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How Does Artificial Light Affect the Behavior of Green Turtles *Chelonia mydas*? (A Case Study in Pangumbahan Turtle Beach Coastal Park, Sukabumi-West Java District, Indonesia)

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ABSTRACT

Turtles are reptiles that live in the sea and can migrate long distances throughout the Indian Ocean, Pacific Ocean and Southeast Asia. Their existence has long been threatened, both by nature and human activities. Light pollution (excess artificial light at night) affects female turtles in choosing a nesting site and affects the orientation of hatchlings to go to the sea on the nesting beach. Moreover, it decreases the efforts of turtles to nest and increases the death of hatchlings. This study aimed to analyze the behavior of hatchlings and *Chelonia mydas* toward the color of artificial light, and to propose the appropriate use of artificial light in *Chelonia mydas* conservation areas for sustainable fisheries. The study employed a descriptive analysis approach, utilizing primary and secondary data. The test animals were selected using the simple random method. In testing three different colors of light, namely red, green and blue at night, the results showed that hatchlings were most attracted to blue, with a higher percentage of 69%, while green had a percentage of 31%, and red had 0%. It was found that red light with a wavelength of 600nm did not disturb adult turtles. *Chelonia mydas* can see light colors with wavelengths of 360-500nm. In conclusion, the pattern of reaction to the behavior of hatchlings and adult turtles to the color of light shows that hatchlings and adult turtles are not disturbed by artificial red light. Suggestions for the management of sea turtle nesting protection areas include the use of artificial light with the alternative use of red (600nm) lamps for lighting, artificial light rays shielded from the beach, and the placement of artificial light as low as possible from the ground surface so that the light does not go directly to the beach.

INTRODUCTION

The sea turtle is a reptile that lives in the sea and can migrate long distances throughout the Indian Ocean, Pacific Ocean and Southeast Asia. Its existence has long been threatened, both by nature and by human activities that endanger its population directly or indirectly **(Li, J *et al.*, 2016; Banerjee *et al.*, 2020)**. In Indonesia, there are six (6) of the seven (7) species of sea turtles in the world. Of these six (6) species, four (4) of

them: the leatherback turtle (*Dermochelys coriacea*), the green turtle (*Chelonia mydas*), the hawksbill turtle (*Eremochelys imbricate*), and the olive ridley turtle (*Lepidochelys olivacea*) are known to breed in Indonesia, while the other species, the loggerhead turtle (*Caretta caretta*), is also thought to breed in Indonesia. The sixth species, the flatback turtle (*Natator epressus*) is known to breed only in Australia but has been observed foraging in Indonesian waters **(Kitchener, 1996 in the MMAF, 2009; Robinson *et al.*, 2016)**.

Internationally, turtles are on the IUCN 'red list' and CITES Appendix I, which means that their existence in nature is threatened with extinction. Meanwhile, in Indonesia, these turtles have been protected by Government Regulation Number 7 of 1999 concerning the preservation of protected plants and animal species, so all forms of utilization and circulation must receive serious attention **(Morton *et al.*, 2023; Peng *et al.*, 2023)**. Light pollution (excess artificial light at night) is known to influence female turtles to choose nesting sites and affect the orientation of hatchlings to go to the sea on nesting beaches. This reduces the number of turtles nesting and increases the mortality of hatchlings **(Witherington, 1997 in Magyar, 2009; Chambault *et al.*, 2018; Liles *et al.*, 2019; Redding *et al.*, 2024)**.

The Pangumbahan Turtle Beach Coastal Park is one of the turtle conservation areas, especially for green turtles (*Chelonia mydas*). This is indicated by the official IUCN document issued in 2004 regarding the status of the green turtle (*Chelonia mydas*) population in the world. The document states that Pangumbahan Beach and the surrounding sea waters in Sukabumi Regency, West Java Province are one of three locations in Indonesia and 30 other locations around the world that are index locations for observing the population status of green turtles **(Sukabumi Regency Fisheries Service, 2012; Barbour *et al.*, 2023; Cutzi *et al.*, 2023; Massey *et al.*, 2023)**.

