www.trjfas.org
ISSN 1303-2712
Turkish Journal of Fisheries and Aquatic Sciences 17: 283-291 (2017) DOI: 10.4194/1303-2712-v17_2_07

PROOF

RESEARCH PAPER

Fishing Efficiency of LED Lamps for Fixed Lift Net Fisheries in Banten Bay Indonesia

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Received 27 July 2016
Accepted 22 September 2016

Abstract

Fixed lift net fisheries in Banten Bay used compact fluorescent lamp (CFL) since the middle of 2000 for replacement the traditional pressured kerosene lantern. It was increased the light intensity, but this lamps consumed high energy and fuels. Application of light emitting diode (LED) is considered to energy saving and increased catches in lift net fisheries. The fishing trial was conducted on 22 May-16 June 2015 in Banten Bay Indonesia using 2 units of lift net with 6 units of CFL and LED respectively. The result shows both lamps did not have significant effect on total catches. Meanwhile, application of LED lamps has significant effect to main catch (anchovy). There were increasing catch weight of anchovy with mean 29.49%. LED also decreased of fuel consumption with mean saving 35.15%. It is evident enough to conclude that LED lamps have high efficiency and effectiveness for lift net fishing in Banten Bay.

Keywords: Anchovy, compact fluorescent lamp, light fishing, fuel consumption.

Introduction

Fishing with light is a successful of modern fishing technique that was used in Indonesia since 1950 in various fishing gears (Ben-Yami 1976). The light fishing gears in Indonesia dominated by lift net (bagan) and purse seine (Sudirman and Musbir, 2009). There are 2 types of bagan in Banten Bay Indonesia, fixed lift net as the small scale fisheries, and boat lift net as the thrive of light fishing activities. Bagan has used compact fluorescent lamp (CFL) as fishing lamps to attract photo taxis positive of fish schooling since 15 years ago. It replaced pressurized kerosene lanterns that were used by fishers before developing of gasoline generator as the electric power source. There are variety of light power (W), number of light units, and manufacture of CFL lamps used on bagan fisheries based on traditional knowledge and fishermen experience.

Fishing lamp is a key component for light fishing activities. The light sources of fishing lamps have developed from torch, acetylene, kerosene, incandescent, mercury, fluorescent, and halogen lamps to the metal halide (MH) lamps (Inada and Arimoto, 2007; Ben-Yami, 1976). Fishermen generally think that the catch of light fishing will increase with the rises of light power. However, there are many factors that affect fish attraction such as the quality of light (e.g. wavelength), quantity of light (e.g. power), and arrangement of fishing lights. In addition, underwater illuminance, irradiance level and distribution created by these factors are influenced by the optical characteristics of seawater and influence to the fish behaviour (Arakawa *et al*., 1998; Shikata *et al*., 2011).

The scientific basis evident for selecting the appropriate of light source and its power as fishing lamps still remains unverified. Information about the relationship between fishing lights and fish behavior is still limited and consequently fishermen determine the type, number and power of fishing lights based on their personal experience (Yamashita *et al*., 2012). Meanwhile, light source in fishing attraction by light, which mainly includes filament lamp, halogen tungsten lamp, mercury and metal halide, all belongs to thermal light source (Hua and Xing, 2013). The light from these lamps is omnidirectional and, therefore, most of it does not reach the target areas, such as the deck and the surrounding water (Lai *et al*., 2015). Although these sources have improved light intensity, their main handicap is that these lamps consumed a great amount of electric energy and fuel (Kehayias *et al*., 2016).

Compared with these conventional lamps, LED (light emitting diode) have many advantages, such as high efficiency, a long lifetime, fast response and together with climate resistance (Lai *et al*., 2015). Furthermore, LEDs, which do not contain mercury (as opposed to CFL), are tolerant of low voltages, very small and portable, and have high optical efficiency. LEDs are often submersible, and it can be compared favourably, technically and economically with all other forms of lighting for small-scale applications (McHenry *et al*., 2014). Thus, LEDs have been considered the most promising new lighting solution for a fishing fleet.

