest crayfish, e.g., seines (Huner, 1994), trawls (Faulkner and Huner, 1994), fyke-nets (Balik *et al*., 2005) and baited traps (McClain *et al*., 1998). The use of seines and dragged nets or trawls is ineffective in vegetated ponds (D'Abramo and Niquette, 1991). Electrofishing equipment however, improved the fishing efficiency of dip nets or trawls in vegetated ponds (D'Abramo and Niquette, 1991) and the nature of the electrotaxis in the American crayfish was demonstrated (Ahmadi *et al*., 2008).

In the past, North American crayfish (genera *Astacus* and *Cambarus*) were often caught at night by lighting a fire near a lake or river bank to lure them to the shore (Chidester, 1912). Westman *et al*.

Corresponding Author: Ahmadi, United graduate School of Agricultural Sciences, Kagoshima University, 1-21-24 Korimoto, Kagoshima 890-0065, Japan Tel: +81-99-286-4240 Fax: +81-99-286-4015

(1978) used gas-lamps or battery-fed car-headlights when sampling the European crayfish *Astacus astacus* (Linnaeus, 1758). While Kozak *et al*. (2007) examined the light intensity preferences of the American crayfish. Experimentally, the range of light intensities that produces behavioral response in the crayfish is still poorly understood. Fernandez-de-Miguel and Aréchiga (1992) examined the effect of placing a white light bulb above a chamber containing *P. clarkii* and showed that they were positively phototactic to low light intensities (0.17-1.4 1x), but negatively phototactic to higher intensities (above 5.6 lx). Kozak *et al*. (2007) reported that the American crayfish showed positively phototactic response to strong light at 1,000 lx. Thus, the information on the phototactic response in the American crayfish is inconsistent.

The use of light would be a potential fishing method for harvesting crayfish. To examine the feasibility of a light-trap, the American crayfish at different developmental stages were subjected to various light intensities in indoor tank experiments and their responses were evaluated. Furthermore, a series of trapping experiments with lamps were carried out in a pond.

MATERIALS AND METHODS

Laboratory Experiment

The objective of this laboratory experiment was to examine phototaxis in the American crayfish by subjecting them to different light intensities. The indoor experiment was conducted in the laboratory of the Faculty of Fisheries, Kagoshima University from June to November 2006.

Animals and Tanks

Two groups of the American crayfish, cultured and wild, were used in the indoor experiments. Crayfish (N = 64) were grouped according to age and size into three developmental stages following established criteria (Sukô, 1953) as follows: (1) cultured adults (N = 10) and wild ones (N = 10), sexually mature and measuring 55 mm or more in total length; (2) cultured juveniles (N = 10) and wild ones (N = 14), 1-3 months old and less than 33.9 mm total length and (3) the second post-embryonic crayfish (N = 20), 10-14 days old and less than 11.8 mm total length. Adult animals were obtained from local suppliers, while juvenile and the second post-embryonic animals were hatched and reared at our laboratory. Individuals were used repeatedly within the same experiment. Prior to the observations, each adult and juvenile was marked on the dorsal carapace with a water-proof white marker for easy identification. Adults or juveniles were kept in a 240 L polyvinyl chloride (PVC) tank (190×42×40 cm) filled with tap water (30 cm deep) at 24.5-28°C. The tank had a sand substrate at the bottom (2.5 cm thick) and water quality was maintained with an undergravel filter (Fig. 1A). The crayfish at the second post-embryonic stage were kept in a 15.5 L glass tank (60×21.5×19 cm) filled with tap water (12 cm deep) at 16-20°C and no sand substrate (Fig. 1B). Dissolved oxygen concentration was 4.8 mg L^{-1}, as determined with a DO meter (YSI 85, YSI Inc., USA). The animals were fed twice a week with commercial crayfish pellets (Japan Pet Drugs, Tokyo) at 0.5% of their body weight.

Post-molt crayfish also were examined for phototactic responses in the same tank and light conditions as those used for adults and juveniles. They were 42 juveniles and 16 adults either the newly molted or several hours after the molt.

The crayfish were handled according to the methods prescribed by Kagoshima University's Guide for the Care and Use of Laboratory Animals.

Experimental Apparatus

The tanks were placed inside a box-shaped black velvet chamber (2.8×1.5×1.75 m) to avoid the interference of external light and to prevent other disturbances. Outside-light could still penetrate

