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IJAB-20-0048 Editor assigned

2 messages

Muhammad Kasib KHAN <kasibdadra@hotmail.com> 1 February 2020 at 12:45
To: "adisusanto@untirta.ac.id" <adisusanto@untirta.ac.id>

Ms No.: **IJAB-20-0048**

Title: **The behavioral and retinular response of Scad *Selaroides leptolepis* to low light emitting diode**

Dear Author(s),
Reference to above mentioned manuscript, I have been assigned as editor to your manuscript. The current status of your manuscript is "Reviewers Assignment Pending".
For further correspondence related to your manuscript, you can contact me directly.
Thank you for considering IJAB for submission of your manuscript.

Best Regards

Dr. Muhammad Kasib Khan | D.V.M., M.Sc., Ph.D. (HZAU, China)
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Adi Susanto, S.Pi., M.Si <adisusanto@untirta.ac.id> 1 February 2020 at 14:00
To: Muhammad Kasib KHAN <kasibdadra@hotmail.com>

Dear Dr. Khan

Thank you for your information.

We hope the review process will already done soon.

Kind regards.
[Quoted text hidden]

Adi Susanto, S.Pi., M.Si <adisusanto@untirta.ac.id>

MS IJAB-20-0048 Minor revision

3 messages

Muhammad Kasib KHAN <kasibdadra@hotmail.com> 6 March 2020 at 12:04
To: "adisusanto@untirta.ac.id" <adisusanto@untirta.ac.id>

Dear author(s),

The manuscript IJAB-20-0048 has been evaluated by the reviewers and a minor revision is suggested. Please find attached herewith evaluation sheet containing reviewers' comments and a manuscript file with page numbers for understanding of comments of reviewer(s). Please note that the one of the reviewers also commented in the attached manuscript file which needs to be addressed in the revision. The author(s) are advised to make changes in the attached manuscript using track changes and submit marked-up file along with reviewer's response on a separate sheet.

Best Regards

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3 attachments

- **Evaluation IJAB-20-0048.pdf**
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- **Manuscript IJAB-20-0048.docx**
  4390K
- **Manuscript IJAB-20-0048.docx**
  4390K

Adi Susanto, S.Pi., M.Si <adisusanto@untirta.ac.id> 6 March 2020 at 12:53
To: Muhammad Kasib KHAN <kasibdadra@hotmail.com>

Dear Dr. Khan

Thank you very much for your information.
We will address suggestion from the reviewers to our manuscript.

Best regards.

[Quoted text hidden]

Adi Susanto, S.Pi., M.Si <adisusanto@untirta.ac.id> 11 March 2020 at 11:10
To: Muhammad Kasib KHAN <kasibdadra@hotmail.com>

Dear Dr. Khan

Friends Science Publishers
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Manuscript Evaluation Report

MS No: **IJAB-20-0048**

Title: The behavioral and retinular response of Scad *Selaroides leptolepis* to low light emitting diode

Author(s): Sugeng Hari Wisudo, Adi Susanto, Mochammad Riyanto, Mulyono Sumitro Baskoro, Fis Purwangka

COMMENTS

Reviewer 1

In generally, it is a good manuscript and well prepared.

Title

Please consider to change to "The behavior and retinular response of scad, *Selaroides leptolepis* to the different colors of light emitting diode."

Abstract

Please consider to add "The combination of both green and white LED can be more effective light attractant to scad for lift net fishing" around the end of the abstract.

Keyword

Please consider to add "behavioral response, retinular response, *Selaroides leptolepis*, LED fishing"

Introduction

- Line 51-52, how prominent/important of the lift-net fishing in Indonesia? What are the target species of the life net? Why the scad was interested/focused in this study?... It is pretty good if the authors can show some catch statistics and others.
- Line 55, what is the CFL lamps?

Materials and Methods

Regarding the experiment conditions, for example the tank size (150x200x50 cm) and the water depth (30 cm, real fishing ground about 10 m you mentioned) and so on, how the size and depth can be accepted for such a kind like this experiment particularly in the view point of the fish schooling observations for the pelagic fish as scad? Please explain clearly or add some references to make clear that the tank conditions/methods can be accepted for the experiment.

Discussions

Good discussions!

- Line 249, Fig 7, please try to discuss more why the swimming patterns of the scad in the green and orange LED had similar tendencies (b &d) but quite different from white LED (d)?
- Regarding the lift net fishing operation, from the results of behavioral and reitnular response of this study, besides the schooling and swimming patterns of the scad, are there any good points to apply for improving the catch efficiency or better understanding of the capture process?

It was a good research work and the manuscript was well prepared, so it should be accepted with minor revisions.

Reviewer 2:

The paper is in good condition. However, some reviews must be done especially in reference part.
Suggestions have been included in manuscript file.

DECISION

Minor revision

Reviewer 1

No	Reviewer Comment	Revision
1	Please consider to change to "The behavior and retinular response of scad, *Selaroides leptolepis* to the different colors of light emitting diode."	Already revised in Title The behaviour and retinular response of Yellowstripe scad, *Selaroides leptolepis* to the different colors of light emitting diode
2	Please consider to add "The combination of both green and white LED can be more effective light attractant to scad for lift net fishing" around the end of the abstract	We have revised in Abstract in Line 40-41
3	Please consider to add "behavioral response, retinular response, Selaroides leptolepis, LED fishing"	We have revised in keywords in Line 42
4	Line 51-52, how prominent/important of the lift-net fishing in Indonesia? What are the target species of the life net? Why the scad was interested/focused in this study? It is pretty good if the authors can show some catch statistics and others.	Thank you very much for your question and suggestion to improve this paper, we have added the information regarding your comment in 53-58 with catch statistics and proportion of scad in lift net fisheries
5	Line 55, what is the CFL lamps	We have added the information regarding CFL lamps in Line 58
6	Regarding the experiment conditions, for example the tank size (150x200x50 cm) and the water depth (30 cm, real fishing ground about 10 m you mentioned) and so on, how the size and depth can be accepted for such a kind like this experiment particularly in the view point of the fish schooling observations for the pelagic fish as scad? Please explain clearly or add some references to make clear that the tank conditions/methods can be accepted for the experiment.	Thank you for the comment: All experimental setup is following to previous research, especially from Marchesan et al. (2005), Pignatelli et al. (2011), Cha et al. (2012), and Utne-Palm et al. (2018). We have revised in Line 93-94
7	Line 249, Fig 7, please try to discuss more why the swimming patterns of the scad in the green and orange LED had similar tendencies (b &d) but quite different from white LED (d)?	Thank you for your suggestion: we added some discussion regarding the swimming pattern of the scad to the LED lamps in Line 283-300.
8	Regarding the lift net fishing operation, from the results of behavioural and retinular response of this study, besides the schooling and swimming patterns of the scad, are there any good points to apply for improving the catch efficiency or better understanding of the capture process?	We have added the discussion regarding on your suggestion in Line 312-321

Reviewer 2

No	Reviewer Comment	Revision
1	Scad, please write in complete common name	Thank you very much for your suggestion, we have revised in title to Yellowstripe scad
2	Matsushita and Yamashita, 2012: This one was not found in References	We have added the reference as your suggestion in Line 383-385
3	Where the location of the laboratory? At a laboratory? At your university?	We have added the information of the laboratory in IPB University. We have revised in Line 87-88
4	Nguyen and Tran, 2015 This one was not found in References	We have added the reference as your suggestion in Line 405-406

Received 09 Jan.

Running title: ~~Behavioral~~Behavioural and ~~retinular~~reticular response of Scad

The ~~behavioral~~behavioural and ~~retinular~~reticular response of Scad, *Selaroides leptolepis* [SG1]to low light emitting diode

Novelty statement

In this manuscript, we describe the novel approach to design efficient and effective fishing lamp using low light LED lamp due to behavioral and retinular response of fish. The new approach was conducted to determine the light intensity threshold and colour preference of fishing lamp for concentrating and focusing the fish at catchable area. We found that the white LED is suitable enough for attract the fish and the green one is effective for focusing and control the ~~behavior~~behaviour of fish in catchable area.

Abstract

The objective of this research is to ~~analyze~~analyse the ~~behavioral~~behavioural and the ~~retinular~~reticular response of scad through both laboratory observation and a fishing trial as scientific evidence to designate the effective LED light for lift net fisheries. Different colors were used in a laboratory experiment, including green, orange, and white LED. Laboratory experiment were conducted in three illumination levels, low, medium, and high intensity. Light intensity strongly affects fish ~~behavior~~behaviour and activity. Green light improves the vision of fish and the ability to maintain schooling ~~behavior~~behaviour. Using the same LED colors, the adaptation stage of cone cells increases as the light intensity grows. The exposure of high-intensity LEDs rapidly induces the cone cells into photopic adaptation. The same results are found in both fishing trials and laboratory observations. Regarding the ability to induce good light adaptation and stable swimming patterns, it is argued that green LED lamps are preferable to substitute fluorescent lamps currently used in the lift net fishing.

Keywords: adaptation, cone, intensity, lift net

Introduction

Light fishing is one of the most effective and advanced fishing methods to catch commercial pelagic species in both small-scale and large-scale fisheries. In the common fishing practices, fishers use either fixed or mobile fishing gear (Ben-Yami, 1976; Wang et al., 2010; Yamashita et al., 2012; Ortiz et al., 2016; Solomon and Ahmed, 2016; Nguyen et al., 2017; Nguyen and Winger 2019). However, artificial light consumes a significant amount of energy due to the use of numerous high powered lamps. One of the prominent small-scale light fishing practices in Indonesia is lift net fishing, which uses a fluorescent lamp as the typical light sources. The application of fluorescent lamp in lift net fishing has several problems, including short lifetime, high fuel consumption and low effectiveness to control the fish ~~behavior~~behaviour during fishing operation. Fishing operation using CFL lamps in fixed lift net consumed 5.20 to 7.00 l/night (mean 6.33 ±0.54 SD) while light emitting diode (LED) lamps consumed 3.30 to 5.30 l/night (mean 4.11±0.61 SD). However, it is argued that differences in fluorescent lamp quantities and wattages significantly affect the fishers' income (Susanto et al. 2017a).

Light emitting diode as the latest efficient light source technology, has the potential to be applied as an artificial light source for fishing with light (An et al., 2017; Susanto et al., 2017b; Nguyen and Winger 2019). This lamp provides the maximum illumination power combined with lower energy consumption, longer lifetime, higher efficiency, better chromatic performance, and lower environmental impact compared to traditional lighting technology (Matsushita et al., 2012; Matsushita and Yamashita, 2012[SG2]; Yamashita et al., 2012; Breen and Lerner, 2013; Hua and Xing, 2013; Yeh et al., 2014; An et al., 2017; Nguyen and Winger 2019). Furthermore, the light distribution of LEDs, colour and intensity considerably affect fish ~~behavioral~~behavioural and ~~retinular~~reticular response. Therefore, understanding the ~~behavior~~behaviour of target species in response to LEDs is an important step to develop an efficient LEDs for lift net fisheries.

We illuminate scad (*Selairoides leptolepis*) by three different low powered LED light sources including green, orange, and white lamps, as well as dark conditions to investigate the ~~behavioral~~behavioural and retinular response. Furthermore, in order to determine the LEDs performance for lift net fishing, we focused to construct the basic evidence regarding the behavioral and the retinular response of scad through fishing trial. This information is important to develop efficient and effective LEDs for lift net fishing in Indonesia.

Materials and Methods

Fish and Tank Experiment

For the laboratory experiment, the ~~behavior~~behaviour monitoring was conducted in a black fiberglass of rectangular prims open tank (150W x 200L x 50H cm) and the water depth was maintained at 30 cm. [SG3]The tank was placed in the controlled dark room to secure no natural light existing during experiment. The tank was divided into six zones and marked at the bottom in 10 cm intervals as the calibration scale (Fig. 1). Being closer to the light source zone 3 and 4 are light zones (bright zones), while zone 1,2,5, and 6 are the dark zones. The LEDs were assembled approximately 20 cm from sea water level at experiment tank.