The objective of this research is to compare and to analyse the effectiveness of LED lamps application by using catches and fuel consumption indicators. The results from this research can be considered to replace the traditional CFL lamps with LED fishing lamps that was more efficient and environmental friendly to promote sustainable fisheries at Bagan fishing in Banten Bay Indonesia.

Materials and Methods

Lift net fishing in Banten Bay used varies CFL lamps with ranged of output power between 24 W to 90 W per unit. In this research, we tried to introduce the new LED lamps and analysed the effectiveness of both lamps based on catch weight and fuel consumption. Light sources in this experiment are white LED lamps (Fujilight bulb 30 W, 2500 lumens) and white CFL lamps (Cahaya 4U model 90 W, 2400 lumens). These lamps were chosen based on several reasons. The CFL lamps are an existing light source that was used by local fishermen because low price, easy to be obtained, and bright enough to attract fish schooling. Meanwhile, LED lamps have very long operating life, small, low energy consumption (Shen *et al*., 2012; Matsushita and Yamashita, 2012; Hua and Xing, 2013) and they have similar lumens output with CFL lamps based on manufacture specification.

The CFL and LED lamps have different model and construction. They will affect to difference of light distribution of both lamps. To analyse the pattern of light distribution, we investigated the illuminance of both lamps in air and bottom of the sea water. Measurements of luminous intensity in air were performed in dark room at Fisheries Department Laboratory Sultan Ageng Tirtayasa University using digital lux meter (Lutron model LX-103 min scale 1 lx). The light intensity distributions were investigated by rotating sensor at every 10-degree with radius 1 m from the light source to the sensor (Wisudo *et al*., 2002).

Fishing operation was conducted at 2 fixed lift net in Banten Bay with coordinate of LED and CFL lamps at 05º58'02"S; 106º09'40"E and 05º58'05"S; 106º09'58"E, respectively. The platform size of both bagan was 14 m length, 14 m breadth and 12 m depth. Its box-shaped net was 12 m length and 12 m breadth, with 3 mm mesh size of polyamide. Light illuminance of LED and CFL lamps at night in sea water was measured by underwater lux meter (LUW 1000D) at sea surface to 10 m depth during fishing operation. The measurements were conducted at the centre, middle and corner of platform with 1 m interval (Figure 1).

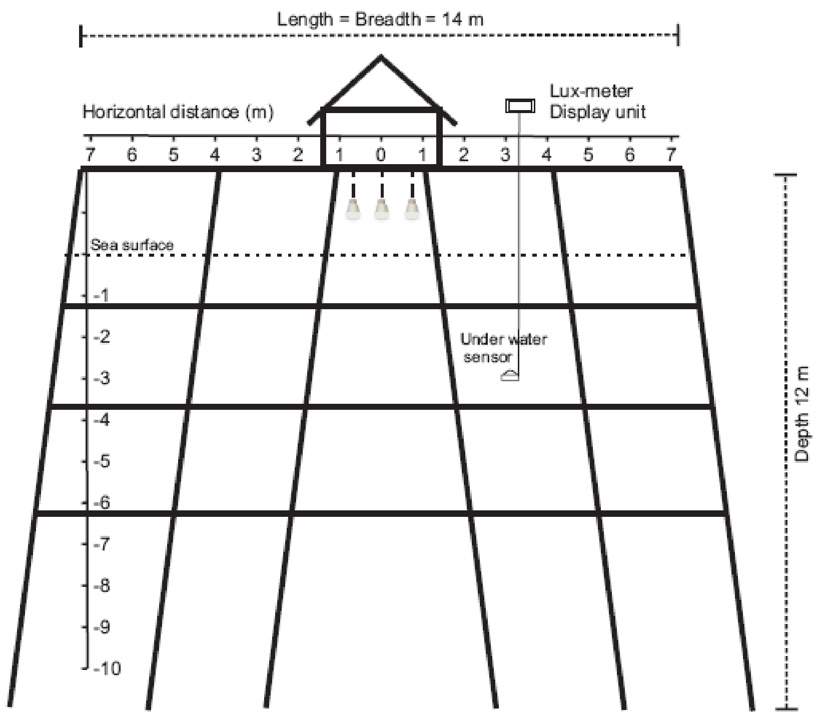

Figure 1. The arrangement of light intensity measurement in sea water.