The objectives of this study were (1) to analyze the behavior of hatchlings and green sea turtles *(Chelonia mydas)* in Pangumbahan Turtle Coastal Park toward the color of artificial light, (2) propose the appropriate use of artificial light in the green sea turtle (*Chelonia mydas*) conservation area in Pangumbahan Turtle Coastal Park for sustainable fisheries use, aa well as (3) recommending the sustainable utilization of artificial light in sea turtle nesting beach areas.

MATERIALS AND METHODS

The research was conducted from January 2014 to May 2014. The research site for conducting field tests was Pangumbahan Turtle Beach Coastal Park, Sukabumi Regency, West Java. The research was based on primary data obtained through direct field experiments and interviews with managers and tourists at Pangumbahan Turtle Beach Coastal Park. Secondary data were obtained from various sources including the Sukabumi Regency Marine and Fisheries Service, and the Pangumbahan Turtle Conservation Technical Implementation Unit.

The sample used was a green sea turtle (*Chelonia mydas*) hatchling, which was obtained at Pangumbahan Turtle Beach Coastal Park. A total of 10 hatchlings were used from 2 (two) different randomly selected nests. This test was conducted to determine what color of artificial light attracts green turtle hatchlings.

RESULTS AND DISCUSSION

Artificial light is a disturbance that can cause a decrease in the number of adult green turtles that will land to lay eggs and can cause death to turtles and hatchlings when looking for the sea. Artificial light can cause turtles and hatchlings to go in the wrong direction, not toward the sea but toward the artificial light. The turtles and hatchlings will die of dehydration, hunted by humans or eaten by predators on the beach **(Johansen *et al.*, 2020; Soeiro *et al.*, 2022; Miguel *et al.*, 2023)**.

1. The behavior of *Chelonia mydas* hatchlings toward red, green and blue artificial lights in the lab (Dark room)

In this research, it was found that the red color of artificial light tends not to disturb turtles and hatchlings, whereas the red light has a very long wavelength compared to other colors of light **(Lanszki *et al.*, 2024)**.

The pattern of reaction or behavior of hatchlings to light color, based on the results of the experiment, shows that hatchlings are very attracted to blue color during irradiation for 5 minutes. From the test results, even though the hatchlings always move actively during the test, always toward the blue color, it can be seen from Table (3) that blue has a higher percentage of 69%. Meanwhile, green has a percentage of 31% (thirty-one per cent), while red has a percentage of 0% (zero per cent).

Twenty (20) hatchlings were sampled from two (2) different nests, the hatchlings were not attracted to the red light. Hatchlings moved actively in the test tanks with a red light. The average number of green turtle hatchlings attracted to blue artificial light was 6.875, while the average number of hatchlings attracted to green artificial light was 3.125. From the test results, it was found that hatchlings are more attracted to light colors that have a short wavelength, namely blue **(Kelly *et al.*, 2017; Hall *et al.*, 2018)**.

Meanwhile, at the longest wavelength, red, the hatchlings are not interested or even recognize it. Reducing the impact of artificial light in the green turtle protection area can be done if the use of artificial light is properly managed. Therefore, these things need to be considered as a preventive measure against artificial light disturbance to the sustainability of green turtles in Pangumbahan Turtle Beach Coastal Park, Sukabumi Regency.

2. Behavior of green sea turtle (*Chelonia mydas*) hatchlings towards red, green and blue artificial lights on the beach

The study of hatchling behavior on this beach consisted of three (3) treatments and one (1) positive control (+) with six (6) replicates each, using 20 green sea turtle hatchlings (*Chelonia mydas*) from two (2) different nests, 10 hatchlings each. The results

of testing on hatchlings from the first nest showed that the hatchling/turtle cub will look for the sea after it hatches or comes out of the nest. In this study, it was found that artificial light can affect the orientation of hatchlings to look for the sea. The results showed that blue and green artificial lights attract the attention of hatchlings, causing them to walk around under the light. The impact of the artificial light makes the hatchlings go in the wrong direction, where they should be crawling toward the sea. Meanwhile, for red artificial light, the hatchlings do not go toward the light, but toward the sea. This is the same as positive control/ without lights where without any artificial light, the hatchlings will go towards the sea **(Esteban *et al.*, 2016; Del Monte-Luna *et al.*, 2023; Lasala *et al.*, 2023)**.