The running water systems were installed to ensure the fish remain alive in optimum water quality during observation. Scad (12.45 cm in average total length (TL), N=60) were collected using a guiding barrier at Banten Bay and transferred to the laboratory for adaptation and acclimatization period for seven days. The scad were exposed to normal daily light-dark cycle (12 L: 12 D, sun light were used in daytime). The water salinity in all tanks was maintained at 30-33 ‰, the temperature was at 29-31°C and dissolved oxygen ranged from 5.9-6.1 mg/L. Before and after the experiments, fish were fed two times per day with *Arthemia sp*. Therefore, the behavior experiment was conducted on static water circulation. All of the experiments were performed during the night to minimize the influence of light from any endogenous circadian effects on the fish ~~behavioral~~behavioural and ~~retinular~~reticular responses.

Light Source and ~~Behavioral~~Behavioural Methods

Lamps were assembled using four dual inline package (DIP) LEDs (Shenzhen Yuliang Optoelectronics Technology Co. Ltd) mounted on the metal housing (11L x 5W x 7H cm), powered by 4 V DC supply. The experiments were conducted in three colors of LEDs i.e. green [approximate peak wavelength = 565 nm], orange [approximate peak wavelength = 600 nm], and white [approximate peak wavelength = 450 nm and 545 nm]. Therefore, each of which consists of three illumination levels i.e. 20, 35, 50 lux. Light intensities were measured using ILT 5000 research radiometer at 15 cm distance bellowed sea water level of the tank. The intensity of green LEDs at 20 lux, 35 lux, and 50 lux is 24 μW.cm^{-2}, 54 μW.cm^{-2}, 90 μW.cm^{-2}, respectively. In the same order of illumination level, the intensity for orange LEDs was 20 μW.cm^{-2}, 21 μW.cm^{-2}, and 24 μW.cm^{-2} while for the white LEDs was 15 μW.cm^{-2}, 76 μW.cm^{-2}, and 94 μW. cm^{-2}.

The order of the experimental procedures is as follows. Firstly, before being tested 30 scad were left at the experimental tank at least three days to acclimate, and were subjected to a 12 L:12 D photoperiod (light from 06:00 to 18:00; dark from 18:00 to 06:00). Ambient illumination at 15 cm deep below seawater-level was about 16 nW.cm^{-2} in light conditions. All experimental sessions started at 19:00 and ended at 22:00. Secondly, before the experiment was started and between each experiment, fish were kept in the dark state for 30 minutes to ensure their retina in a scotopic condition. Subsequently, each lamp was turned on for 30 minutes to allow fish to respond and adapt to the light. Visual observation and video recording using the infrared camera were conducted during the dark and lighted conditions. Three replications were conducted for each experiment (Marchesan et al., 2005). A total of 540 minutes of video recording was analyzed for each color to define fish proportion, scad swimming speed around illumination zone, mean of nearest ~~neighbor~~neighbour distance (MNND), and swimming pattern of the fish schooling.

Retinular Response to Irradiance Changes

We used eighteen fish for the retinal adaptation experiment using the following procedure. Firstly, two fish were taken from the storage tank and placed in a cylinder tank with diameter 50 cm and height 43 cm. After 30 minutes set in the dark state, each LED lamp was illuminated for approximately 30 min, and at the end of each treatment, eye specimens from both fish were collected. Subsequently, each specimen was fixed in Bouin's solution and infiltrated with paraffin. Tissue samples were cut in cross-sections of 4-6 μm thickness and were stained with ~~hematoxylin~~haematoxylin and eosin for examination under the microscope. This histological process followed the procedures from Arimoto et al. (2010) and Jeong et al. (2013).

Fishing Experiment

The result of laboratory experiment was applied to define the suitable LEDs color for the fishing trial which was conducted using a fixed lift net in Banten Bay during peak fishing season on August 2018. The fishing trial was conducted at 10 m water depth as common fishing ground in Banten Bay. According to the laboratory experiment, scad are especially responsive to white and green LEDs. Therefore, both lamps were compared to a fluorescent lamp, the light source used in the existing lift net fishing. We conducted the fishing experiment using 50 W of a fluorescent lamp (typical lamp for lift net fishing) and 1.4 W of LEDs due to the similar light output in the seawater column (12-15 μW.cm^{-2}; measured using ILT 5000 at 1 m below sea water). Ten fish were collected from each lamp making it 30 fish in total. Subsequently, all fish's eyes went through the histological procedures, followed by the examination of retinular adaptation under the microscope.

Data Analysis

In order to determine the degree of fish preference on each light stimulus, the proportion of fish at each zone was ~~analyzed~~analysed by counting the number of gathered fish in each zone per minute observation (Kim and Mandrak, 2017). Social ~~behavior~~behaviour was determined by the mean nearest ~~neighbor~~neighbour distance (MNND), which is the average of the planar distances between each fish (head) and its closest ~~neighbor~~neighbour (Parrish et al., 2002). It was used to define the effect of different colors and intensity of schooling characteristics of fish (Torisawa et al., 2007; Jolles et al., 2017). The MNND was ~~analyzed~~analysed using images that converted from the movie at the beginning (< 10 min), intermediate (11-20 min), and the end of observation (21-30 min). The distance was analyzed with Kinovea 0.8.15 at the center head of fish (Fig 2).

The degree of retinal light adaptation was represented in the adaptation ratio (%) (Arimoto et al., 2010), which was calculated by $(B/A) \times 100$ (%), where A (μm) represents the distance between the limiting membrane and the surface of the retina, and B (μm) represents the migration of cone cells when it was stimulated by light. A and B were measured using photomicrographs (Fig. 3). Swimming patterns at both LEDs colors and irradiance levels were analyzed by using video tracking and trajectory software (Kinovea 0.8.15). Videotapes were preliminary observed at 4X speed, to obtain the first qualitative swimming pattern and the characteristic of each stage. In all experiments at every repetition, three dominant swimming patterns from each LED's stimulus were chosen at the beginning, intermediate and the end of the observation period. Parameters used to ~~analyze~~analyse the swimming speed of each pattern in total length per second (TL/s) are (1) time-lapse in each pattern; (2) number of frames; (3) distance of each pattern. One-way ANOVA was applied to ~~analyze~~analyse the effect of different light stimuli (as explanatory variable) to proportion, MNND, and swimming speed during observation (as response variable). Post-hoc comparisons, wherever significance was found, were conducted using Tukey HSD test with the significance level was set at $p<0.05$.

Results

Fish Preference to Light Stimuli

The scad responded to the different light colors. At all illumination levels of each color, fish showed high aggregation levels to the light zone. It was indicated by higher fish proportions in zone 3 and 4 than dark zone as presented in Fig. 4. However, there was not a significant difference in fish proportions at the dark condition for all zones (zone 1 to 6). The fish proportion at the dark condition between the range 14 and 19%. The proportion tended to increase related to the aggregating of light intensity, especially at the light zone. At the low intensity, the proportion of fish at zone 3 and zone 4 was ranged between 22-32%. However, the proportion was increased to 34-44% at high intensity level. There was also evidence to suggest that light intensity (in the range 15-94 $\mu W.cm^{-2}$) influences the behavior of the fish by modifying swimming aggregations and preference in all LEDs colors.

Relationship Between The Retinular Response and Irradiance Change

The light adaptation of scad was influenced by LEDs color and intensity. The degrees of adaptation of scad at scotopic adaptation are in the range between 26 and 34%. Adaptation ratio increased with increasing light intensity at each LEDs color (Fig. 5a). The green LEDs generated the highest adaptation ratio with a slight increase, range 83% (low intensity) to 93% (high intensity). However, the degree of light adaptation with orange and white LEDs produced a various tendencies. The adaptation ratio of orange LEDs at low intensities is 32%, and increase to 67% for the high light level. Furthermore, white LEDs generated higher adaptation ratio than orange LEDs with the ratio between 73% (low intensity) to 92% (high intensity).

Swimming Behavior

The swimming behavior of scad was strongly affected by light intensities at each LED color. There was a significant decrease of MNND in all treatment with increasing intensity. The farthest individual distance generated with orange LED was 14.8 cm, while the closest distance was found at a white LED of 8.2 cm. In all experiments, the decline of MNND has a relationship with increasing swimming speed. Scad has the fastest swimming speed at green LED approximately 3.0 $TL.s^{-1}$, while the lowest speed was initiated at low intensity of white LED approximately 1.4 $TL.s^{-1}$ (Fig. 6).

The different LED treatments also influenced the pattern of swimming behavior. In all dark conditions, fish swam randomly around the experiment tank. There are inconsistent and irregular swimming patterns of scad during the dark observation period. The light exposure caused changes in swimming behavior. In low intensity, the different color of LEDs did not affect the behavioral patterns. Moreover, the increasing light intensity induces the transformed swimming pattern in all colors. The fish swam randomly and inconsistently at a high intensity of the white LED. However, the scad showed a consistent response to orange and green LED with different radii in swimming patterns. Its radius with green LED is closer to the main light zone than orange LEDs, as presented in Figure 7. Moreover, there were constant and stable swimming patterns related to the time elapsed at the green LEDs, approximately after 20 minutes of observation. The specifics of fish swimming behavior are presented in Table 1.

Fishing Trials

There are 1,082 scads were caught during fishing experiment. The light adaptation of the retina collected during the fishing trial is shown in Fig 5b. The cone index was found to be between the range of 78 and 91%. The green LED generated a higher mean adaptation ratio (84%) than white LED (81%) and a fluorescent lamp (83%). However, there were no significant differences in cone index from the sea experiment ($P>0.05$).

Discussions

The highest number of fish proportion in the bright observation zone indicated the scad as a phototaxis fish that attracted by light. The proportion was superior to the bright zones. However, these zones have a smaller area than shadow zones. There were significant differences in the fish proportion between colors and intensities, whereas the proportion in the bright zone at each color gradually increased with rising intensity. The brightness level influences the level of fish activity. Thus, it would have been relevant to increase the fish proportion in all bright zones (Marchesan et al., 2005; Utne-Palm et al., 2018). This condition is an adaptation response to maintaining the formed characteristic of scad schooling behavior, related to the exposure of light intensity in their environment (Woodhead, 1966; Martin and Perez, 2006).

There were significant differences in light adaptation ratio between dark and light state ($p<0.05$). The degree of light adaptation ratio has a positive association with an increase of light intensity (Susanto et al., 2017c). With all colors used in the experiment, the adaptation stage of cone cells increases with expanding intensity. The exposure of high-intensity LEDs induces the cone cells into photopic adaptation rapidly. Thus the light adaptation ratio was increased (Tamura and Niwa, 1967; Nakano et al., 2006; Migaud et al., 2007). The green LEDs generated the highest adaptation ratio of scad in all intensity levels. Thus, it would have been relevant to conclude that the maximum sensitivity of the Carangidae fish family, including scad, has a peak sensitivity between 494-500 nm (Munz and McFarland, 1973).

Light intensity has prevailing influence on the visual ability of fish. However, scad's ability to use vision to maintain the schooling characteristic during light level increases necessitates phototaxis. Moreover, there were significant differences in swimming behavior, including swimming patterns and MNND in the different light conditions, whereas the fish activity increased with rising intensity. The MNND has a negative relationship with light intensity, whereas the MNND decreased with increasing intensity levels. However, the swimming speeds of scad showed different tendencies with MNND during expanding light levels. The fish swam faster at the high intensity at all LED colors. The high intensity induced fish easier to maintain the direction and orientation of their schooling, due to an increase in their swimming speed at all treatments (Miyazaki et al., 2000). Similar tendencies were found at the swimming speed of Atlantic salmon *Salmo salar*. Its speed was increased from 0.2 BL/s to 0.5 BL/s related to the increase of the light level at sea cage observation (Hansen et al., 2017).