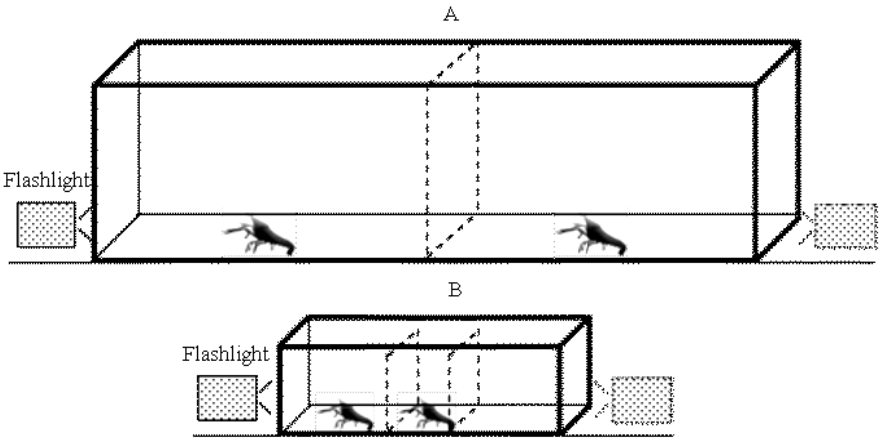

Fig. 1: Experimental apparatuses for the indoor experiments. (A) a PVC tank used for adults and juveniles and (B) a glass tank used for the second post-embryonic of crayfish. The dashed lines at the center of the tanks indicate where the partitions were placed. A flashlight is placed at left or right end sides of the tanks

through the black velvet resulting in dim light, but no adverse effect was observed on the animals because most of them remained motionless. During the night, a ceiling lamp (384 W) was switched on to give a similar ambient light environment during the day. All experiments were conducted with the same light presentations, both in the absence and the presence of shelters in the tanks. For adults and juveniles, the shelters were made of PVC pipe pieces (4.8 cm diameter, 15 cm long), while for the second post-embryonic crayfish the shelters used were artificial water plants.

A 4.5 W flashlight was used as a light source. The light intensity was varied with 1 to 10 white-paper filters and the light intensity at 5 cm away from the lamps was determined with an illuminometer (IM-2D, Topcon Ltd., Japan). The light intensity ranged from 46 to 1,290 lx. The flashlight was placed 5 cm from the left or right side along the axis of the tank wall, in line with the animals inside tank. To avoid shadows or the reflection of the light beam at the opposite side of the tank wall, a reversible black screen was used. This screen was painted with glossless black paint and placed at the opposite end of the light inside the tank wall.

Experiment, Data Collection and Analysis

Observations of the movements of the crayfish before and after the onset of light were made both during day and night. The duration of the light stimulus at the respective intensities was 5 min in 5 trials with the adult or juvenile and 5 min in 3 trials with the second post-embryonic crayfish; this included the reversal of the light source from one side of the tank to the other. The crayfish were given 2 min rest time after each trial. To observe the crayfish in the dark, a 1.5 W dimmed-flashlight was used for 2-3 seconds from the side of tank wall, which did not appear to affect crayfish behavior.

Before each trial, adults or juveniles were confined between the center and the dark area of the tank with a PVC partition, thus providing them with enough space for free crawling. At the start of each trial was a control period of 5 min, when the partition was removed and the crayfish were allowed to move freely. Then the partition was returned to its original place and the crayfish confined again. The trial consisted of stabilizing light for 15 sec by putting a black partition in front of light source, removing the partition and applying the light stimulus for 5 min at a particular intensity. The second post-embryonic stage of crayfish was confined to the center of the tank with two PVC partitions placed 13 cm apart. The experimental procedure was the same as those used for adults and juveniles.

Movements of the animals during the stimulation in each trial were observed for 5 min (test period) and recorded with a digital video camera (Sony DCR-TRV18, Tokyo). Directional crawling towards the light source within the 5 min test period was considered a positive response. Movement of the animal by crawling away from the light during the stimulation and staying in the dark area for a long period of time (5-25 min) was defined as negative response.

For the quantitative analysis of the response to the light, magnitude of group response (GR) (%) was defined for each trial by the following formula for adults or juveniles:

$$\text{Magnitude of GR} = [(\text{No. of Cp})/(\text{No. of crayfish in test})]\times 100$$

For the second post-embryonic crayfish:

$$\text{Magnitude of GR} = [(\text{No. of Cp-No. of Cn})/(\text{No. of crayfish in test})]\times 100$$

where, Cp is crayfish showing positive response and Cn is crayfish showing negative response.

The percent values from 5 trials at each light intensity were statistically compared with the percent in the control period using the Mann-Whitney test (Conover, 1980). When the test values were positive and they were significantly higher than the control value, the group response was considered positive. When the test values were negative and they were significantly higher than the control value, the group response was considered negative. Threshold intensities for positive or negative responses were determined at the 5% level.

Trapping Experiment

Trapping experiments were conducted during the night in a concrete pond (10.0×5.8×0.7 m, 55 cm deep) at the Faculty of Fisheries, Kagoshima University from July to November 2007.

Animals and Pond

Four hundred adult crayfish (31-57 mm carapace length) with a sex ratio of 1:1 male to female were obtained from local suppliers and used in this study. They were fed twice a week with the kuruma shrimp pellet food (Higashimaru, Kagoshima, Japan) at a feeding ratio of 0.5-1% of their body weight. Water grass *Hydrilla verticillata* and zooplankton were introduced into the pond and kept as natural dietary items for the crayfish. The animals were kept in 3,200 L of tap water at 18.5-29.5°C. A polyethylene net and a blue plastic sheet were placed above the pond to reduce solar radiation and to inhibit unwanted algae growth. Shelters made of PVC pipe pieces (approx. 15 cm long and 6 cm diameter) were placed in the pond. Aeration was applied for 24 h. Dissolved oxygen was 5.7-6.7 mg L^{-1}, measured with a DO meter (YSI 85, YSI Inc., USA).