The first lift net used 6 units of CFL (each lamps is 90 W) and the second bagan used 6 unit LED (each lamps is 30 W) to attract fish schooling into catchable area. The fishing operations were conducted from 7:00 PM to 05:00 AM and the lamps were turned on between 2-4 hours every setting process. The catch data were recorded soon after hauling by sorting the fish based on species, and then weight measured for each species. Fuel consumption of gasoline generator was investigated by adding new fuel using measuring glass every morning after finishing the fishing operation.

Light distribution of LED and CFL lamp in air presented and compared graphically as radar diagram. Luminous intensity of both lamps in sea water shown as graphic of light intensity distribution pattern and describe descriptively. Catch weight (kg) and fuel consumption (l) data were evaluated graphically and performed by *t*-test analysis (α = 0.05). The graphical comparisons of catch weight combined across with fishing trip using total catch, main catch and proportion of main catch that expressed as a percentage of main catch.

Results

Distribution pattern of luminous intensity (lux) of the CFL and LED lamps in the air shows in Figure 2. The light distributions of CFL lamp have main area around the left and right side. Meanwhile the LED lamp has majority of illumination on the bottom of the bulb. The maximum intensity of CFL and LED lamps are 775 lx and 783 lx respectively.

Light illuminances in sea water from CFL and LED lamps have different distribution as shows in Figure 3. The LEDs have higher intensity in surface

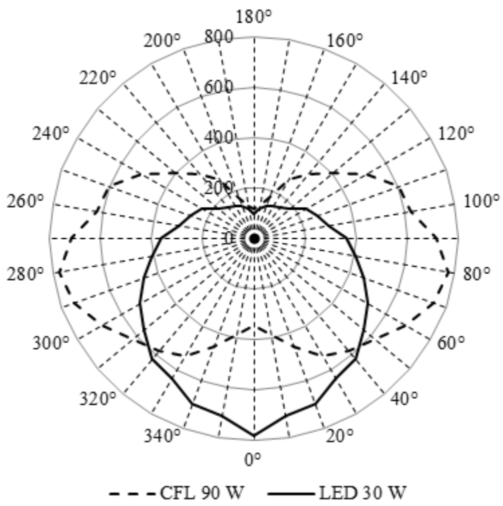

Figure 2. Distribution of light intensity of CFL and LED lamps in the air.

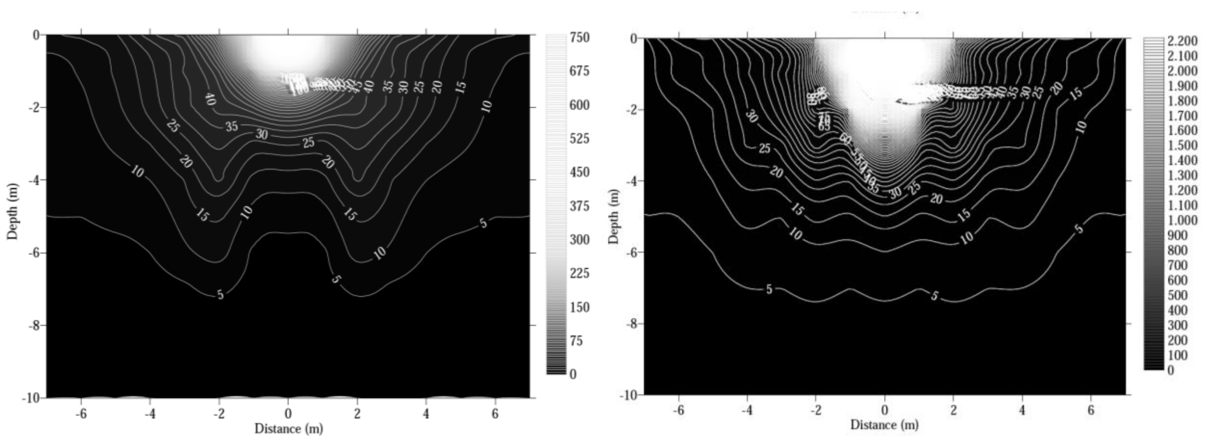

Figure 3. Sea water light distribution of CFL (A) and LED (B) lamps.