The swimming patterns of scad in the green and orange LEDs have similar tendencies. However, the swimming radius at the green LED was closer to the center of the light zone than an orange LED. The fish have a proper response to green light due to an increase in visual ability and significant influence to fish capability to maintain their schooling characteristics. In one example of schooling during increased light intensity, increasing visual ability influenced each individual, enabling them to maintain their distance and formation relative to the rest of the school during swimming (Glass et al., 1986; McMahon and Holanov, 1995; Miyazaki and Nakamura, 1990).

The light adaptation of scad from the fishing experiment has similar tendencies with laboratory observations. The green LED generated a higher degree of adaptation than the white LED and fluorescent lamp at the same intensity. The information on the retinular response and adaptation to light source was utilized in studying the relationship between a light fishing procedure, light color, and light intensity to develop an efficient use of the LED fishing lamp (Jeong et al., 2013). In this research, we compare the characteristics of scad swimming behavior, and light adaptation between experimental tanks and fishing trials to determine the suitable low powered LED color as a light source when fishing. From these results, the green LED, which induces good light adaptation and stable swimming patterns, is suitable enough to substitute fluorescent lamps currently used in lift net fishing.

The combination in both green and white LED can be a more effective light attractant to scad fishing at lift net fisheries. The white LED is useful when gathering scads and induces high light adaptation. However, the swimming pattern of scad at white LED was random and unstable, due to the light source having to change with green LED when focusing the fish at a catchable area. The LED innovation as artificial light has several advantages. The LED provides maximum illumination power, combined with minimum energy consumption, long lifespan, high efficiency, better chromatic performance, and reduced environmental impact compared to traditional lighting technology (Matsushita et al., 2012; Matsushita and Yamashita, 2012; Yamashita et al., 2012; Breen and Lerner, 2013; Hua and Xing, 2013; Yeh et al., 2014; Nguyen and Tran, 2015[SG4]; An et al., 2017). However, further fishing trials are recommended to validate the effectiveness of both white and green LED as a light stimulus for gathering and focusing scad at lift net fisheries.

Conclusions

Present investigation showed the white LED is a suitable enough to attract fish to catchable area while the green LED is an effective color for focusing and control behavior of scad in catchable area. We conclude that combination of white and green LED can be a more effective light attractant to scad fishing at lift net fisheries.

Acknowledgments

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References[SG5]

An, Y.I., P. He, P., T. –Arimoto, T., U. J. Jang, U.J. 2017. Catch performance and fuel consumption of LED fishing lamps in the Korea hairtail angling fishery. Fish. Sci., 83: 343–352.

Arimoto, T., Glass, C.W., Zhang, X. 2010. Fish vision and its role in fish capture. He, P. (Eds), Behavior of marine fishes: capture processes and conservation challenges. Blackwell Scientific, USA

Ben-Yami, M., 1976. Fishing with light. Fishing News Books, Oxford USA

Breen, M., Lerner, A. 2013. An introduction to light and its measurement when investigating fish behaviour. Symposium on the Light session and the Topic Group Lights: ICES-FAO Working Group on Fishing Technology and Fish Behaviour. May 6–10, Bangkok, Thailand

Glass, C.W., Vardle, C.S., Mojsiewicz, W.R. 1986. A light intensity threshold for schooling in the Atlantic Mackerel *Scomber scombrus*. J. Fish Biol., 29 (Suppl A): 71-81

Hansen, T.J., Fjelldal, P.G., Folkedal, O., Vågseth, T., Oppedal, F. 2017. Effects of light source and intensity on sexual maturation, growth and swimming behaviour of Atlantic Salmon in sea cages. *Aquac. Environ. Interact.*, 9: 193-204

Hua, L.T. and Xing, J. 2013. Research on LED fishing light. *Res. J. Appl. Sci, Eng. and Technol.*, 5: 4138-4141

Jeong, H., Yoo, S., Lee,.J., An, YI. 2013. The retinular responses of common squid *Todarodes pacificus* for energy efficient fishing lamp using LED. Renew. Energy., 54: 101-104

Jolles, J.W., Boogert, N.J., Sridhar, V.H., Couzin, L.D., Manica, A. 2017. Consistent individual differences drive collective behavior and group functioning of schooling fish. *Current Biol.*, 27: 1-7

Kim, J. and Mandrak, N.E. 2017. Effects of strobe lights on the behaviour of fresh water fishes. Environ. *Biol. Fish.*, 100: 1427-1434

Marchesan, M., Spoto, M., Verginellab, L., Ferreroa, E.A. 2005. Behavioural effects of artificial light on fish species of commercial interest. *Fish. Res.*, 73: 171-185

Martin, R.S. and Perez, J.A.A. 2006. Cephalopods and fish attracted by night lights in coastal shallow-waters, off Southern Brazil, with the description of squid and fish behavior. *Revista de Etologia.*, 8: 27-34

Matsui, H., Takayama, G., Sakurai, Y. 2016. Physiological response of the eye to different colored light-emitting diodes in Japanese flying squid *Todarodes pacificus*. Fish. Sci., 82: 303-309

Matsushita, Y., Azuno, T., Yamashita, Y. 2012. Fuel reduction in coastal squid jigging boats equipped with various combinations of conventional metal halide lamps and low-energy LED panels. *Fish. Res.*, 125-126: 14-19

Matsushita, Y., Yamashita, Y. 2012. Effect of a stepwise lighting method termed "stage reduced lighting" using LED and metal halide fishing lamps in the japanese common squid jigging fishery. *Fish. Sci.*, 78: 977-983

McMahon, T.E. and Holanov, S.H. 1995. Foraging success of largemouth bass at different light intensities: implications for time and depth of feeding. *J. Fish. Biol.*, 46: 759-767

Migaud, H., Cowan, M., Taylor, J., Ferguson, H.W. 2007. The effect of spectral composition and light intensity on melatonin, stress and retinal damage in post-smolt Atlantic salmon, *Salmo salar*. *Aquac.*, 270: 390-404

Miyazaki, T. and Nakamura, Y. 1990. Single line acuity of 0-yearold Japanese parrotfish determined by the conditioned reflex method. *Nippon Suisan Gakkaishi.*, 56: 887-892

Miyazaki, T., Shiozawa, S., Kogane, T., Masuda, R., Maruyama, K., Tsukamoto, K. 2000. Developmental changes of the light intensity threshold for school formation in the striped jack *Pseudocaranx dentex*. *Mar. Ecol. Prog. Ser.*, 192: 267-275

Munz, F.W. and McFarland, W.N. 1973. The significance of spectral position in the rhodopsins of tropical marine fishes. *Vis. Res*., 13: 1829-1874

Nakano, N., Kawabe, R., Yamashita, N., Hiraishi, T., Yamamoto, K., Nashimoto, K. 2006. Color vision, spectral sensitivity, accommodation, and visual acuity in juvenile masu salmon *Oncorhynchus masou masou*. *Fish. Sci*., 72: 239-249

Nguyen, K.Q., Winger, P.D., Morris, C., Grant, S.M. 2017. Artificial lights improve the catchability of snow crab (*Chionoecetes opilio*) traps. *Aquac. Fish.*, 2: 124–133

Nguyen, K.Q., Winger, P.D. 2019. Artificial light in commercial industrialized fishing applications: a review. Rev. in Fish. Sci. & Aquac., 27: 106-126

Ortiz, N., Mangel, J.C., Wang, J., Alfaro-Shigueto, J., Pingo, S., Jimenez, A., Suarez, T., Swimmer, Y., Carvalho, F., Godley, B.J. 2016. Reducing green turtle bycatch in small-scale fisheries using illuminated gillnets: The cost of saving a sea turtle. Mar. Ecol. Progr. Ser., 545: 251–259

Parrish, J.K., S. V. Viscido, D. ~~S.V.,~~ Grunbaum, ~~D~~ .2002. Self-organizedfish schools: an examination of emergent properties. Biol. Bull., 202: 296–305

Solomon, O.O.~~,~~ and O. O. Ahmed, ~~O.O.~~ 2016. Fishing with light: Ecological consequences for coastal habitats. *Int. J. Fish. Aquac. Stud*., 4: 474–483

Susanto, A., R. Irnawati, ~~R.~~, ~~Mustahal, Syabana~~, M. A. Mustahal Syabana, 2017a. Fishing efficiency of LED lamps for fixed lift net fisheries in Banten Bay Indonesia. *Turkish J. of Fish. and Aqua. Sci*., 17: 283-291

Susanto, A., Baskoro, M.S., Wisudo, S.H., Riyanto, M., Purwangka, F. 2017b. Seawater battery with Al-Cu, Zn-Cu, Gal-Cu electrodes for fishing lamp. Inter. J. of Renew. Energy Res., 7: 1857-1868

Susanto, A., Fitri, A.D.P., Putra, Y., Sutanto, H., Alawiyah, T. 2017c. Respons dan adaptasi ikan teri (*Stolephorus* sp.) terhadap lampu light emitting diode (LED). *Mar. Fish*., 8: 39-49

Tamura, T. and Niwa, H. 1967. Spectral sensitivity and color vision of fish as indicated by S-potential. *Comp. Biochem. Physiol*., 22: 745-754

Torisawa, S., Takagi, T., Fukuda, H., Ishibhasi, Y., Sawada, Y., Okada, T., Miyashita, S., Suzuki, K., Yamane, T. 2007. Schooling behaviour and retinomotor response of juvenile Pacific bluefin tuna *Thunnus orientalis* under different light intensities. *J. of Fish Biol*., 71: 411-420

Utne-Palm, A.C., Breen, M., Løkkeborg, S., Humborstad, O.B. 2018. Behavioural responses of krill and cod to artificial light in laboratory experiments. *Plos One*., 13: 1-17

Viscido, S.V. and Grünbaum, D. 2002. Self-organized fish schools: an examination of emergent properties. *Biol. Bull*., 202: 296–305

Wang, J. H., Fisler S., Swimmer, Y. 2010. Developing visual deterrents to reduce sea turtle bycatch in gill net fisheries. Mar. Ecol. Progr. Ser., 408: 241–250

Woodhead, P.M.J. 1966. The behaviour of fish in relation to light in the sea. *Oceanog. and Marine Biol. Annu. Rev*., 4: 337-403

Yamashita, Y., Matsushita, Y., Azuno, T. 2012. Catch performance of coastal squid jigging boats using LED Panels in combination with metal halide lamps. *Fish. Res*., 113: 182–189

Yeh, N., Yeh, P., Shih, N., Byadgi, O., Cheng, T.C. 2014. Applications of light-emitting diodes in researches conducted in aquatic environment. *Renew. Sustain. Energy Rev*., 32: 611–618

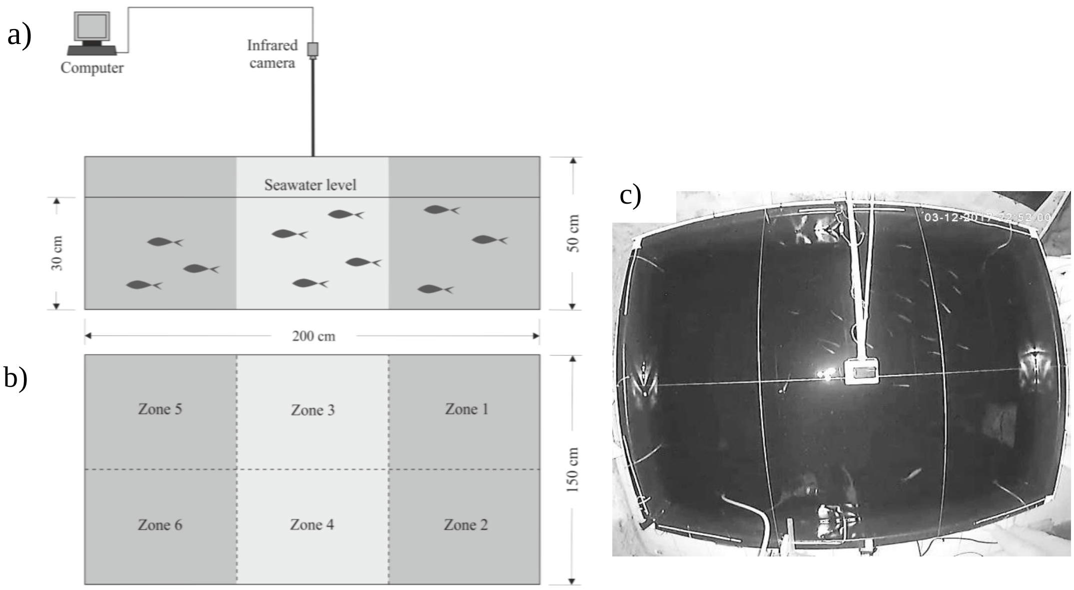

Fig. 1: The open tank experiment for the behavioral response. The side view of experimental tank set up (a), top view (b), and infrared camera view (c).