Experimental Apparatus

Four box-shaped traps were constructed with the same dimensions and materials (Fig. 2). They were lighted, dimmed, baited and non baited traps. For lighted and dimmed traps, a 4.5 W lamp was placed inside a waterproof acrylic box (14×8×15 cm) and attached to the center of the trap base. For the dimmed lamp, white-paper was used to line the walls of the box. Light intensity of both lamps was 2,050 and 1,010 lx at 5 cm away from the lamps. Turbidity of the pond water was 1-15 FTU (Formazin turbidity unit) determined with a spectrophotometer (DR-2000, HACH, USA).

For the baited trap, a piece of the Pacific mackerel *Scomber japonicus* (33-60 g) was placed in a wire bait container (14×6 cm) between the funnel entrances. The bait that remained after retrieving the trap was reweighed to find the actual amount of bait consumed. The non-baited trap served as a control.

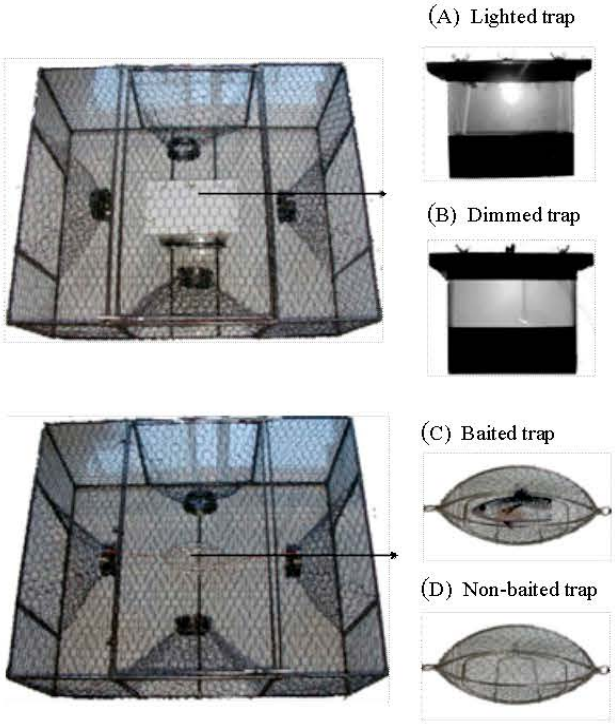

Fig. 2: Traps used during the trapping experiments. Four box-shaped traps were constructed with 6 mm iron frames (60 cm long by 50 cm wide by 25 cm height) and black 1.5 cm hexagonal mesh wire (16 gauge PVC-coated wires). They had four large entry funnels located on each side of the trap with a 6 cm inside ring entrance. A trap door (48×25 cm) on the top allowed removal of the catch

Experiment, Data Collection and Analysis

The traps were set at random positions at sunset and retrieved next morning. The soaking time varied from 12-14 h. At the retrieval of the traps, the crayfish in the traps were checked for sex, carapace length, body length, chelipeds length, weight and released back into the pond. During night, the behavior of the animals around the traps was observed using the 1.5 W flashlight which did not disturb the behavior of the crayfish. Total number of trapping trials was 35, consisting of 4 trials in the first experiment (lighted and dimmed traps), 10 trials in the second experiment (all trap types) and 10 trials in the third experiment (lighted, dimmed and non baited traps) and 11 trials in the fourth experiment (a follow-up of the third experiment where the amount of aeration was increased).

For the statistical analysis, the Mann-Whitney test was employed to compare the catches between the lighted and dimmed traps at the 5% level in the first experiment. The Kruskal-Wallis test was used in the second, third and fourth experiments to examine the differences between the traps. The Multiple Comparison test was conducted to see which catch differed among the traps.

RESULTS

Laboratory Experiment

In the laboratory experiments, adults and juveniles showed a positive group photoresponse regardless they were wild or cultured and the magnitude of the group response tended to increase with light intensity (Fig. 3). In the dark in daytime (daytime dark) and in the dark in nighttime (nighttime