Table 1. Behavior of green sea turtle hatchlings 1 and 2 toward red, green, and blue artificial lights on the beach

Hatchling	Treatment			
	Red	Blue	Green	Without light
1	100% To the sea	100% Turn – Turn Under Lights	100% Turn–Turn Under Lights	100% To The Sea
2	100% To the sea	100% Turn – Turn Under Lights	100% Turn – Turn Under Lights	100% To The Sea
3	100% To the sea	100% Turn – Turn Under Lights	100% Turn – Turn Under Lights	100% To The Sea
4	100% To the sea	100% Turn – Turn Under Lights	100% Turn – Turn Under Lights	100% To The Sea
5	100% To the sea	100% Turn – Turn Under Lights	100% Turn – Turn Under Lights	100% To The Sea
6	100% To the sea	100% Turn – Turn Under Lights	100% Turn – Turn Under Lights	100% To The Sea
7	100% To the sea	100% Turn – Turn Under Lights	100% Turn – Turn Under Lights	100% To The Sea
8	100% To the sea	100% Turn – Turn Under Lights	100% Turn – Turn Under Lights	100% To The Sea
9	100% To the sea	100% Turn – Turn Under Lights	100% Turn – Turn Under Lights	100% To The Sea
10	100% To the sea	100% Turn – Turn Under Lights	100% Turn – Turn Under Lights	100% To The Sea

3. Behavior of *Chelonia mydas* towards artificial light when going to the beach to lay eggs

The study of the behavior of adult turtles on this beach consisted of two treatments and one positive control (+). In this stage of the study, a flashlight was used as a source of artificial light, while mica was used as a color producer in the flashlight to produce the color. The research found that female green turtles are deterred by white artificial light, prompting them to return to the sea instead of nesting. Among the 10 adult

female green turtles tested, none laid eggs or remained on the beach. White artificial light is commonly used for lighting around the nesting area, and guards at Pangumbahan Turtle Beach Coastal Park also use white flashlights. In contrast, when exposed to red light, the turtles continued their journey onto the beach and successfully laid their eggs.

Table 2. Results of artificial light color test on green turtles at Pangumbahan Beach

Turtle	Treatment		
	No lights	Red	White
1	100% Towards the beach	100% Towards the beach	100% Back to the sea
2	100% Towards the beach	100% Towards the beach	100% Back to the sea
3	100% Towards the beach	100% Towards the beach	100% Back to the sea
4	100% Towards the beach	100% Towards the beach	100% Back to the sea
5	100% Towards the beach	100% Towards the beach	100% Back to the sea
6	100% Towards the beach	100% Towards the beach	100% Back to the sea
7	100% Towards the beach	100% Towards the beach	100% Back to the sea
8	100% Towards the beach	100% Towards the beach	100% Back to the sea
9	100% Towards the beach	100% Towards the beach	100% Back to the sea
10	100% Towards the beach	100% Towards the beach	100% Back to the sea

4. Behavior of *Chelonia mydas* toward artificial light when going to the sea after laying eggs

The study of the behavior of adult turtles on this beach consisted of three (3) treatments and one (1) positive control (+). In this stage of the research, a flashlight was used as a source of artificial light, while the colors produced were red, green and blue mica to produce color in the flashlight. This research was conducted on adult green turtles after laying eggs on the beach. When using a flashlight on the beach, it is advisable not to shine it toward the sea, so as not to disturb the turtles that are about to come up to lay their eggs. Meanwhile, tests on adult green turtles when they are about to return to the beach where blue artificial light affects the behavior of adult green turtles, even with green artificial light, turtles tend to follow the direction of the color of the artificial light. This greatly affects the behavior of green turtles towards blue and green artificial light. Meanwhile, red artificial light does not affect turtles in their search for the sea after laying eggs. The color red has the longest light wave compared to blue and green.