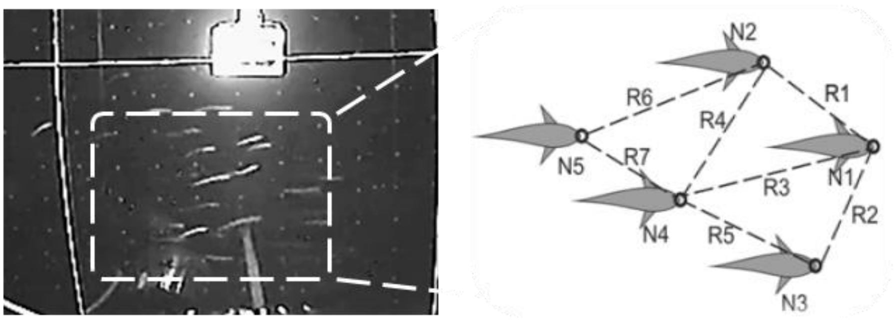

Fig. 2: Illustration of NND method from the image recording. N1 to N5 represent the number of fish. R1 to R7 represent the planar distances between each fish (head) and its closest neighbor

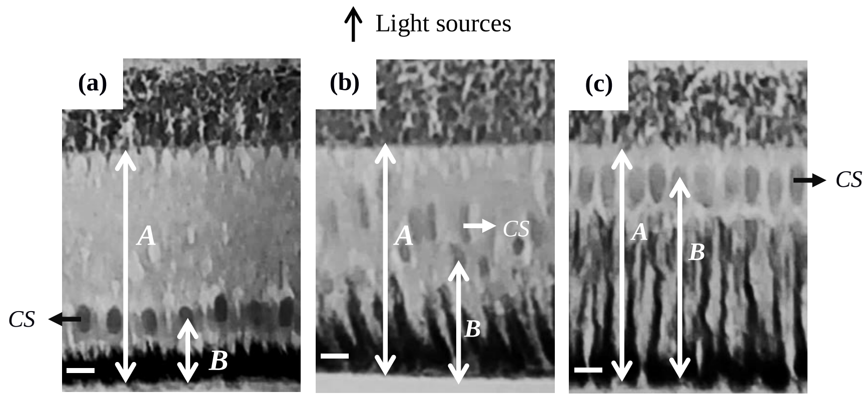

Fig. 3: Photomicrographs show various states of retinal light adaptation of *Selaroides* sp. *A* thickness from the limiting membrane to the surface of the retina and *B* thickness of cone cell migration. **a.** Dark adapted, **b.** transitional stage, and **c.** light adapted. *CS*: *cone cell. Scale bar* = 10 µm.

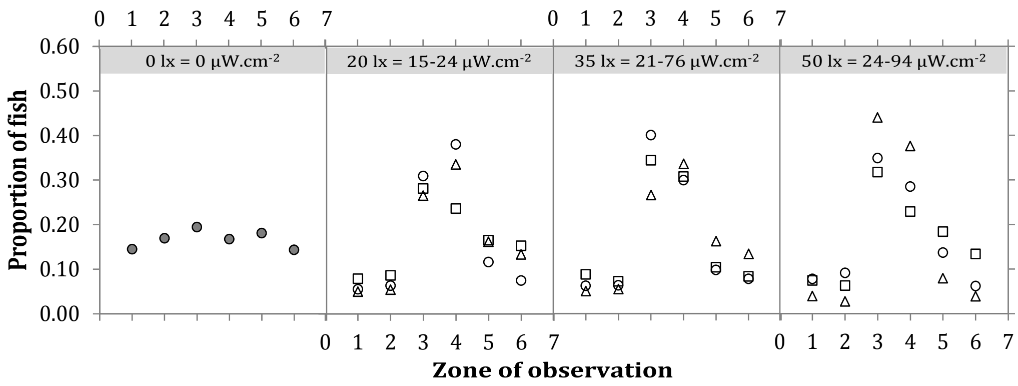

Fig. 4: The proportion of fish related to the color and light intensity. The proportion of scad observed during replicated color treatments (green-circle; orange-square; white-triangle;) and dark condition (filled circle).

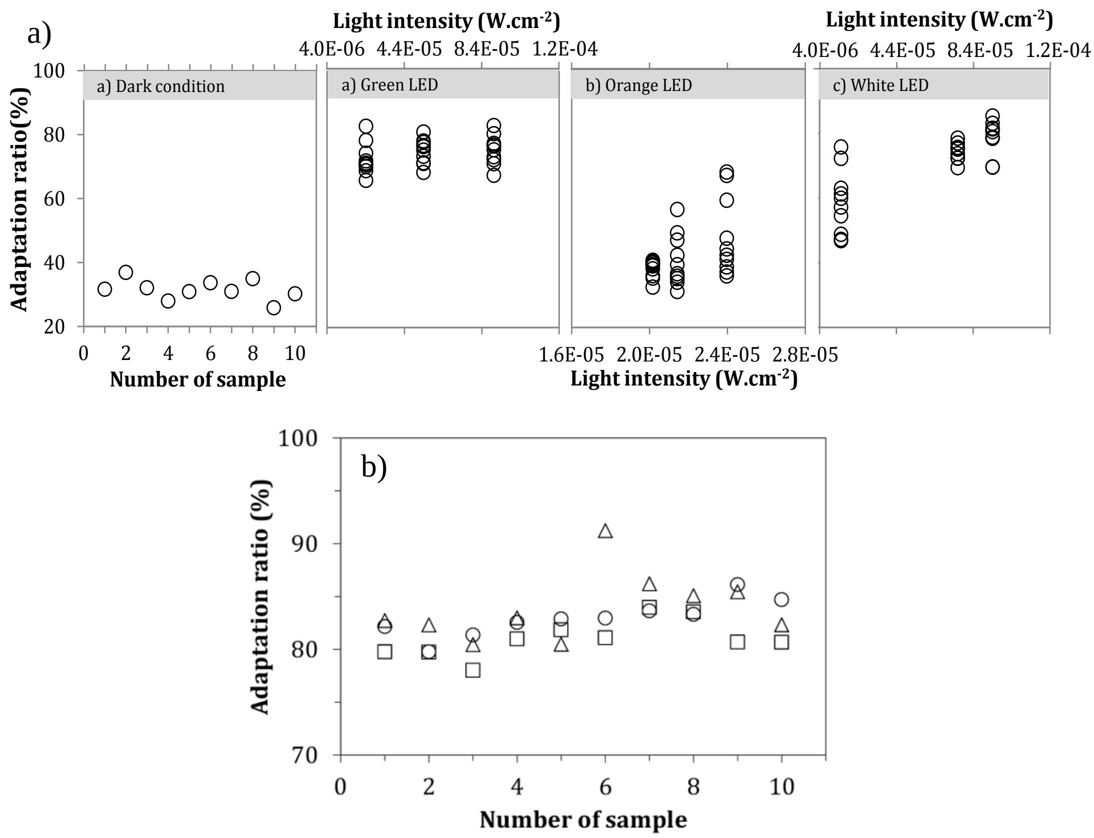

Fig. 5: The light adaptation of scad retina cells to different color and light intensity in laboratory experiment (a) and the light adaptation of the retina cells collected from the fishing experiment (b). The cone index of fluorescent-circle, white LED-square, and green LED-triangle.

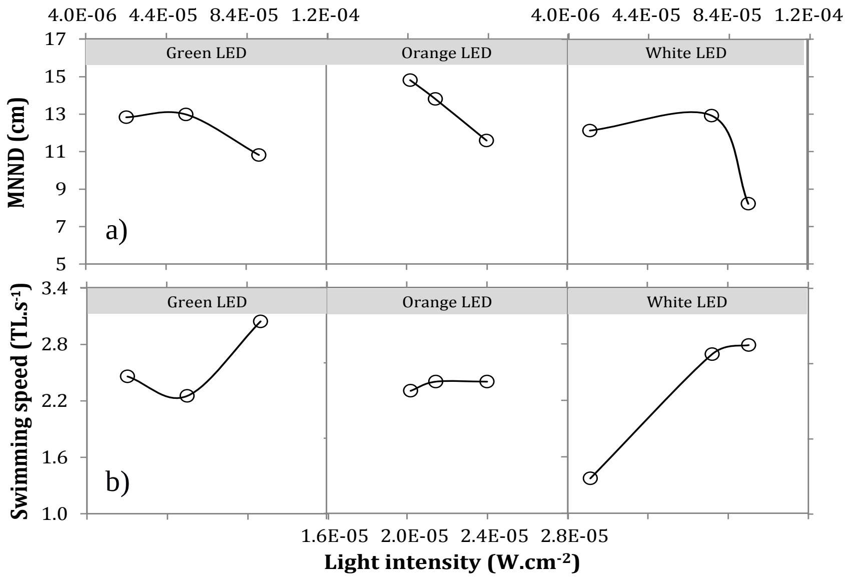

Fig. 6: The swimming behavior of scad to different LED colors and intensities. The mean nearest neighbor distances (a) and swimming speed (b).

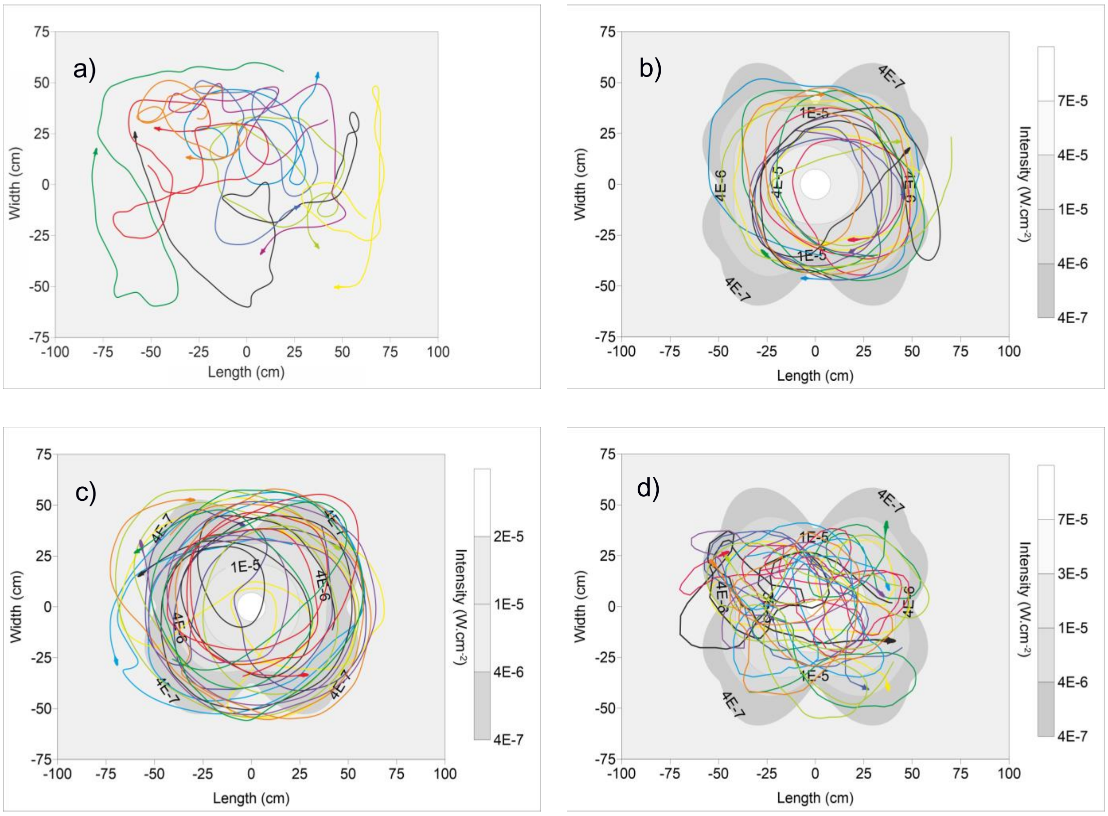

Fig.7: The individual swimming pattern of scad in different color and LEDs intensity. The swimming pattern in dark condition (a), green LED (b), orange LED (c) white LED (d). Different fish are color-coded.