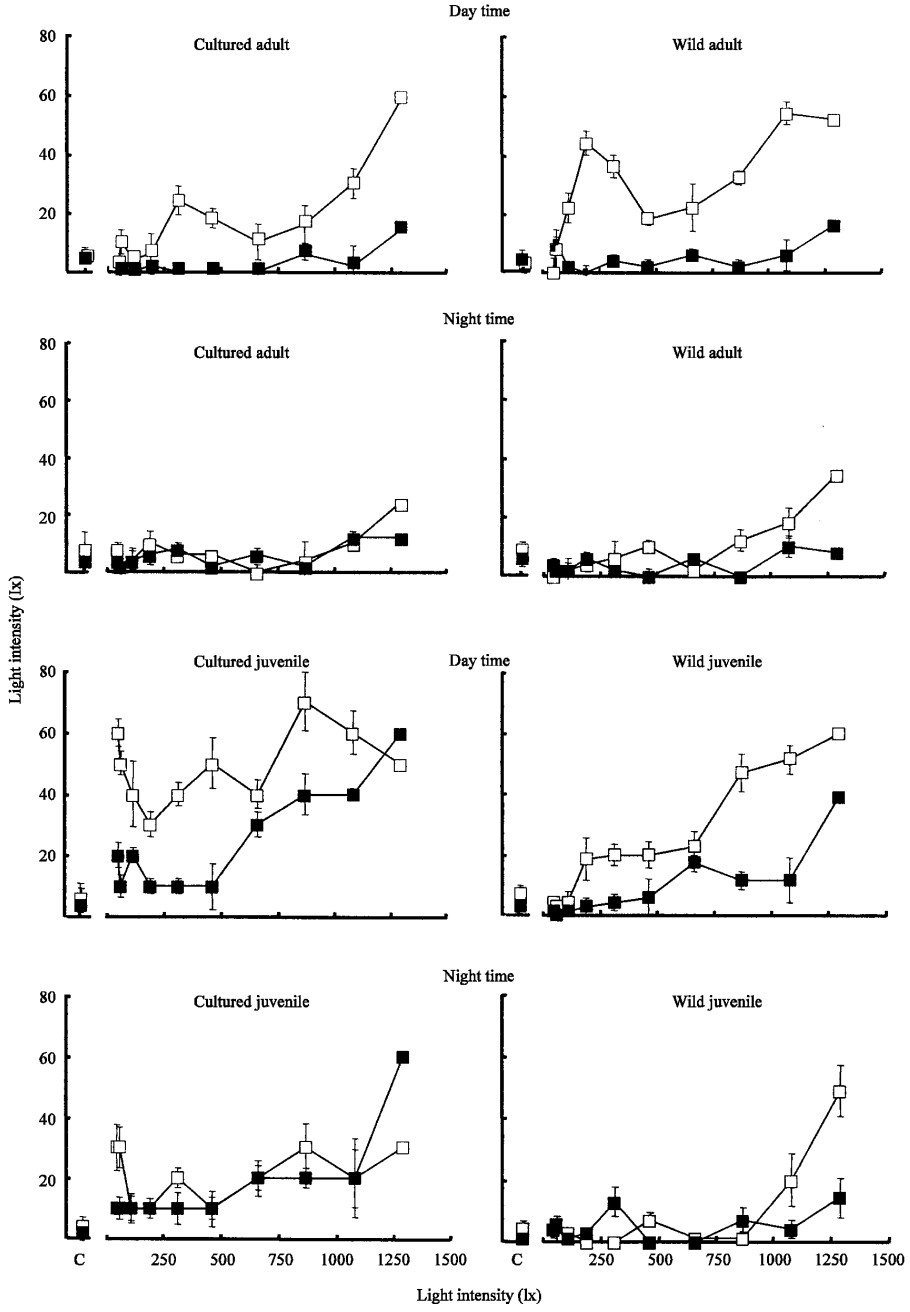

Fig. 3: Group response (mean %±SE) of adults and juveniles to the lights during the control (C) without light and at different light intensities both in the absence (□) and the presence of shelters (■)

dark), most of the adults and juveniles tended to remain motionless during the control period, the control group response ranged between 1±1.4% (mean %±SE) and 10±4.5% (Table 1).

Table 1: Magnitude of group response (mean %±SE) in adults and juveniles during the control periods

	Magnitude of control group response (%)			
	Day time		Night time	
Crayfish	Without shelter	With shelter	Without shelter	With shelter
Cultured adult	6±2.4	6±4.0	8±3.7	4±8.9
Wild adult	4±2.4	4±2.4	10±4.5	6±2.4
Cultured juvenile	6±4.0	4±2.0	4±2.4	2±2.0
Wild juvenile	7±2.3	3±2.9	3±1.8	1±1.4

Table 2: Threshold light intensities and most effective light intensities which induced highest positive phototaxis in adults and juveniles

	Threshold light intensities (lx)				Most effective light intensities (lx)			
	No shelter		Shelter present		No shelter		Shelter present	
Crayfish	Day time	Night time	Day time	Night time	Day time	Night time	Day time	Night time
Cultured adult	312	***	***	***	1,290	1,290	1,290	1,290
Wild adult	111	***	58	***	1,290	1,080	1,080-1,290	1,290
Cultured juvenile	46	46	58	46	1,290	1,290	866-1,290	866-1,290
Wild juvenile	190	***	659	46	1,290	1,290	866-1,290	1,290

***Threshold is not determined

During the test periods in the daytime dark, adults and juveniles exhibited typical photopositive responses towards the light source and showed higher magnitude of group response in the absence of shelters than in the presence of shelters (Mann-Whitney test, $p<0.05$). The lowest threshold was 46 lx for juveniles in the presence of shelter in the nighttime dark and the highest threshold was 659 lx in the presence of shelter in daytime dark (Table 2). Any consistent tendency between the daytime and nighttime darks and between adults and juveniles were not detected since the threshold largely varied and was not determined for the adults in nighttime dark due to low magnitude of group response during the test periods. The magnitude of group response was significantly higher during the daytime dark than nighttime dark (Mann-Whitney test, $p<0.01$).