Table 3. Artificial light color test on adult *Chelonia mydas* after laying eggs on Pangumbahan Beach

Hatchling	Treatment			
	Red	Blue	Green	Without light
1	100% To the sea	100% Following the light beam	100% Turn–Turn Under Lights	100% To The Sea
2	100% To the sea	100% Following the light beam	100% Turn – Turn Under Lights	100% To The Sea

3	100% To the sea	100% Following the light beam	100% Following the light beam	100% To The Sea
4	100% To the sea	100% Following the light beam	100% Following the light beam	100% To The Sea
5	100% To the sea	100% Following the light beam	100% Following the light beam	100% To The Sea
6	100% To the sea	100% Following the light beam	100% Following the light beam	100% To The Sea
7	100% To the sea	100% Following the light beam	100% Following the light beam	100% To The Sea
8	100% To the sea	100% Following the light beam	100% Following the light beam	100% To The Sea
9	100% To the sea	100% Following the light beam	100% Following the light beam	100% To The Sea
10	100% To the sea	100% Following the light beam	100% Following the light beam	100% To The Sea

5. Management and utilization of the *Chelonia mydas* conservation area

a) Tourism

Sukabumi Regency is known for its GURILAPS (Mountains, Jungle, Sea and Rivers) tourist attractions which can provide freshness and comfort for recreation. The utilization of these natural resources has also been carried out and provides a livelihood for some of the people in Pangumbahan Village and Ujung Genteng Village. Some of them become guards and managers of lodging places owned by people from outside the area (Jakarta and Bogor). Along with getting monthly money from the owners, they also earn income from the services they provide to staying tourists.