Table 1: Fish behavior related to the time elapsed observation

Time elapsed (minute)	Fish Behavioral Response
0 - 5	There was no schooling and swimming behavior pattern at the beginning treatment. Fish swam in all directions due to orientation and adaptation period related to the light color and intensity at the experimental tank.
6 - 10	The fish started to school with several swimming patterns. However, there were an unstable direction and swimming speed.
11 - 20	There was a stable and consistent swimming pattern. The swimming speed was increased related to time-lapse.
21 - 30	The swimming patterns were stable and consistent with steady swimming speed. The radius of swimming was stable and relatively closest to the center of the light zone.

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1 message

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From: Adi Susanto, S.Pi., M.Si <adisusanto@untirta.ac.id>
Sent: Sunday, March 15, 2020 3:45 AM
To: Muhammad Kasib KHAN <kasibdadra@hotmail.com>
Subject: Re: MS IJAB-20-0048 Minor revision is again suggested

Dear Dr Khan

Here I attached the revised manuscript, especially in reference list as you requested.

Please feel free to inform me if there is anything incorrect.

Best regards

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On Sat, 14 Mar 2020 at 13:42, Muhammad Kasib KHAN <kasibdadra@hotmail.com> wrote:

> Dear Adi Susanto,
>
> The revised manuscript IJAB-20-0048 has been evaluated and i am pleased to inform you that it still needs minor revision in the following areas:
>
> 1. The references in the list need to be formatted according to journal's requirement.

Manuscript type: Original Research Article

Running title: Behaviour and retinular response of Yellowstripe scad

The behaviour and retinular response of Yellowstripe scad, *Selaroides leptolepis* to the different colors of light emitting diode

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Novelty statement

In this manuscript, we describe the novel approach to design efficient and effective fishing lamp using low light LED lamp due to behavioural and retinular response of fish. The new approach was conducted to determine the light intensity threshold and colour preference of fishing lamp for concentrating and focusing the fish at catchable area. We found that the white LED is suitable enough for attract the fish and the green one is effective for focusing and control the behaviour of fish in catchable area.

Abstract

The objective of this research is to analyse the behavioural and the retinular response of scad through both laboratory observation and a fishing trial as scientific evidence to designate the effective LED light for lift net fisheries. Different colors were used in a laboratory experiment, including green, orange, and white LED. Laboratory experiment were conducted in three illumination levels, low, medium, and high intensity. Light intensity strongly affects fish behaviour and activity. Green light improves the vision of

fish and the ability to maintain schooling behaviour. Using the same LED colors, the adaptation stage of cone cells increases as the light intensity grows. The exposure of high-intensity LEDs rapidly induces the cone cells into photopic adaptation. The same results are found in both fishing trials and laboratory observations. Regarding the ability to induce good light adaptation and stable swimming patterns, it is argued that green LED lamps are preferable to substitute fluorescent lamps currently used in the lift net fishing. The combination of both green and white LED can be more effective light attractant to Yellowstripe scad for lift net fishing.

Keywords: behavioural response, LED fishing, retinular response, *Selaroides leptolepis*

Introduction

Light fishing is one of the most effective and advanced fishing methods to catch commercial pelagic species in both small-scale and large-scale fisheries. In the common fishing practices, fishers use either fixed or mobile fishing gear (Ben-Yami 1976; Wang *et al.* 2010; Yamashita *et al.* 2012; Ortiz *et al.* 2016; Solomon and Ahmed 2016; Nguyen *et al.* 2017; Nguyen and Winger 2019). However, artificial light consumes a significant amount of energy due to the use of numerous high powered lamps. One of the prominent small-scale light fishing practices in Indonesia is lift net fishing, which uses a fluorescent lamp as the typical light sources. Fish production of lift net fishing in 2017 reached 48% from total production of small-scale light fishing in Indonesia (Ministry of Marine Affairs and Fisheries Republic of Indonesia 2018). The main targets of lift net fishing are anchovy, scad, sardinella and squid, which proportion of scad ranged between 10-45% from the total catch (Guntur *et al.* 2015; Rudin *et al.* 2017). The application of fluorescent lamp in lift net fishing has several problems, including short lifetime, high fuel consumption and low effectiveness to control the fish behaviour during fishing operation. Fishing operation using fluorescent lamps in fixed lift net consumed 5.20 to 7.00 l/night (mean 6.33 ±0.54 SD) while light emitting diode (LED) lamps consumed 3.30 to 5.30 l/night (mean 4.11±0.61 SD). However, it is argued that differences in fluorescent lamp quantities and wattages significantly affect the fishers' income (Susanto *et al.* 2017a).

Light emitting diode as the latest efficient light source technology, has the potential to be applied as an artificial light source for fishing with light (An *et al.* 2017; Susanto *et al.* 2017b; Nguyen and Winger 2019). This lamp provides the maximum illumination power combined with lower energy consumption, longer lifetime, higher efficiency, better chromatic performance, and lower environmental impact compared to traditional lighting technology (Matsushita *et al.* 2012; Matsushita and Yamashita 2012; Yamashita *et al*. 2012; Breen and Lerner 2013; Hua and Xing 2013; Yeh *et al.* 2014; An *et al.* 2017; Nguyen and Winger 2019). Furthermore, the light distribution of LEDs, colour and intensity considerably affect fish behavioural and retinular response. Therefore, understanding the behaviour of target species in response to LEDs is an important step to develop an efficient LEDs for lift net fisheries.

We illuminate scad (*Selairoides leptolepis*) by three different low powered LED light sources including green, orange, and white lamps, as well as dark conditions to investigate the behavioural and retinular response. Furthermore, in order to determine the LEDs performance for lift net fishing, we focused to construct the basic evidence regarding the behavioural and the retinular response of scad through fishing trial. This information is important to develop efficient and effective LEDs for lift net fishing in Indonesia.

Materials and Methods

Fish and Tank Experiment

For the laboratory experiment, the behaviour monitoring was conducted in a black fiberglass of rectangular prims open tank (150W x 200L x 50H cm) and the water depth was maintained at 30 cm. The tank was placed in the controlled dark room at State College of Fisheries Serang City, to secure no natural light existing during experiment. The tank was divided into six zones and marked at the bottom in 10 cm intervals as the calibration scale (Fig. 1). Being closer to the light source zone 3 and 4 are light zones (bright zones), while zone 1,2,5, and 6 are the dark zones. The LEDs were assembled approximately 20 cm from sea water level at experiment tank. The experimental setup following the research from Marchesan *et al.* (2005), Pignatelli *et al.* (2011), Cha *et al.* (2012), and Utne-Palm *et al.* (2018).

The running water systems were installed to ensure the fish remain alive in optimum water quality during observation. Scad (12.45 cm in average total length (TL), N=60) were collected using a guiding barrier at Banten Bay and transferred to the laboratory for adaptation and acclimatization period for seven days. The scad were exposed to normal daily light-dark cycle (12 L: 12 D, sun light were used in daytime). The water salinity in all tanks was maintained at 30-33 ‰, the temperature was at 29-31°C and dissolved oxygen ranged from 5.9-6.1 mg/L. Before and after the experiments, fish were fed two times per day with *Arthemia sp*. Therefore, the behaviour experiment was conducted on static water circulation. All of the experiments were performed during the night to minimize the influence of light from any endogenous circadian effects on the fish behavioural and retinular responses.

Light Source and Behavioural Methods

Lamps were assembled using four dual inline package (DIP) LEDs (Shenzhen Yuliang Optoelectronics Technology Co. Ltd) mounted on the metal housing (11L x 5W x 7H cm), powered by 4 V DC supply. The experiments were conducted in three colors of LEDs i.e. green [approximate peak wavelength = 565 nm], orange [approximate peak wavelength = 600 nm], and white [approximate peak wavelength = 450 nm and 545 nm]. Therefore, each of which consists of three illumination levels i.e. 20, 35, 50 lux. Light intensities were measured using ILT 5000 research radiometer at 15 cm distance bellowed sea water level of the tank. The intensity of green LEDs at 20 lux, 35 lux, and 50 lux is 24 $\mu W.cm^{-2}$, 54 $\mu W.cm^{-2}$, 90 $\mu W.cm^{-2}$, respectively. In the same order of illumination level, the intensity for orange LEDs was 20 $\mu W.cm^{-2}$, 21 $\mu W.cm^{-2}$, and 24 $\mu W.cm^{-2}$ while for the white LEDs was 15 $\mu W.cm^{-2}$, 76 $\mu W.cm^{-2}$, and 94 $\mu W. cm^{-2}$.

The order of the experimental procedures is as follows. Firstly, before being tested 30 scad were left at the experimental tank at least three days to acclimate, and were subjected to a 12 L:12 D photoperiod (light from 06:00 to 18:00; dark from 18:00 to 06:00). Ambient illumination at 15 cm deep below seawater-level was about 16 $nW.cm^{-2}$ in light conditions. All experimental sessions started at 19:00 and ended at 22:00. Secondly, before the experiment was started and between each experiment, fish were kept in the dark state for 30 minutes to ensure their retina in a scotopic condition. Subsequently, each lamp was turned on for 30 minutes to allow fish to respond and adapt to the light. Visual observation and video recording using the infrared camera were conducted during the dark and lighted conditions. Three replications were conducted for each experiment (Marchesan *et al.* 2005). A total of 540 minutes of video recording was analysed for each color to define fish proportion, scad swimming speed around illumination zone, mean of nearest neighbour distance (MNND), and swimming pattern of the fish schooling.

Retinular Response to Irradiance Changes

We used eighteen fish for the retinal adaptation experiment using the following procedure. Firstly, two fish were taken from the storage tank and placed in a cylinder tank with diameter 50 cm and height 43 cm. After 30 minutes set in the dark state, each LED lamp was illuminated for approximately 30 min, and at the end of each treatment, eye specimens from both fish were collected. Subsequently, each specimen was fixed in Bouin's solution and infiltrated with paraffin. Tissue samples were cut in cross-sections of 4-6 μm thickness and were stained with haematoxylin and eosin for examination under the microscope. This histological process followed the procedures from Arimoto *et al.* (2010) and Jeong *et al.* (2013).