Both in daytime and nighttime darks, adults and juveniles tended to exhibit higher magnitudes of group response at higher light intensities especially in the absence of shelters (Fig. 3). At 1,290 lx (the highest intensity tested), the cultured and wild adults crawled about the tank or moved to the light source, reached the light source in less than one minute (24-57 sec) at different starting points from the light source (100-185 cm). The highest mean magnitude of group response during the daytime was 70±4.5% at 866 lx for cultured juveniles and 60±4.8% at 1,290 lx for cultured adults (Fig. 3). The highest light intensity induced highest positive group response and was most attractive for adults and juveniles (Table 2). The positive photoresponses in the absence of shelters were significantly higher ($p<0.01$) than with the presence of shelters most of the time. Response to the lights was significantly higher ($p<0.01$) during the daytime dark than nighttime dark and proportionally increased with light intensities. Cultured juveniles were more attracted to the lights than wild ones.

In the second post-embryonic crayfish, they often gathered at the center of the tank but tended to move against the light source position and the mean magnitude of the control group response was negative; from -14±4.3 to -10±2% in the daytime dark and from -21±2.9 to -4±2.4% in the nighttime dark (Fig. 4). During the test periods in the daytime dark, they showed typical negative phototactic responses at high light intensities and the magnitude of group response fluctuated between -30±5.7 and -39±6.9%. In the daytime dark, the threshold light intensity for the negative phototaxis was determined

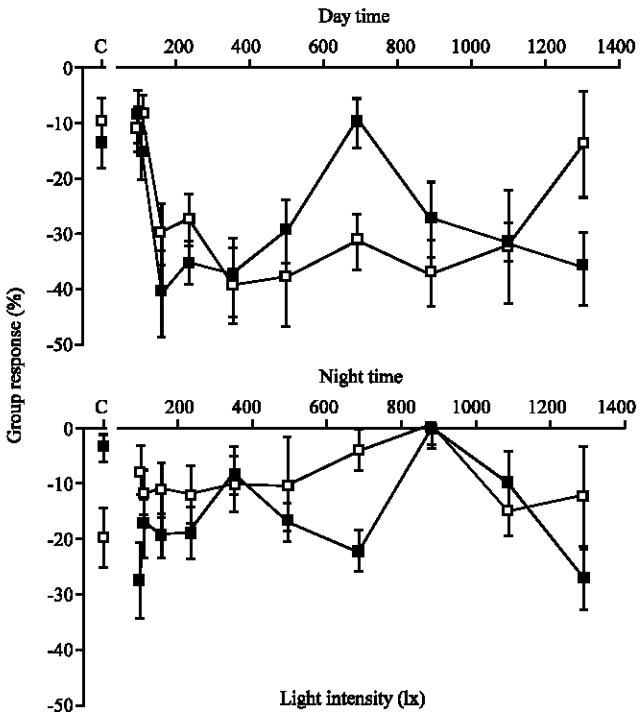

Fig. 4: Group response (mean %±SE) of the second post-embryonic crayfish during the control (C) without light and at different light intensities both in the absence (□) and the presence of shelters (■)

as 111 lx both in the presence and absence of shelters. In the nighttime dark, on the other hand, they did not exhibit strong phototactic response and the threshold light intensity was determined only in the presence of shelter as 46 lx.

Post-molt juveniles and adults tended to crawl away from the light and to remain in the dark for several hours after molt. They behaved negatively phototactic when stimulated at 461-1,290 lx and showed little or no further response at lower intensities. In the presence of shelters, only three animals hid inside shelters for a long period of time.

Trapping Experiment

The results of the trapping experiment sequences are shown in Table 3. In the first experiment with the lighted and dimmed traps, the crayfish crawled toward the traps and searched for the funnel entrances. They climbed and crawled on the traps and held to the netting, but most of them remained motionless outside the trap while facing the light. Inside the traps, the animals crawled around, flicked their tails when they encountered each other or elevated their postures in front of the light. There were no significant differences in the total catch between the two trap treatments (Mann Whitney test, $p>0.05$).

In the second experiment with the lighted, dimmed, baited and non-baited traps, when the baited trap was lowered to the bottom of the pond, the animals approached the baited entrance by crawling. They struggled to touch the bait by inserting claws and legs through the bait container. In the first day of trials, when no pellet food was given, the catch in the baited trap increased rapidly during the first hours after setting the trap, the bait was soon consumed and 47 crayfish were caught. On the following