water until 5 m deep than CFLs, but the both light source have similar characteristics at 5 to 10 m deep. Light distribution of LED light is more effective and it has homogenous pattern on vertical and horizontal direction. Meanwhile the CFLs are slightly different on vertical, especially on the centre of lift net that have lower intensity than left and right side. The illumination zone for CFL lamps is narrow than LED lamps and it will affect to catchable area on fish capture process.

A total of 120 operations were conducted on 20 days fishing trip by 2 lift net during 22 May-16 June 2015. There was no fishing trips around the full moon (1-5 June) and fixed lift net located in shallow water of Banten Bay less than 15 m deep. The total catch from 2 lift net is 616.57 kg (mean 15.41±0.15 SD). The highest catches is 310.50 kg on lift net that using CFL lamps. The daily catch of CFLs ranged from 6 to 39 kg (mean 15.53±8.94 SD) and LEDs have varied from 7 to 31 kg (mean 15.30±6.10 SD). Figure 4 shows the daily catch from each lift net during experiment. There are no significant different between the total catch of CFL and LED lamps.

Anchovy (*Stolephorus* sp.) is an economic commodity that becomes main target species of lift net fisheries. Figure 5 shows the daily catch of anchovy during experiment. There are a significant different of catches between LEDs and CFLs on trip 1, 3, 5, 6, 8, 9, 11, 13, 17 and 20, respectively. Lift net with CFL lamps get high catches on trip 8, 10 and 19, meanwhile LEDs have more catches on other fishing trip. The maximum catches of LEDs and CFLs were 15.4 kg (mean 9.82±3.72 SD) and 14.0 kg (mean 8.09±3.11 SD) respectively.

Catch composition during experiment shows the LEDs fixed lift net dominated by Stolephorus sp (61.77%), Sardinella fimbriata (14.70%), Leiognathus sp (14.20%), Terapon sp (3.96) and others species

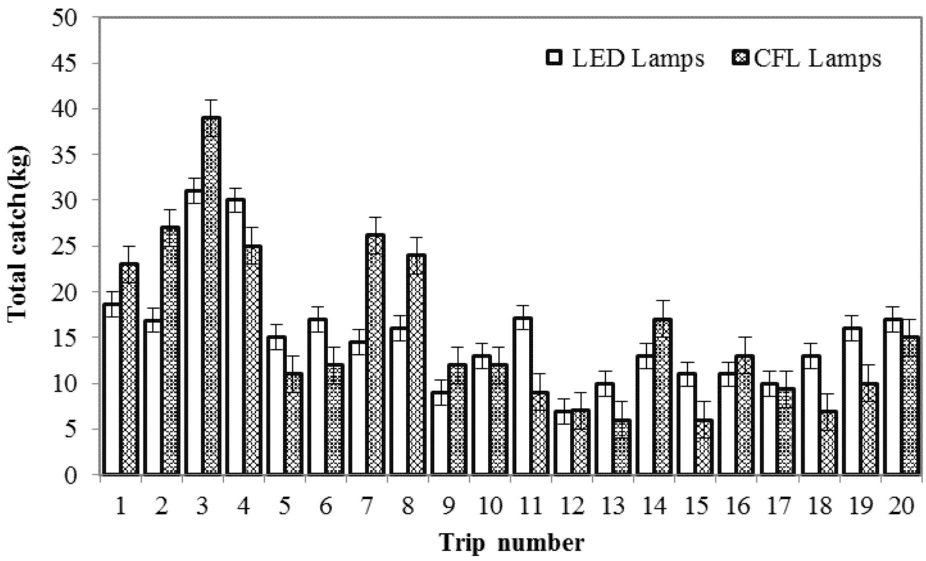

Figure 4. Daily catch of CFLs and LEDs lamps (Vertical lines denote standard errors).