Fishing Experiment

The result of laboratory experiment was applied to define the suitable LEDs color for the fishing trial which was conducted using a fixed lift net in Banten Bay during peak fishing season on August 2018. The fishing trial was conducted at 10 m water depth as common fishing ground in Banten Bay. According to the laboratory experiment, scad are especially responsive to white and green LEDs. Therefore, both lamps were compared to a fluorescent lamp, the light source used in the existing lift net fishing. We conducted the fishing experiment using 50 W of a fluorescent lamp (typical lamp for lift net fishing) and 1.4 W of LEDs due to the similar light output in the seawater column (12-15 $\mu W.cm^{-2}$; measured using ILT 5000 at 1 m below sea water). Ten fish were collected from each lamp making it 30 fish in total. Subsequently, all fish's eyes went through the histological procedures, followed by the examination of retinular adaptation under the microscope.

Data Analysis

In order to determine the degree of fish preference on each light stimulus, the proportion of fish at each zone was analysed by counting the number of gathered fish in each zone per minute observation (Kim and Mandrak 2017). Social behaviour was determined by the mean nearest neighbour distance (MNND), which is the average of the planar distances between each fish (head) and its closest neighbour (Parrish *et al.* 2002). It was used to define the effect of different colors and intensity of schooling characteristics of fish (Torisawa *et al.* 2007; Jolles *et al.* 2017). The MNND was analysed using images that converted from the movie at the beginning (< 10 min), intermediate (11-20 min), and the end of observation (21-30 min). The distance was analysed with Kinovea 0.8.15 at the center head of fish (Fig 2).

The degree of retinal light adaptation was represented in the adaptation ratio (%) (Arimoto *et al.* 2010), which was calculated by $(B/A) \times 100$ (%), where A (μm) represents the distance between the limiting membrane and the surface of the retina, and B (μm) represents the migration of cone cells when it was stimulated by light. A and B were measured using photomicrographs (Fig. 3). Swimming patterns at both LEDs colors and irradiance levels were analysed by using video tracking and trajectory software (Kinovea 0.8.15). Videotapes were preliminary observed at 4X speed, to obtain the first qualitative swimming pattern and the characteristic of each stage. In all experiments at every repetition, three dominant swimming patterns from each LED's stimulus were chosen at the beginning, intermediate and the end of the observation period. Parameters used to analyse the swimming speed of each pattern in total length per second (TL/s) are (1) time-lapse in each pattern; (2) number of frames; (3) distance of each pattern. One-way ANOVA was applied to analyse the effect of different light stimuli (as explanatory variable) to proportion, MNND, and swimming speed during observation (as response variable). Post-hoc comparisons, wherever significance was found, were conducted using Tukey HSD test with the significance level was set at $p<0.05$.

Results

Fish Preference to Light Stimuli

The scad responded to the different light colors. At all illumination levels of each color, fish showed high aggregation levels to the light zone. It was indicated by higher fish proportions in zone 3 and 4 than dark zone as presented in Fig. 4. However, there was not a significant difference in fish proportions at the dark condition for all zones (zone 1 to 6). The fish proportion at the dark condition between the range 14 and 19%. The proportion tended to increase related to the aggregating of light intensity, especially at the light zone. At the low intensity, the proportion of fish at zone 3 and zone 4 was ranged between 22-32%. However, the proportion was increased to 34-44% at high intensity level. There was also evidence to suggest that light intensity (in the range 15-94 $\mu W.cm^{-2}$) influences the behaviour of the fish by modifying swimming aggregations and preference in all LEDs colors.

Relationship Between The Retinular Response and Irradiance Change

The light adaptation of scad was influenced by LEDs color and intensity. The degrees of adaptation of scad at scotopic adaptation are in the range between 26 and 34%. Adaptation ratio increased with increasing light intensity at each LEDs color (Fig. 5a). The green LEDs generated the highest adaptation ratio with a slight increase, range 83% (low intensity) to 93% (high intensity). However, the degree of light adaptation with orange and white LEDs produced a various tendencies. The adaptation ratio of orange LEDs at low intensities is 32%, and increase to 67% for the high light level. Furthermore, white LEDs generated higher adaptation ratio than orange LEDs with the ratio between 73% (low intensity) to 92% (high intensity).

Swimming Behaviour

The swimming behaviour of scad was strongly affected by light intensities at each LED color. There was a significant decrease of MNND in all treatment with increasing intensity. The farthest individual distance generated with orange LED was 14.8 cm, while the closest distance was found at a white LED of 8.2 cm. In all experiments, the decline of MNND has a relationship with increasing swimming speed. Scad has the fastest swimming speed at green LED approximately 3.0 $TL.s^{-1}$, while the lowest speed was initiated at low intensity of white LED approximately 1.4 $TL.s^{-1}$ (Fig. 6).

The different LED treatments also influenced the pattern of swimming behaviour. In all dark conditions, fish swam randomly around the experiment tank. There are inconsistent and irregular swimming patterns of scad during the dark observation period. The light exposure caused changes in swimming behaviour. In low intensity, the different color of LEDs did not affect the behavioural patterns. Moreover, the increasing light intensity induces the transformed swimming pattern in all colors.

The fish swam randomly and inconsistently at a high intensity of the white LED. However, the scad showed a consistent response to orange and green LED with different radii in swimming patterns. Its radius with green LED is closer to the main light zone than orange LEDs, as presented in Figure 7. Moreover, there were constant and stable swimming patterns related to the time elapsed at the green LEDs, approximately after 20 minutes of observation. The specifics of fish swimming behaviour are presented in Table 1.

Fishing Trials

There are 1,082 scads were caught during fishing experiment. The light adaptation of the retina collected during the fishing trial is shown in Fig 5b. The cone index was found to be between the range of 78 and 91%. The green LED generated a higher mean adaptation ratio (84%) than white LED (81%) and a fluorescent lamp (83%). However, there were no significant differences in cone index from the sea experiment (P>0.05).

Discussions

The highest number of fish proportion in the bright observation zone indicated the scad as a phototaxis fish that attracted by light. The proportion was superior to the bright zones. However, these zones have a smaller area than shadow zones. There were significant differences in the fish proportion between colors and intensities, whereas the proportion in the bright zone at each color gradually increased with rising intensity. The brightness level influences the level of fish activity. Thus, it would have been relevant to increase the fish proportion in all bright zones (Marchesan *et al.* 2005; Utne-Palm *et al.* 2018). This condition is an adaptation response to maintaining the formed characteristic of scad schooling behaviour, related to the exposure of light intensity in their environment (Woodhead 1966; Martin and Perez 2006).

There were significant differences in light adaptation ratio between dark and light state ($p<0.05$). The degree of light adaptation ratio has a positive association with an increase of light intensity (Susanto *et al.* 2017c). With all colors used in the experiment, the adaptation stage of cone cells increases with expanding intensity. The exposure of high-intensity LEDs induces the cone cells into photopic adaptation rapidly. Thus the light adaptation ratio was increased (Tamura and Niwa 1967; Nakano *et al.* 2006; Migaud *et al.* 2007). The green LEDs generated the highest adaptation ratio of scad in all intensity levels. Thus, it would have been relevant to conclude that the maximum sensitivity of the Carangidae fish family, including scad, has peak sensitivity between 494-500 nm (Munz and McFarland 1973).

Light intensity has prevailing influence on the visual ability of fish. However, scad's ability to use vision to maintain the schooling characteristic during light level increases necessitates phototaxis. Moreover, there were significant differences in swimming behaviour, including swimming patterns and MNND in the different light conditions, whereas the fish activity increased with rising intensity. The MNND has a negative relationship with light intensity, whereas the MNND decreased with increasing intensity levels. However, the swimming speeds of scad showed different tendencies with MNND during expanding light levels. The fish swam faster at the high intensity at all LED colors. The high intensity induced fish easier to maintain the direction and orientation of their schooling, due to an increase in their swimming speed at all treatments (Miyazaki *et al.* 2000). Similar tendencies were found at the swimming speed of Atlantic salmon *Salmo salar*. Its speed was increased from 0.2 BL/s to 0.5

BL/s related to the increase of the light level at sea cage observation (Hansen *et al.* 2017).

The swimming patterns of scad in the green and orange LEDs have similar tendencies. However, the swimming radius at the green LED was closer to the center of the light zone than an orange LED. It was related to the visual adaptation level and the spectral sensitivity of scad. The scad have more reactive to the green light because it is suitable with peak sensitivity level. The fish have a proper response to green light due to an increase in visual ability and significant influence to fish capability to maintain their schooling characteristics. Exposure of green light in different light intensities was induced the stable and consistence swimming pattern. In one example of schooling during increased light intensity, increasing visual ability influenced each individual, enabling them to maintain their distance and formation relative to the rest of the school during swimming (Glass *et al.* 1986; McMahon and Holanov 1995; Miyazaki and Nakamura 1990).

Even though the orange light has longer wavelength than green light, it has lower of photon energy. It cause the scads have less reactive and induce wider swimming radius than green light. However, the swimming pattern of scad in orange light was relatively stable and consistence during observation. In other example, orange light has similar influenced with green light to the schooling characteristic of *Mugil cephalus*, *Sparus auratus*, and *Lithognathus mormyrus* (Marchesan *et al.* 2005).

The light adaptation of scad from the fishing experiment has similar tendencies with laboratory observations. The green LED generated a higher degree of adaptation than the white LED and fluorescent lamp at the same intensity. The information on the retinular response and adaptation to light source was utilized in studying the relationship between a light fishing procedure, light color, and light intensity to develop an efficient use of the LED fishing lamp (Jeong *et al.* 2013). In this research, we compare the characteristics of scad swimming behaviour, and light adaptation between experimental tanks and fishing trials to determine the suitable low powered LED color as a light source when fishing. From these results, the green LED, which induces good light adaptation and stable swimming patterns, is suitable enough to substitute fluorescent lamps currently used in lift net fishing.

The combination in both green and white LED can be a more effective light attractant to scad fishing at lift net fisheries. In lift net fisheries, white LED is useful when gathering scads and other target species at the initial fishing operation. However, the swimming pattern of fish school at white LED was random and unstable, due to the light source having to change with green LED when focusing the fish at a catchable area. Green light would be more suitable to keep fish close to the light source. Moreover, this light not induces stress behaviour for long exposure time (Shin *et al.* 2013; Stien *et al.* 2014; Sierra-Flores *et al.* 2015). The application of green light in focusing of fish can reduce uncaught fish during hauling process and improve the fishing efficiency and effectiveness in lift net fishing.

The LED innovation as artificial light has several advantages. The LED provides maximum illumination power, combined with minimum energy consumption, long lifespan, high efficiency, better chromatic performance, and reduced environmental impact compared to traditional lighting technology (Matsushita *et al.* 2012; Matsushita and Yamashita 2012; Yamashita *et al.* 2012; Breen and Lerner 2013; Hua and Xing 2013; Yeh *et al.* 2014; Nguyen and Tran 2015; An *et al.* 2017). However, further fishing trials are recommended to validate the effectiveness of both white and green LED as a light stimulus for gathering and focusing scad at lift net fisheries.

Conclusions

Present investigation showed the white LED is a suitable enough to attract fish to catchable area while the green LED is an effective color for focusing and control behaviour of scad in catchable area. We conclude that combination of white and green LED can be a more effective light attractant to scad fishing at lift net fisheries.