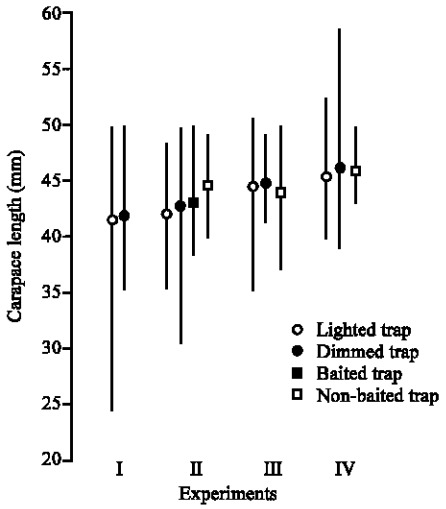

Fig. 5: Mean carapace length (mm) and range of male crayfish captured by traps in first to fourth experiments

Table 3: Total number of catch in each trap treatment. Number of crayfish in the pond was 400 and catches were released into the pond for the next trial

			Catch		
Experiment (water temperature)	No. of trials	Traps	Male	Female	Total
I	4	Lighted	33	36	69
(28.0 -29.5°C)		Dimmed	35	27	62
II	10	Lighted	22 (1)	11	33[b]
(29.0-28.0°C)		Dimmed	20	15	35[b]
		Baited	111 (4)	68	179**[a]
		Non-baited	19 (1)	11	30[b]
III	10	Lighted	50(4)	43 (4)	93**[a]
(28.5 -26.0°C)		Dimmed	26	25	51*[b]
		Non-baited	23	7	30[c]
IV	11	Lighted	21	22	43
26.5 -18.5°C		Dimmed	32	12	44
		Non-baited	25	10	35
	Total		417(10)	287(4)	704

Significantly different between superscript a, b and c. *p<0.05; **p<0.01, The bracketed numbers indicate number of post-molt crayfish (1-2 days after molt)

days, when the animals were daily fed with pellets, the catch in the baited trap remarkably declined to 10-21/day. The bait attractiveness also decreased, the crayfish consumed 18 to 45% of fish bait given indicating that most crayfish were still satiated. The effect of this feeding frequency was followed by a decreasing catch in the other traps (3-4 in the average per tap). During the day, they were also voraciously consuming the water grass present in the pond. Inside the trap, they crawled along the base of the trap, climbed and held onto the netting or fought with each other. These behaviors were also observed in the crayfish caught in the non-baited trap. The baited trap captured a significantly larger number of crayfish than the other three traps (Multiple comparison test, $p<0.01$) and there were no significant difference in catches between the lighted, dimmed and non-baited traps (Kruskal-Wallis test, $p>0.05$).

In the third experiment, the performance of lighted and dimmed traps was compared with that of a non-baited trap. There were significant differences in the total catch between the three traps (Kruskal-Wallis test, $p<0.05$) and the lighted and dimmed traps captured significant larger number of crayfish than the non-baited trap (Multiple comparison test, $p<0.05$).

In the fourth experiment with lighted, dimmed and non-baited traps, the water temperature largely decreased from 26.5 to 18.5°C, the crayfish remained active (3-4 in the average catch per trap a day) and were attracted to the lights, but were not as active as they were in warmer water. There were no significant differences in the total catch between the three traps (Kruskal-Wallis test, $p>0.05$), even the amount of aeration was increased.

The sex ratio of the catch from 35 night trials was remarkably biased to male; 417 males, including 10 post-molt crayfish with a soft-shell and 287 females including 4 post-molt crayfish (Table 3). Among these 14 soft-shell crayfish, 9 were from the lighted trap, 4 from the baited trap and 1 from the non-baited trap. We collected empty carapaces of 45 crayfish besides these soft-shell crayfish, but it was difficult to determine the exact molting ratio.

The size of crayfish captured ranged from 24 to 58 mm in carapace length and there were no significant differences between catches from respective four traps ($p>0.05$) (Fig. 5).

DISCUSSION

Present tank experiments show that the positive phototactic response is much more intense in the daytime dark than in the nighttime dark. However, it has long been known that the American crayfish are nocturnal animals and that the levels of general locomotor activity are much greater during the night than during the day (Gherardi *et al*., 2000). Crayfish emerge from diurnal hidings (e.g., rocks in streams or dense vegetation in lakes and ponds) at night to forage for food or to avoid predation (Hill and Lodge, 1994; Garvey *et al*., 1994). The daytime dark might be an unusual light condition for the crayfish which have never experienced it.

Although the positive group response largely fluctuated in the present study, it is evident that the juvenile and adult American crayfish are positively phototactic and can be allured into a trap equipped with a lamp. The positive phototaxis became more prominent with increasing light intensity in the laboratory, but the trapping unexpectedly showed no differences in catch between lighted and dimmed traps. The light intensity of the dimmed trap was 1,010 lx which was only half of that of lighted trap 2,050 lx. The difference in the light intensity might not be large enough to cause a different catch and both lights were attractive enough to allure the crayfish into the traps in the pond.