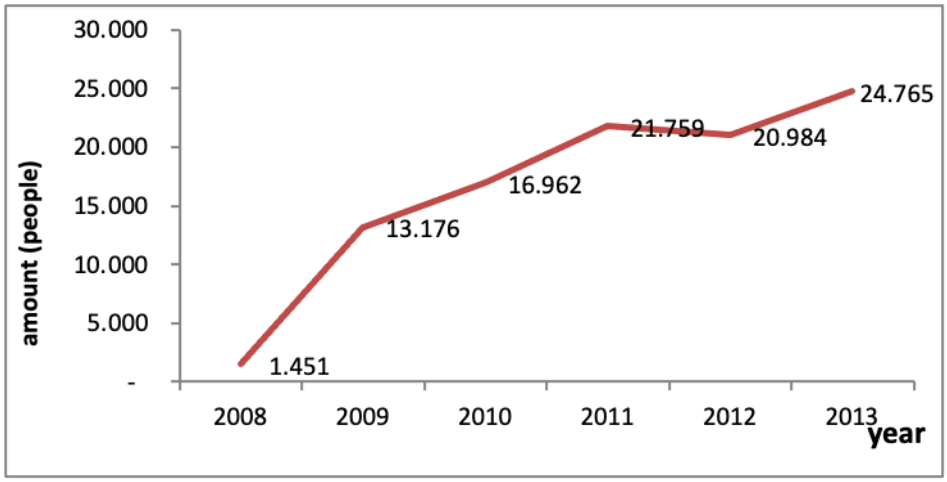

Fig. 1. Data on tourist visits to Pangumbahan Beach

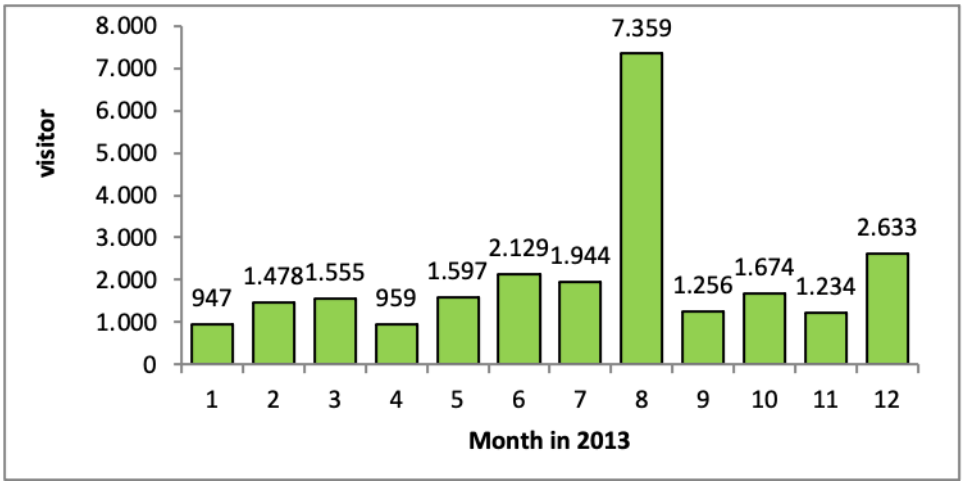

Fig. 2. Monthly data for tourist visits

B. *Chelonia mydas* population in Pangumbahan

The data on the number of *Chelonia mydas* in Pangumbahan Turtle Beach Coastal Park from 2008 to 2013 can be seen in Fig. (3).