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References

An YI, P He, T Arimoto, UJ Jang (2017). Catch performance and fuel consumption of LED fishing lamps in the Korea hairtail angling fishery. *Fish Sci* 83:343–352

Arimoto T, CW Glass, X Zhang (2010). *Fish vision and its role in fish capture*. He, P. (Eds), *Behaviour of marine fishes: capture processes and conservation challenges*. Blackwell Scientific, USA

Ben-Yami M (1976). *Fishing with light*. Fishing News Books, Oxford USA

Breen M, A Lerner (2013). An introduction to light and its measurement when investigating fish behaviour. Symposium on the Light session and the Topic Group Lights: ICES-FAO Working Group on Fishing Technology and Fish Behaviour. May 6–10, Bangkok, Thailand

Chaa BJ, BS Baea, SK Chob, JK Oh (2011). A simple method to quantify fish behaviour by forming time-lapse images. *Aquacultural Engineering* 51:15-20

Glass CW, CS Vardle, WR Mojsiewicz (1986). A light intensity threshold for schooling in the Atlantic Mackerel *Scomber scombrus*. *J Fish Biol* 29(Suppl A):71-81

Guntur, Fuad, A Munataha (2015).Effect of underwater lamp intensity on the lift net's fishing catches. *Mar Fish* 6(2):195-202

Hansen TJ, PG Fjelldal, O Folkedal, T Vågseth, F Oppedal (2017). Effects of light source and intensity on sexual maturation, growth and swimming behaviour of Atlantic Salmon in sea cages. *Aquac Environ Interact* 9:193-204

Hua LT, J Xing (2013). Research on LED fishing light. *Res J Appl Sc, Eng and Technol* 5:4138-4141

Jeong H, S Yoo, J Lee, YI An (2013). The retinular responses of common squid *Todarodes pacificus* for energy efficient fishing lamp using LED. *Renew Energy* 54:101-104

Jolles JW, NJ Boogert, VH Sridhar, LD Couzin, A Manica (2017). Consistent individual differences drive collective behaviour and group functioning of schooling fish. *Current Biol* 27: 1-7

Kim J, NE Mandrak (2017). Effects of strobe lights on the behaviour of fresh water fishes. *Environ Biol Fish* 100:1427-1434

Marchesan M, M Spoto, L Verginellab, EA Ferreroa (2005). Behavioural effects of artificial light on fish species of commercial interest. *Fish Res* 73:171-185

Martin RS, JAA Perez (2006). Cephalopods and fish attracted by night lights in coastal shallow-waters, off Southern Brazil, with the description of squid and fish behaviour. *Revista de Etologia* 8:27-34

Matsui H, G Takayama, Y Sakurai (2016). Physiological response of the eye to different colored light-emitting diodes in Japanese flying squid *Todarodes pacificus*. *Fish Sci* 82:303-309

Matsushita Y, T Azuno, Y Yamashita (2012). Fuel reduction in coastal squid jigging boats equipped with various combinations of conventional metal halide lamps and low-energy LED panels. *Fish Res* 125-126:14-19

Matsushita Y, Y Yamashita (2012). Effect of a stepwise lighting method termed "stage reduced lighting" using LED and metal halide fishing lamps in the japanese common squid jigging fishery. *Fish Sci* 78:977-983

McMahon TE, SH Holanov (1995). Foraging success of largemouth bass at different light intensities: implications for time and depth of feeding. *J Fish Biol* 46:759-767

Migaud H, M Cowan, J Taylor, HW Ferguson (2007). The effect of spectral composition and light intensity on melatonin, stress and retinal damage in post-smolt Atlantic salmon, *Salmo salar*. *Aquac* 270:390-404

Miyazaki T, Y Nakamura (1990). Single line acuity of 0-yearold Japanese parrotfish determined by the conditioned reflex method. *Nippon Suisan Gakkaishi* 56:887-892

Miyazaki T, S Shiozawa, T Kogane, R Masuda, K Maruyama, K Tsukamoto (2000). Developmental changes of the light intensity threshold for school formation in the striped jack *Pseudocaranx dentex*. *Mar Ecol Prog Ser* 192:267-275

Ministry of Marine Affairs and Fisheries Republic of Indonesia (2018). *Statisctics of Fish Production based on Fishing Gear in Indonesia 2017*. Jakarta, Indonesia.

Torisawa S, T Takagi, H Fukuda, Y Ishibhasi, Y Sawada, T Okada, S Miyashita, K Suzuki, T Yamane (2007). Schooling behaviour and retinomotor response of juvenile Pacific bluefin tuna *Thunnus orientalis* under different light intensities. *J of Fish Biol* 71:411-420

Utne-Palm AC, M Breen, S Løkkeborg, OB Humborstad (2018). Behavioural responses of krill and cod to artificial light in laboratory experiments. *Plos One* 13:1-17

Viscido SV, D Grünbaum (2002). Self-organized fish schools: an examination of emergent properties. *Biol Bull* 202:296–305

Wang JH, S Fisler, Y Swimmer (2010). Developing visual deterrents to reduce sea turtle bycatch in gill net fisheries. *Mar Ecol Progr Ser* 408:241–250

Woodhead PMJ (1966). The behaviour of fish in relation to light in the sea. *Oceanog and Marine Biol Annu Rev* 4:337-403

Yamashita Y, Y Matsushita, T Azuno (2012). Catch performance of coastal squid jigging boats using LED Panels in combination with metal halide lamps. *Fish Res* 113: 182–189

Yeh N, P Yeh, N Shih, O Byadgi, TC Cheng (2014). Applications of light-emitting diodes in researches conducted in aquatic environment. *Renew Sustain Energy Rev* 32:611–618

Munz FW, WN McFarland (1973). The significance of spectral position in the rhodopsins of tropical marine fishes. *Vis Res* 13:1829-1874

Nakano N, R Kawabe, N Yamashita, T Hiraishi, K Yamamoto, K Nashimoto (2006). Color vision, spectral sensitivity, accommodation, and visual acuity in juvenile masu salmon *Oncorhynchus masou masou*. *Fish Sci* 72:239-249

Nguyen QK, DP Tran (2015). Benefits of using LED light for purse seine fisheries: A case study in Ninh Thuan Province, Viet Nam. *Fish People* 13:30-36

Nguyen KQ, PD Winger, C Morris, SM Grant (2017). Artificial lights improve the catchability of snow crab (*Chionoecetes opilio*) traps. *Aquac Fish* 2:124–133

Nguyen KQ, PD Winger (2019). Artificial light in commercial industrialized fishing applications: a review. *Rev in Fish Sci & Aquac* 27:106-126

Ortiz N, JC Mangel, J Wang, J Alfaro-Shigueto, S Pingo, A Jimenez, T Suarez, Y Swimmer, F Carvalho, BJ Godley (2016). Reducing green turtle bycatch in small-scale fisheries using illuminated gillnets: The cost of saving a sea turtle. *Mar Ecol Progr Ser* 545:251–259

Parrish JK, SV Viscido, D Grunbaum (2002). Self-organizedfish schools: an examination of emergent properties. *Biol Bull* 202:296–305

Pignatelli V, SE Temple, T-H Chiou, NW Roberts, SP Collin, NJ Marshall (2011). Behavioural relevance of polarization sensitivity as a target detection mechanism in cephalopods and fishes. *Phil Trans R Soc B* 366:734-741

Rudin MJ, R Irnawati, A Rahmawati (2017). Differences of fixed lift net catch result by using CFL lamps and underwater Led in Banten Bay water. *Mar and Fish Journal* 7(2):167-180

Shin SH, NN Kima, YJ Choi, HR Habibi, JW Kim, CY Choi (2013). Light-emitting diode spectral sensitivity relationship with reproductive parameters and ovarian maturation in Yellowtail damselfish, *Chrysiptera parasema*. *Journal of Photochem and Photobiol B*: *Biology* 127:108-113

Sierra-Flores R, A Davie, B Grant, S Carboni, T Atack, H Migaud (2015). Effects of light spectrum and tank background colour on Atlantic cod (*Gadus morhua*) and turbot (*Scophthalmus maximus*) larvae performances. *Aquac* 450:6-13

Solomon OO, OO Ahmed (2016). Fishing with light: Ecological consequences for coastal habitats. *Int J Fish Aquac Stud* 4:474–483

Stien LH, JE Fosseidengen, ME Malm, H Sveier, T Torgersen, DW Wright, F Oppedal (2014). Low intensity light of different colours modifies Atlantic salmon depth use. *Aquac Engine* 62:42-48

Susanto A, R Irnawati, Mustahal, MA Syabana (2017a). Fishing efficiency of LED lamps for fixed lift net fisheries in Banten Bay Indonesia. *Turkish J of Fish and Aqua Sci* 17:283-291

Susanto A, MS Baskoro, SH Wisudo, M Riyanto, F Purwangka (2017b). Seawater battery with Al-Cu, Zn-Cu, Gal-Cu electrodes for fishing lamp. *Inter J of Renew Energy Res* 7:1857-1868

Susanto A, ADP Fitri, Y Putra, H Sutanto, T Alawiyah (2017c). Response and adaptation of Anchovy (*Stolephorus* sp.) to light emitting diode (LED) lamp. *Mar Fish* 8:39-49

Tamura T, H Niwa (1967). Spectral sensitivity and color vision of fish as indicated by S-potential. *Comp Biochem Physiol* 22:745-754

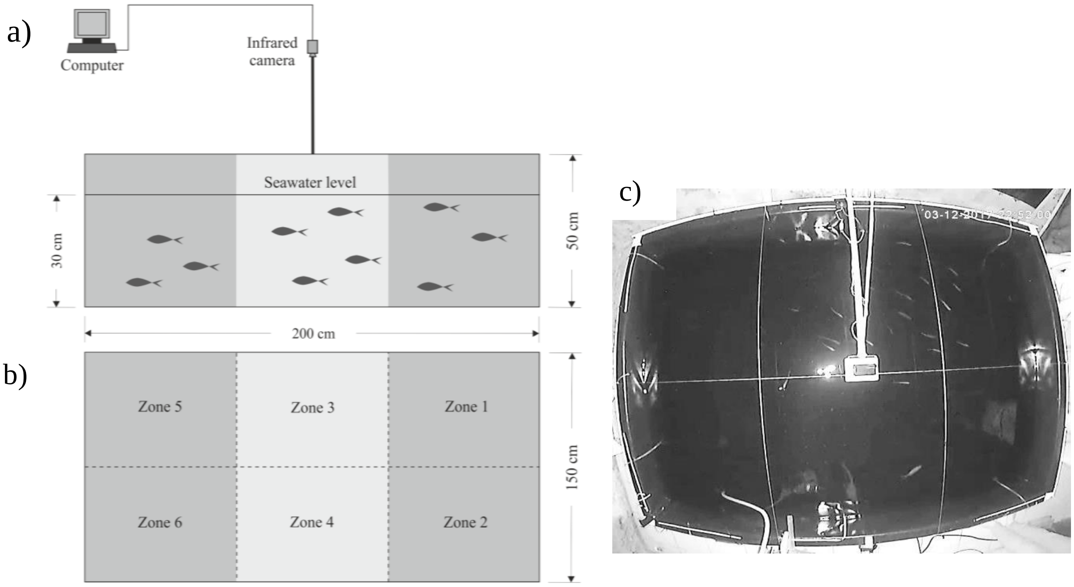

Fig. 1: The open tank experiment for the behavioural response. The side view of experimental tank set up (a), top view (b), and infrared camera view (c).