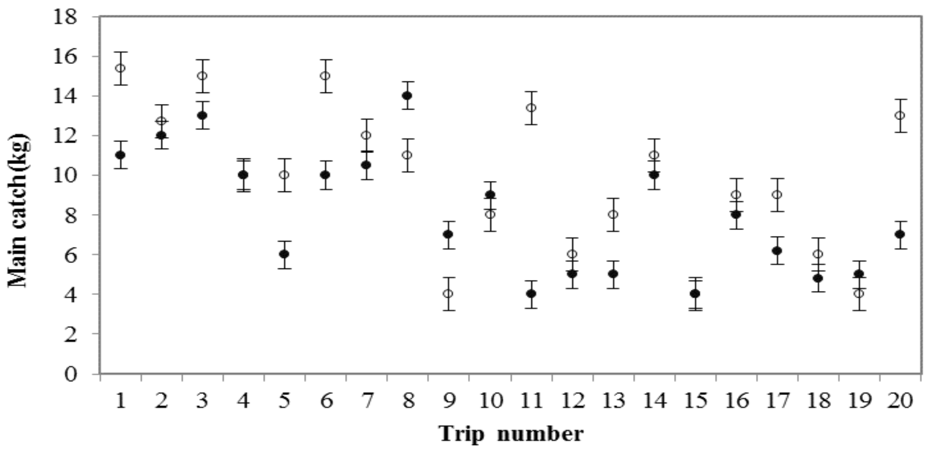

Figure 5. Daily main catches of lift net with LED (circle) and CFL (point) (Vertical lines denote standard errors).

(5.29%). The CFLs catches also dominated by Stolephorus sp (59.99%), followed by Sardinella fimbriata (22.60%), Leiognathus sp (8.18%), Terapon sp (5.61) and others species (3.61%). Meanwhile there was no significant difference between daily total catch of each lamp (p-value 0.2218). Figure 6 shows the proportion (%) of catches weight of LED and CFL during fishing operation. There are slightly different of catches between LED and CFL almost on every fishing trip. The application of LED lamps can get 25% to 90% of anchovy (mean 67±21 SD), while CFL lamps produce 33% to 83% (mean 58± 14 SD). The field experiment of the LED lamps presented no technical problems, especially for the maintenance and replacing the CFL lamps. Specifically, overall increase of main catches using LED lamps of 29%.

The lift net fishing used gasoline generator as a main source of electric power. The maximum output of the generator reaches 2,000 W. Duration for lighting in one day trip approximately 10 hours (07:00 AM to 05:00 PM). Fuel consumption of CFL lamps is higher than LED lamps as shows in Figure 7. Fishing operation using LED lamps consumed 3.30 to 5.30 l/night (mean 4.11±0.61 SD), while CFL lamps consumed 5.20 to 7.00 l/night (mean 6.33 ±0.54 SD). Fuel consumption rate (l/h) under various lamps showed different tendencies. When all the lamps were turn on, lift net with LED lamps consumed 0.33-5.33 l/h for lighting output 180 W and lift net with CFL lamps consumed 0.52-0.70 l/h against 560 W output.

Figure 8 shows the reduction of fuel consumption (%) on lift net operation using LED lamps. Replacing CFL with LED lamps will decrease of fuel consumption during fishing experiment.