In the trapping experiments, many more males were captured than females in all type traps while the sex ratio of the population was 1:1 in the pond (Table 3). Such male dominant catch is also reported for *Astacus leptodactylus* (Eschscholtz, 1823) from fyke-nets in a lake (Balik *et al*., 2005), the signal crayfish *Pacifastacus leniusculus* (Dana, 1852) or the noble crayfish *Astacus astacus* (Linnaeus, 1758) from baited traps in rivers (Reeve, 2004; Faller *et al*., 2006), the rusty crayfish *Orconectes rusticus* (Girard, 1852) or *Orconectes virilis* (Hagen, 1870) and *Cambarus bartoni* (Fabricius, 1798) from baited traps in lakes (Somers and Green, 1993; Hein *et al*., 2007). The fyke-net and trap are passive gears and their catch largely depends on the activity of animals and competition between males and females. Molting crayfish are less active especially females (Reynolds, 2002). Egg-bearing females are also less active than males (Holdich, 2002). They become more active after releasing the young and preparing for mating (Faller *et al*., 2006). According to this study, egg-bearing females can be allured into a lighted trap. Crayfish with larger chelae win competitive interactions for shelter (Capelli and Munjal, 1982). Male American crayfish have larger chelae than females of the same size and males might inhibit females from entering traps. Perhaps this is why females comprised only 41% of total catch in the present study. Although the traps are male-biased gear, female ratio in catch would increase when population density decreases and competitive interactions are rare.

It is interesting to note that soft-shell crayfish were captured in the lighted trap. In the laboratory we found post-molt crayfish within several hours after molt tended to crawl away from the lights. When the crayfish molts, the eye functions less well due to the old cornea becoming detached just

before the molt and this probably continues for several hours until the new cornea hardens. The photonegative behavior during the recovery time might be mediated by the caudal photoreceptor located in the 6th abdominal ganglion. It is known that illumination of the tail produces tail flexion followed by backward walking (Edwards, 1984). The capture of the soft-shell crayfish in the lighted trap might indicate that the eye recovers its function soon after the molt and then the crayfish become photopositive again.

The use of light is advantageous in harvesting post-molt crayfish. The post-molt crayfish are not attracted to food or bait as they have no appetite for several days after molt (Nakamura, 1980). The American crayfish show a feeding pattern closely related to the molting cycle; starvation during molt and 2-3 days after molt, highly active feeding for several days after the starvation, steep decrease in feeding activity and a quite low food intake for several days before a next molt (Nakamura, 1980). The use of baited traps might be effective only during the highly active feeding and a relative effectiveness of the lighted trap increases during the low feeding period.

The lighted trap has another advantage. Crayfish prey animals, such as insect larvae and worms, may be attracted to the light and create a foraging opportunity for the crayfish in the lighted traps.

While the baited trap is most effective among the four luring treatments, trapping results indicate that when baited, lighted, non-baited traps are used, some crayfish prefer bait, some prefer light and the others seek for a non-baited trap as a shelter. Therefore, the use of lamp seems feasible for trapping adult and juvenile crayfish. However, some other method is required to effectively capture second post-embryonic crayfish which avoid light and are untrappable in lighted traps.

As a conclusion, we recommend a use of combination of baited traps, lighted traps and some other method developed for capturing post-embryonic crayfish. By this combination, the invasive crayfish at different growth stages would be captured for its eradication.

ACKNOWLEDGMENTS

The authors are grateful to Dr. Kazuhiko Anraku for his valuable comments, to Mr. Masataka Marugi and Mr. Souji Kodama for their technical assistance constructing the traps and to all the staff of the Laboratory of Fishing Technology, Faculty of Fisheries, Kagoshima University for their technical assistance.

REFERENCES

Ackefors, H., 1999. The Positive Effects of Established Crayfish Introductions in Europe. In: Crayfish in Europe as Alien Species. How to Make the Best of a Bad Situation? Gherardi, F. and D.M. Holdich (Eds.). Balkema, Rotterdam, Brookfield, pp: 31-49.

Ahmadi, G.K., M. Vazquez Archdale and K. Anraku, 2008. True electrotaxis and threshold voltages in the American crayfish *Procambarus clarkii*. J. Fish. Aquat. Sci., 3: 228-239.

Balik, I., H. Cubuk, R. Ozkoka and R. Uysal, 2005. Some biological characteristics of crayfish (*Astacus leptodacctylus* Eschscholtz, 1823) in Lake Egirdir. Turk. J. Zool., 29: 295-300.

Capelli, G.M. and B.L. Munjal, 1982. Aggressive interactions and resource competition in relation to species displacement among crayfish of the genus *Orconectes*. J. Crust. Biol., 2: 486-492.

Chidester, F.E., 1912. The biology of the crayfish. Am. Nat., 46: 279-293.

Conover, W.J., 1980. Practical Nonparametric Statistics. 2nd Edn. Texas Technique University, pp: 493.

D'Abramo, L.R. and D.J. Niquette, 1991. Seine harvesting and feeding of formulated feeds as a new management practices for fond culture of red swam crawfish (*Procambarus clarkii* [Girard, 1852]) and white river crawfish (*P. acutus acutus* [Girard, 1852]) cultured in earthen ponds. J. Shellfish Res., 2: 169-178.

Edwards, D.H., 1984. Crayfish extraretinal photoreception. I. Behavioural and motoneuronal response to abdominal illumination. J. Exp. Biol., 109: 291-306.