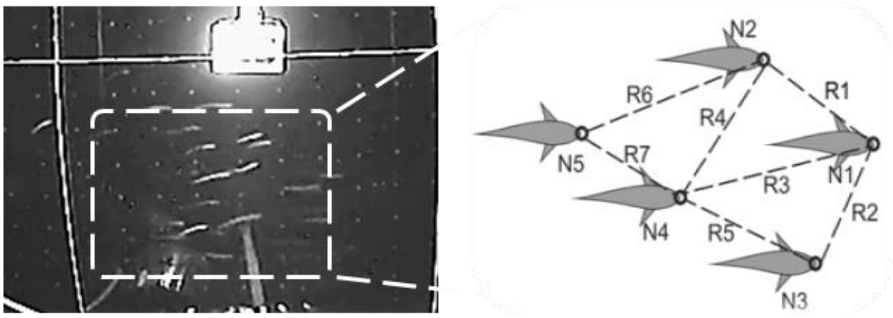

Fig. 2: Illustration of NND method from the image recording. N1 to N5 represent the number of fish. R1 to R7 represent the planar distances between each fish (head) and its closest neighbor

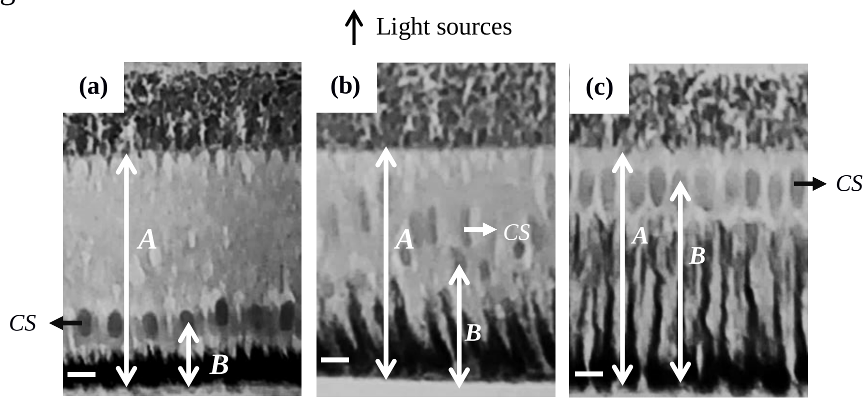

Fig. 3: Photomicrographs show various states of retinal light adaptation of *Selaroides* sp. *A* thickness from the limiting membrane to the surface of the retina and *B* thickness of cone cell migration. **a.** Dark adapted, **b.** transitional stage, and **c.** light adapted. *CS*: *cone cell. Scale bar* = 10 μm.

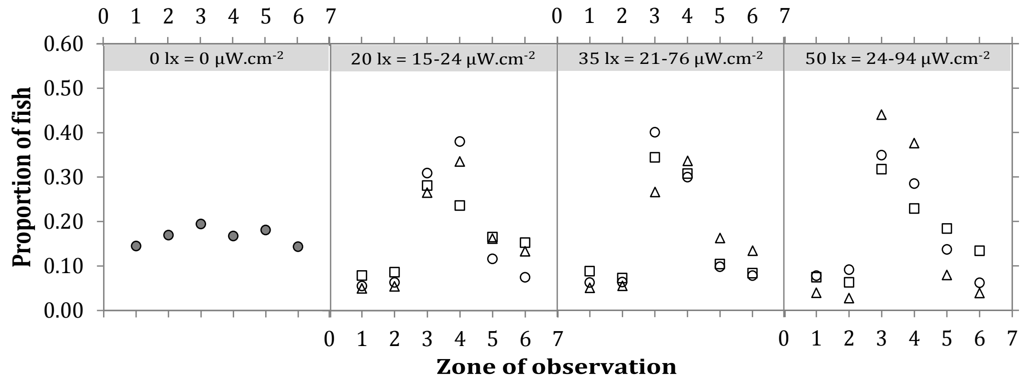

Fig. 4: The proportion of fish related to the color and light intensity. The proportion of scad observed during replicated color treatments (green-circle; orange-square; white-triangle;) and dark condition (filled circle).

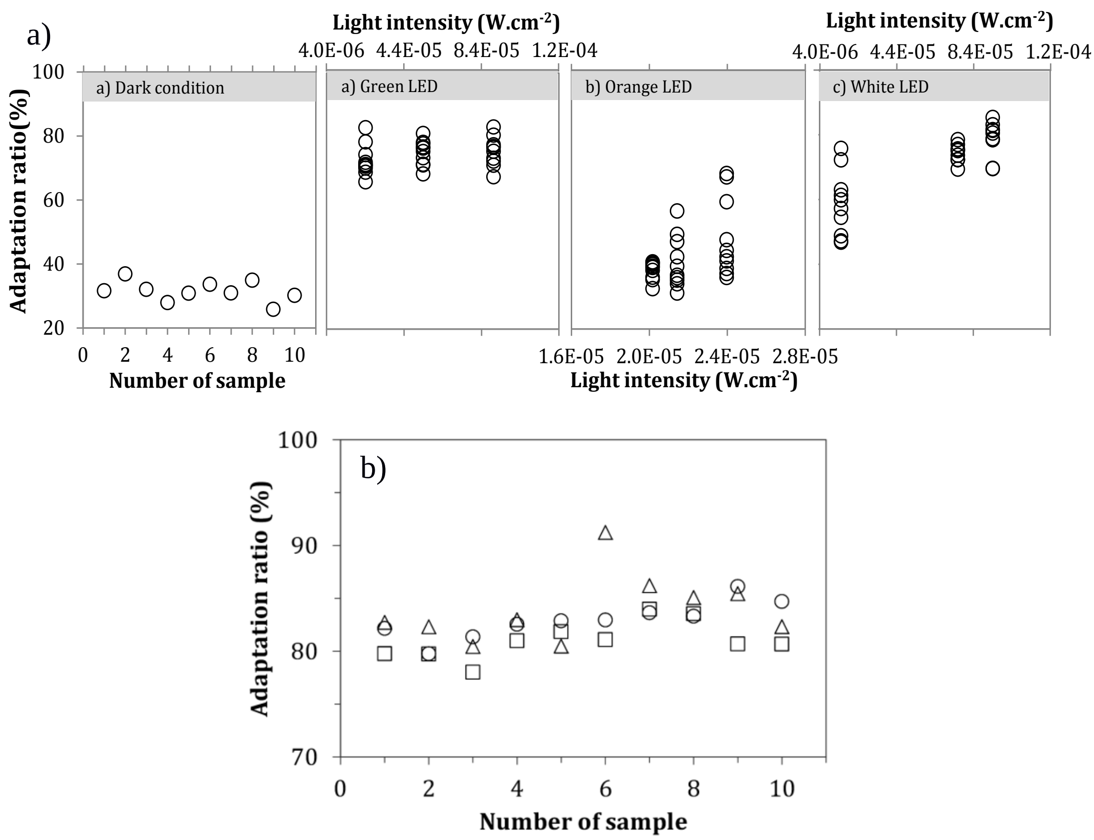

Fig. 5: The light adaptation of scad retina cells to different color and light intensity in laboratory experiment (a) and the light adaptation of the retina cells collected from the fishing experiment (b). The cone index of fluorescent-circle, white LED-square, and green LED-triangle.

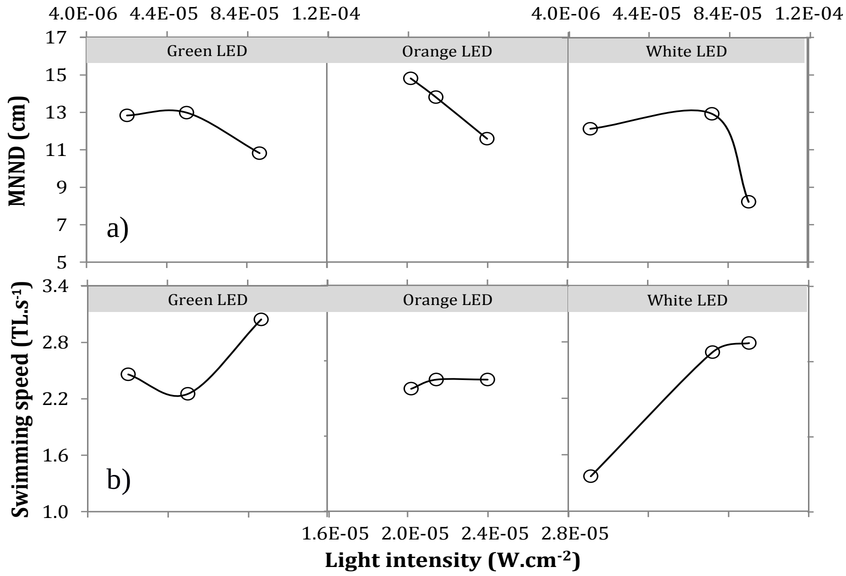

Fig. 6: The swimming behaviour of scad to different LED colors and intensities. The mean nearest neighbor distances (a) and swimming speed (b).

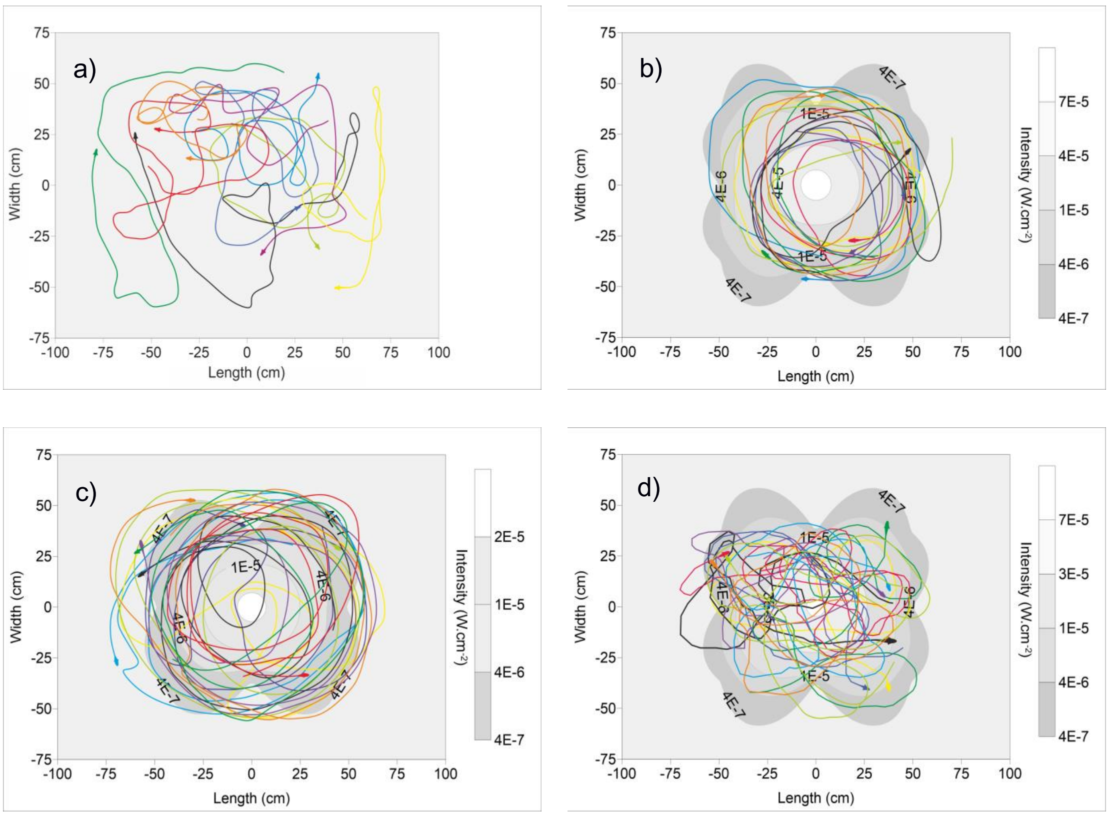

Fig.7: The individual swimming pattern of scad in different color and LEDs intensity. The swimming pattern in dark condition (a), green LED (b), orange LED (c) white LED (d). Different fish are color-coded.

Table 1: Fish behaviour related to the time elapsed observation

Time elapsed (minute)	Fish Behavioural Response
0 - 5	There was no schooling and swimming behaviour pattern at the beginning treatment. Fish swam in all directions due to orientation and adaptation period related to the light color and intensity at the experimental tank.
6 - 10	The fish started to school with several swimming patterns. However, there were an unstable direction and swimming speed.
11 - 20	There was a stable and consistent swimming pattern. The swimming speed was increased related to time-lapse.
21 - 30	The swimming patterns were stable and consistent with steady swimming speed. The radius of swimming was stable and relatively closest to the center of the light zone.