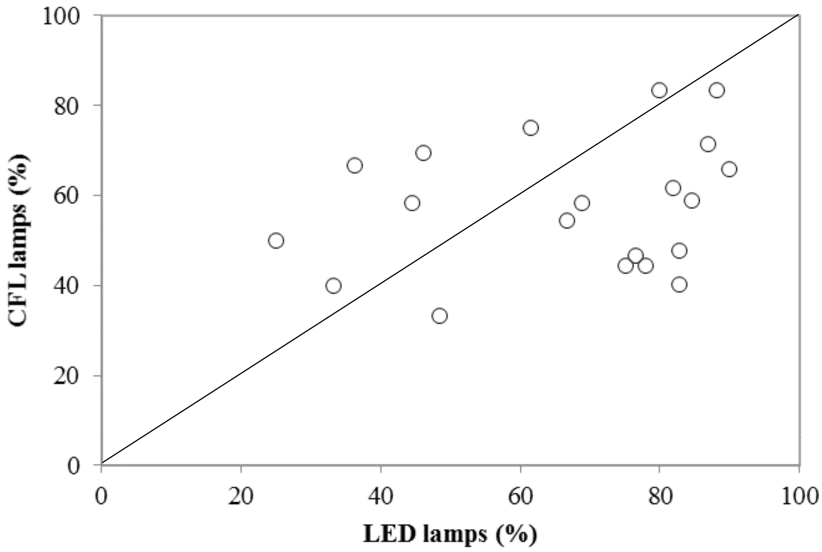

Figure 6. Proportion (%) of lift net main catches using LED lamps plotted against CFL lamps.

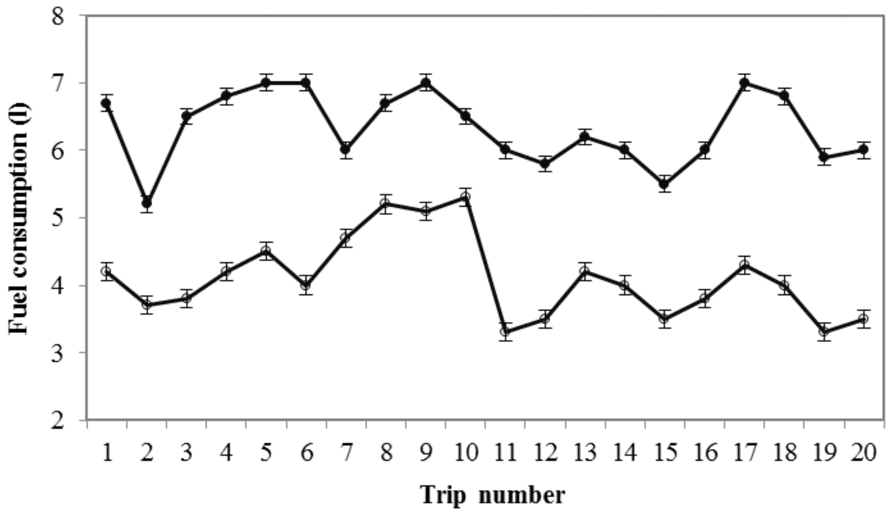

Figure 7. Fuel consumption of lift net using LED (circle) and CFL (point) (Vertical lines denote standard errors).

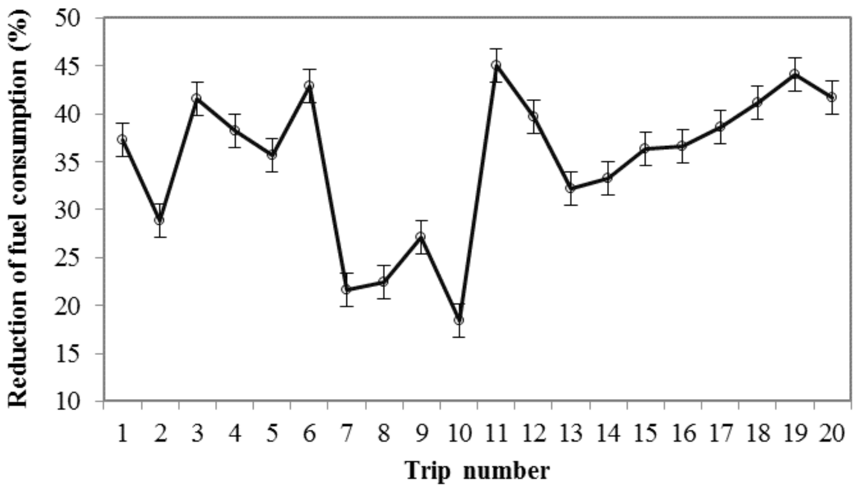

Figure 8. Reduction of fuel consumption of fixed lift net using LED lamps (Vertical lines denote standard errors).