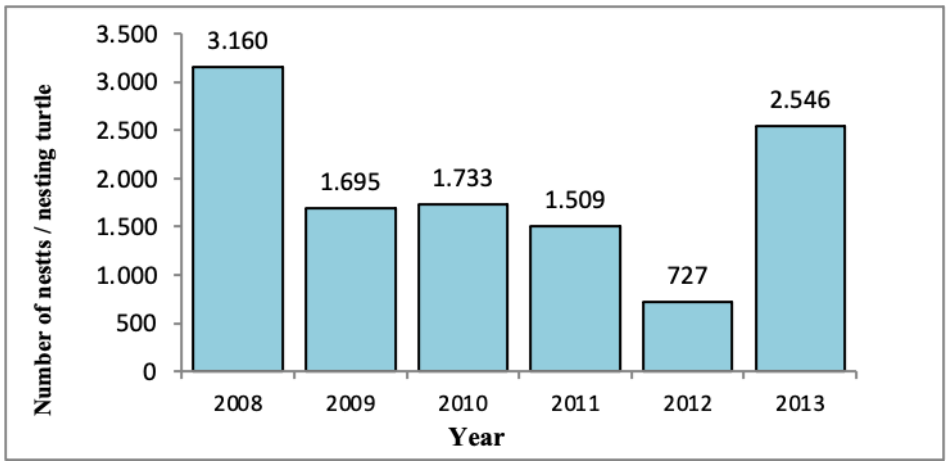

Fig. 3. Number of nests or *Chelonia mydas* laying eggs

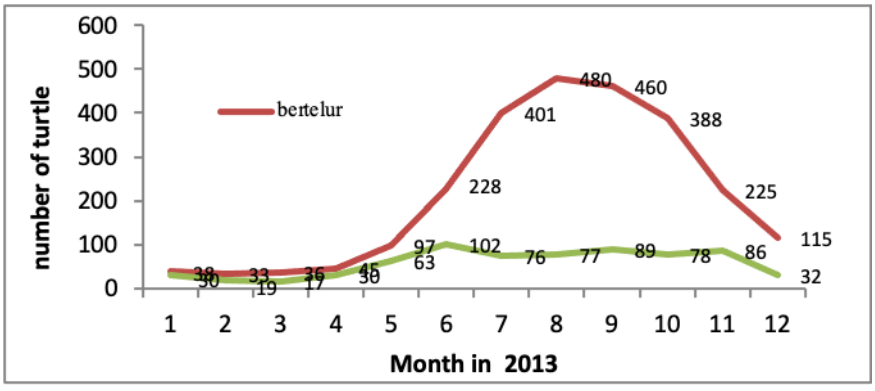

Fig. 4. Egg-laying and non-laying *Chelonia mydas* population data

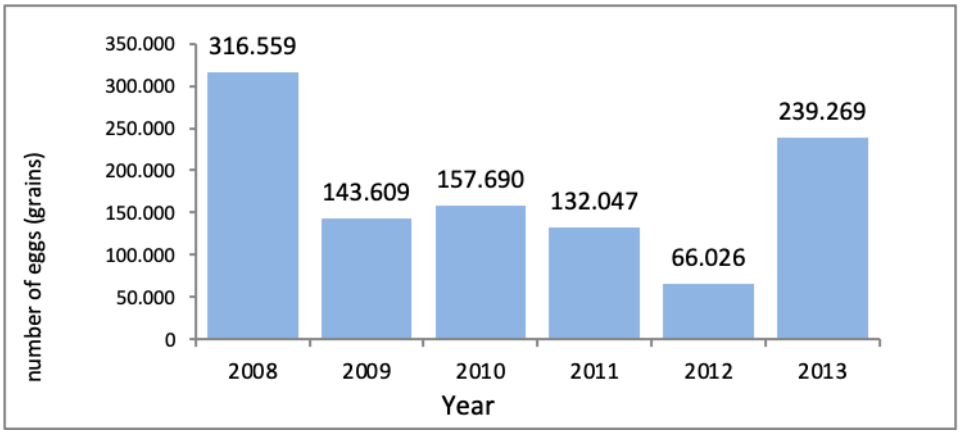

Fig. 5. Data on the number of *Chelonia mydas* eggs collected per year

A number of sea turtle eggs per month can be estimated, using the available data. These data are obtained from the collection of sea turtle eggs carried out by guards at each post.

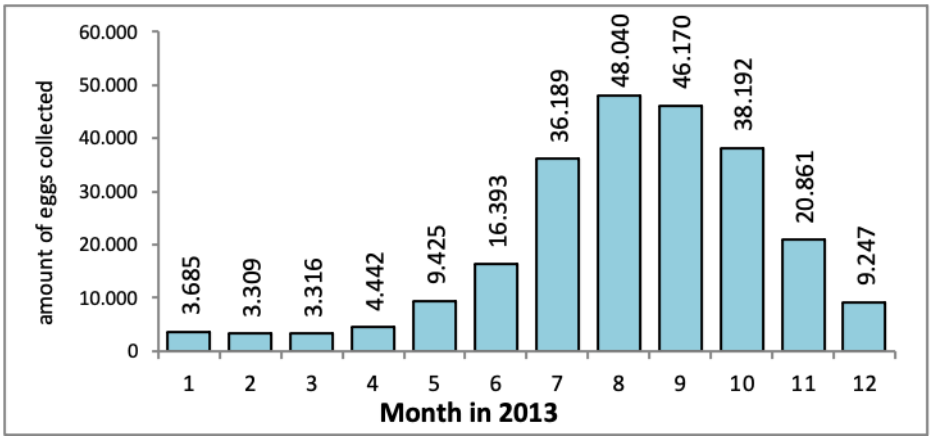

Fig. 6. Data on the number of sea turtle eggs per month

6. Management and utilization of the *Chelonia mydas* conservation area

Tourism management and utilization has a significant impact on the lives of people around the sea turtle conservation area. Some people make a living as laborers in restaurants or food stalls along the beach. The owners of these tourist service facilities are generally not native to Pangumbahan Village or Ujung Genteng Village. In addition, there are members of the community, especially those who have houses near the beach, who earn additional income from renting out their homes as homestays for groups of local tourists.

The number of tourists is increasing every year aligned with an accelerating demand for accommodation/hotels. Development is taking place in all sectors, and if uncontrolled, this development interferes with the sea turtle nesting areas. Looking at the number of visitors in 2013, there was a surge in the number of tourists arriving in August. This month coincides with school holidays and the Eid holiday.