Faller, M., I. Maguire and G. Klobucar, 2006. Annual activity of the noble crayfish (*Astacus asutacus*) in the Orljava River (Croatia). BFPP/Bull. Fr. Peche Piscic., 383: 23-40.

Faulkner, G. and J.V. Huner, 1994. A Polyethylene Trawl System for Harvesting Crayfish, *Procambarus* spp. in Culture Ponds. In: Book of Abstracts, Annual Meeting World Aquaculture Society, New Orleans, Louisiana, January 14-18, US. World Aquatic Society Baton Rouge, Louisiana, pp: 247-247.

Fernandez-de-Miguel, F. and H. Aréchiga, 1992. Sensory input mediating two opposite behavioural responses to light in the crayfish *Procambarus clarkii*. J. Exp. Biol., 164: 153-169.

Garvey, J.E., R.A. Stein and H.M. Thomas, 1994. Assessing how fish predation and interspecific prey competition influence a crayfish assemblage. Ecology, 75: 532-547.

Gherardi, F., S. Barbaresi and G. Salvi, 2000. Spatial and temporal patterns in the movement of *Procambarus clarkii*, an invasive crayfish. Aqua. Sci., 62: 179-193.

Hein, C.L., M.J. Vander Zanden and J.J. Magnuson, 2007. Intensive trapping and increased fish predation cause massive population decline of an invasive crayfish. Freshwater Biol., 52: 1134-1146.

Hill, A.M. and D.M. Lodge, 1994. Diel changes in resource demand: competition and predation in species replacement among crayfishes. Ecology, 75: 2118-2156.

Holdich, D.M., 2002. Biology of Freshwater Crayfish. 1st Edn. Blackwell Science, Oxford, pp: 702.

Huner, J.V., 1994. Cultivation of Freshwater Crayfish in North America. Section 1. Freshwater Crayfish Culture. In: Freshwater Crayfish Aquaculture in North America, Europe and Australia. Families Astacidae, Cambaridae and Parastacidae, Huner, J.V. (Ed.). Haworth Press, Binghamton, New York, pp: 5-89, 137-156.

Huner, J.V., 1998. The Louisiana crawfish story. Louisiana Wildlife Federation Magazine, 26: 32-35.

Huner, J.V. and J.E. Barr, 1991. Red Swamp Crawfish: Biology and Exploitation. 3rd Edn. Louisiana Sea Grant Coll. Prog. Louisiana State Univ. Baton Rouge, pp: 128.

Kozak, P., J. Martín and J. Escudero, 2007. Selective Behaviour of *Procambarus clarkii* in a Light Gradient. In: Book of Abstracts, 15th International Conference on Aquatic Invasive Species, August, Nijmegen, The Netherlands, pp: 66-66.

McClain, W.R., J.L. Avery and R.P. Romaire, 1998. Crawfish Production: Production Systems and Forages. 1st Edn. Southern Regional Aquaculture Center Publication, Island Press, No. 241, pp: 4.

Nakamura, K., 1980. Quantitative analysis on the feeding patterns of the crayfish relating to the molting cycle. Mem. Fac. Fish. Kagoshima Univ., 29: 225-238. (In Japanese, with English abstract).

Nakata, K. and S. Goshima, 2003. Competition for shelter of preferred sizes between the native crayfish species *Cambaroides japonicus* and the alien crayfish species *Pacifastacus leniusculus* in Japan in relation to prior residence, sex difference and body size. J. Crust. Biol., 23: 897-907.

Nakata, K., K. Tsutsumi, T. Kawai and S. Goshima, 2006. Coexistence of two North American, *Pacifastacus leniusculus* (Dana, 1852) and *Procambarus clarkii* (Girard, 1852) in Japan. Crustaceana, 78: 1389-1394.

Reeve, I.D., 2004. The removal of the North American signal crayfish (*Pacifastacus leniusculus*) from the River Clyde. Scottish Natural Heritage Commissioned Report No. 020 (ROAME No. F00LI12), pp: 55.

Reynolds, J.D., 2002. Growth and Reproduction. In: Biology of Freshwater Crayfish, Holdich, G.H. (Ed.). Blackwell Science, Oxford, New York, USA., pp: 152-192.

Romaire, R.P., 1995. Harvesting methods and strategies used in commercial procambarid crawfish aquaculture. J. Shellfish Res., 14: 545-551.

Somers, K.M. and R.H. Green, 1993. Seasonal patterns in trap catches of the crayfish *Cambarus bartoni* and *Orconectes virilis* in six south-central Ontario lakes. Can. J. Zool., 71: 1136-1145.

Sukô, T., 1953. Studies on the development of the crayfish. I. The development of secondary sex characters in appendages. Sci. Rep. Saitama. Univ., 1: 77-96.

Usio, N., M. Konishi and S. Nakano, 2001. Species displacement between an introduced and a vulnerable crayfish: The role of aggressive interactions and shelter competition. Biol. Invasions, 3: 179-185.

Westman, K., O. Sumari and M. Pursiainen, 1978. Electric fishing in sampling crayfish. Br. Library Doc. Supply Center UK., 4: 251-256.