Reduction of fuel consumption ranged from 18% to 45% (mean 35.15±7.76 SD). The LED is an appropriate lamp technology for the lift net fisheries especially to reduce fuel consumption and promote the environmental friendly of small scale fisheries in Banten Bay.

Discussion

The number of fixed lift net in Banten Bay on 2015 reaches 62 units and most of them used CFL lamps to attract target fishes to the catchable area. Fishermen changed their pressurized kerosene lanterns with CFL lamps since 2000 to increase the productivity of lift net fishing operation. The fishers select appropriate CFL lamps based on practical and economic reasons. In this case, low price, easy to used, easy to be obtained, and bright enough are the main consideration that were underlie by local fishermen to select varies of CFL lamps. Nevertheless, application of high output of CFL lamp (up to 90 W per unit) cause increasing of gasoline fuel consumption during fishing operation.

It is evident from Figure 2 that LED produced high intensity at the bottom of lamps (angle 0º-40º and 320º-360º). Meanwhile the CFL transmitted high intensity at both side of lamps (angle 60º-100º and 260º-310º). There are significant different of light distribution because each lamps have different shape and constructions. The CFL lamp has more surface area at the side (u-tube construction), so these sections have maximum light distribution. Light emitted from the bottom of CFL comes from the bottom side of u-tube that had limited surface area and causes the decreasing of light intensity from the lamp (Puspito *et al.*, 2015). Moreover, light from LED lamp has straight direction especially to the bottom area. LED light sources are highly directional and highly efficient light emitters that can focus the light intensity (Shen *et al.*, 2012). It causes maximum intensity at the bottom of lamps position. The spectrum, intensity and light distribution of lamps have specific characteristics depends on shape and purpose of lamps manufacture (Anongponyoskun *et al.*, 2011).

Fishermen used iron lamp shade (350 mm diameter) to focus the light during fishing operation. The characteristic of light sources cause different light distribution pattern in sea water, even if it used same lamp shade. LED light distribution had deeper penetration and widely expanded than CFL light. The maximum intensity of LEDs and CFLs at the sea water surface was 2,244 lx and 758 lx respectively on the centre of lift net platform. There were different pattern of iso-lux contour from each lamps at more than 2 m depth. LED light presented U-shape and CFL light have W-shape that decreased with increasing of depth water. It is related to lamps design, construction and light characteristics from each lamp. Light from LED source have sharp distribution and arrives enough at 15 m depth and have no extreme change in spectrum from the surface to 15 m depth sea water (Okamoto *et al.*, 2008). In this research, lift net fishing operation used the general lighting of LED and CFL lamps that was not designed specifically as fishing lamps. Moreover, the light intensity decrease rapidly related to the emergence angle and it distribution varied at target plane. The lens of LED source with novel design using double freeform surface is an effective method to improve uniformity of light illuminance from 67.20% to 86.43% (Wu *et al.*, 2015).

The light illuminance and distribution from both lamps around fixed lift net platform have similar effectiveness to attract fish into catchable area. Mean catch per unit effort in squid jigging fishery using only 216 LED lamps lower than using 78 Metal Halide Lamps, because LED lamps irradiated only a limited area near of vessel (Shikata *et al.*, 2012). Catch weight of boat lift net using flood LED lamps also lower than mercury lamps (Sulaiman *et al.*, 2015). It was indicated the general lighting of LED lamp cannot used directly as effective fishing lamp on capture fisheries. Fish behaviour and response related to light emitted of LED were investigated to improve design and to obtain an appropriate specification of the new generation of fishing lamps in fishing activities (Mills *et al*., 2014). The new design of white LED lamps used multi-segmented freeform lens (MSFL) can perform better as fishing lamps, 3 times more efficient, than the traditional High Intensity Discharge (HID) lamp (Lai et l., 2015).