Judging from the niche or life niche on Pangumbahan beach, it appears that posts 2-4 (out of a total of 6 posts) are places that turtles tend to prefer for laying eggs. Observations of the biophysical conditions of the beach at each post show that turtles like sloping beach areas with a certain sand texture and supported by a good density of beach vegetation, especially the presence of pandanus (*Pandanus tektorius*) communities which grow quite dominantly at the level of undergrowth in the first layer of the beach vegetation formation **(Baena *et al.*, 2015; Bézy *et al.*, 2015)**.

Turtles are wild animals that are very sensitive to any artificial light when they come ashore to lay their eggs. According to literature, any artificial light is naturally perceived as an indicator that the beach area is unsafe for laying eggs and, as a result, turtles tend to return to the sea. The highest ratio of sea turtles laying eggs is at post 2 and tends to decrease in value from post 3 to post 6. Posts 6 and 1 are areas where the ratio of sea turtles rise and laying eggs become quite low **(Fukuoka *et al.*, 2016; Buscaino *et al.*, 2023)**.

Interviews with officers and field observations show a correlation between the behavior of sea turtles and the intensity of human activity. Post 1 is a relatively open area and intersects with the traffic of tourist transportation that passes close to the post 1 area. The light from the tourist transportation is very disturbing to the turtles' egg-laying activities because turtles are known to be very sensitive to light. As for post 6, it is a crossing point for people who want to go to the Cikepuh Wildlife Sanctuary, which is relatively free to enter. Sometimes, post 6 is also a campground or an area where local tourists make bonfires. These activities are also a source of artificial light that disturbs turtles **(Moorhouse *et al.*, 2015)**.

Based on the results of artificial light research on turtles, turtles will tend to return to the sea. Meanwhile, turtles during their egg-laying period, which generally occurs 4 to 5 times in one egg-laying season (3 to 4 years), always try to return to the spawning beach until they can lay eggs. There is concern that physical exhaustion will affect turtles that have to repeatedly climb onto the beach to lay their eggs, ultimately affecting the quality of the eggs and subsequently causing a decrease in the success rate of hatching **(López-Castro *et al.*, 2022)**.

One attempt is to divert tourist transportation routes and reforestation on the beach, especially those that intersect with the post 1 area, as well as prohibiting human activity at post 6. Another phenomenon that disrupts the activity of sea turtles coming up to lay eggs is human activity on the beach, especially the activity of tourists walking on the beach to the location of sea turtles laying eggs and the use of camera flashes when tourists want to document the activity of sea turtles laying eggs. So far, the use of cameras has been tolerated by officers by covering the turtle's face with a cloth before being photographed and when the turtle has finished laying eggs. The impact of using a flash on the next turtle to come up has not been considered.

Therefore, it is necessary to sterilize the beach area at night outside of surveillance and research activities by providing special footpaths to the 'turtle watching' location prohibiting the use of camera flashes and providing alternative equipment (infrared cameras) for visitor/tourist documentation. In guiding tourists, night surveillance/guardianship of turtles, officers still use flashlights that are not red, because they do not know that red flashlights do not disturb hatchlings and adult green turtles.

The use of artificial light or lamps around sea turtle nesting beaches is still very poorly managed, where the rays or beams produced from the use of these lamps/artificial lights will disturb the turtles when they are about to lay their eggs on the beach.

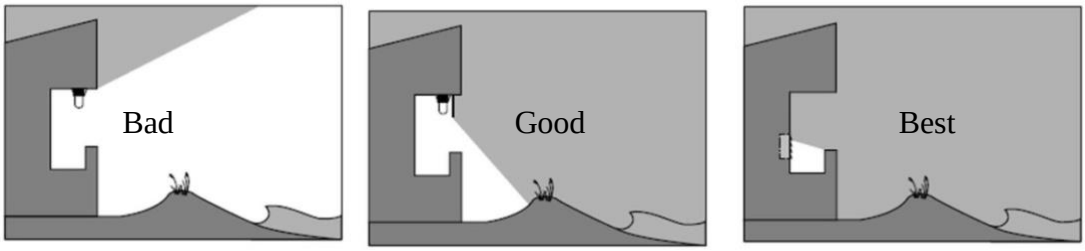

Image 7. Lamp modelling solution in areas close to sea turtle nesting areas **(Blair & Erik, 2003)**

Image (7) illustrates a solution for the use of artificial light in houses or hotels in areas close to sea turtle nesting areas, so that the artificial light used by the local community does not interfere with the process of sea turtles coming up to the beach to lay their eggs. In addition to this solution, there is also modelling of the use of artificial light in car parks or street lights.