The anchovy as main target species of fixed lift net in Banten Bay has high economic value (Indonesia Rupiah/IDR 75,000 – 90,000 per kg/United State Dollar/USD 5.77-6.92 per kg). LED lamps application in this experiment had significant effect to catch weight of anchovy (p-value 0.0087). It is evident from Figure 5 and 6 that catches weight and proportion of main catch using LED lamps is higher than CFL lamps. Previous researches show varied result of LED performance in fishing operation. Combination of LED panel with 24 metal halide lamps presented highest catch of Japanese common squid (Yamashita *et al*. 2012). Light from white LED lamp could penetrate to deeper water and caught more white anchovy (*Stolephorus indicus*) than mercury lamps (Sulaiman *et al*., 2015a). Blue LED was recommended to gathering the squid and white LED was very useful to squid fishing (Jeong *et al*., 2013). Fishing experiment using LED and metal halide lamp in Korean squid jigging fisheries presented that catches of squids per the fishing vessel with 1 W LED fishing lamp were higher up to 135.5% than the fishing vessel with metal halide (An, 2014). Main catch (*Stolephorus* sp.) per unit energy of boat lift net in Sulawesi using LED and mercury lamp is 11.61 kg/W and 3.77 kg/W respectively (Sulaiman *et al*., 2015b).

White LED in this research have dominant wavelength at 450 nm and 590 nm. It is similar properties with Bae *et al*. (2011) that used the dominant wavelength of white LED at 450 nm and 550 nm to attract *Engraulis japonicus.* Characteristic of fishing lamps will have affected to catch weight and species composition. It is related to behaviour and response of fish to light attractant. Each species has different maximum absorbance of light spectrum depend on structure and morphology of retinae. *Stolephorus indicus* have poly-cone type with cone density 684 x 10^4 μm². It is indicate that retinae of this species very adapted to light stimulant (Heb *et al*., 2006). *Engraulis japonicus* and *Engraulis encrasicolus* have triple cone with maximum absorbance wavelength approximately at 502 nm, while the short central components were more shortwave sensitive (α_{max} = 475 nm). The α_{max} of all long and short cones in the ventro-temporal zone was 492 nm, compared to 502 nm in other retinal regions (Kondrashev *et al*., 2012). The dominant catch of *Stolephorus* sp. during experiment indicated the transmitted wavelengths from LED lamps were appropriate enough to the maximum absorbance of anchovy. It schooling influenced, gathering and stay into catchable area for the long times as a response of light adaptation behaviour.

LED lamps had lower fuel consumption than CFL during fishing operation. It is evident from Figure 7 and 8 that LED is efficient light source with mean saving energy up to 35%. Application LED lamps in fixed lift net in Banten Bay had significant effect to reduce fuel consumption (p-value 5.01×10^{-14}). LED fishing lamps in hair-tail angling at Korean fisheries had higher fishing performance, save 33% of fuel consumption, decreased the operation expenses and green house emission (An *et al*., 2012). Fishing experiment at purse seine and squid jigging fisheries showed LED lamps have high productivity and lower fuel consumption than metal halide lamps. LED lamps save 50% of fuel than metal halide (Hua and Xing 2013), more efficient up to 80% than high intensity discharge (Shen *et al*., 2012) and save 24% of fuel in Japanese squid jigging fisheries (Matshushita *et al*., 2012). Application LED lamps in Korean squid jigging industries also decreased 65,163 kl of fuel consumption in a year (Park *et al*., 2015). In small scale fisheries, replacing CFL lamps with LED lamps save 37.5% of fuel consumption in fixed lift net at Lesung Cape Banten Province (Arif *et al*., 2015).

In conclusions, we found the light distribution of commercial LED lamps could penetrate wider and deeper to the catchable area than CFL lamps and were good enough to attract the target species of anchovy. Application of LED lamps had significant effect to the catch weight of anchovy and save fuel consumption. The LED lamps are the potential suitable light source for replacing CFL lamps and developing sustainable lift net fisheries in Banten Bay.

Acknowledgments

This research supported by the Ministry of Education and Culture, Republic of Indonesia. We deeply grateful to Mr.Pendi, a fixed lift net fisherman coordinator, and all the crews of experimental platform for their cooperation during fishing trials.

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