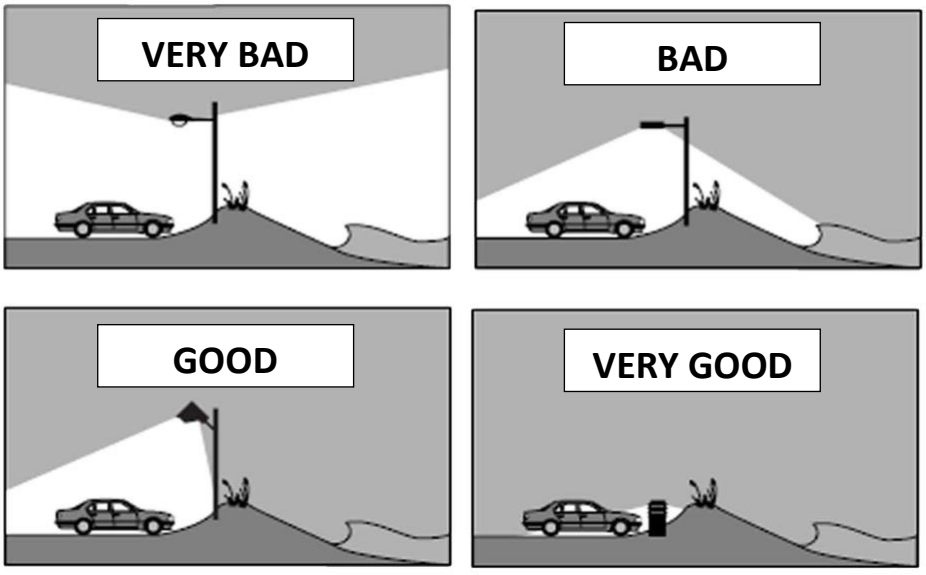

Fig. 8. Modelling solution for street lighting in areas close to turtle nesting areas **(Blair & Erik, 2003)**

CONCLUSION

From the results of the research, it can be concluded that:

1. The pattern of reaction or behavior of hatchlings to the color of light based on the results of the experiment shows that hatchlings are very attracted to the blue color with a higher percentage of 69%. Meanwhile, green has a percentage of 31%, while red has a percentage of 0%. The average number of green sea turtle hatchlings' interest in blue artificial light is 6.875, for the average number of hatchlings' interest in green artificial light is 3.125. Meanwhile, in red, it is 0%.
2. The results of tests on hatchlings from the first and second nests showed that artificial light can influence the orientation of hatchlings in search of the sea. Blue and green artificial lights attract the attention of hatchlings, causing them to walk around and around under the light. In the case of red artificial light, the hatchlings continue to head toward the sea. The same is true for dark beaches with no artificial light sources.
3. Researching the behavior of adult female green turtles when they are about to come ashore to lay their eggs with red and white artificial lights showed that white light shining toward turtles will cause the turtles to return to the sea / not to lay eggs. Meanwhile, testing using red light shining toward female green turtles that will come up to the beach to lay eggs showed that the turtles were not affected by red light and that they continued to walk toward the beach to lay eggs.
4. Studies on adult green turtles returning to the sea after laying eggs show that blue and green artificial lights influence their behavior, causing them to follow the direction of the light. In contrast, red artificial light does not affect their ability to navigate back to the sea.
5. To minimize the impact of artificial lighting on green turtles, several alternatives can be used, including red lights, shielding artificial light to prevent direct exposure to the beach, and positioning lights as low to the ground as possible.

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