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The Effect of Submersible Light Attractors on Tidal Trap Fisheries: Implications for Length at Maturity

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ABSTRACT: This study examined the impact of Submersible Light Attractors (SAL) on catch composition and Length at Maturity (Lm) of fish in tidal trap (*gombang*) fisheries in the Bengkalis Strait, Indonesia. Tidal traps, which are passive and static fishing gear, often capture undersized fish, posing a threat to the sustainability of fish stocks. The use of SAL aimed to improve catch efficiency and selectively target mature fish, thereby enhancing fishery management. The experiment compared catch composition and Lm between two fishing treatments: one with SAL (P1) and one without SAL (P0). The results showed a 17.5% increase in total catch weight when SAL was used, with significant improvements in catch size, particularly for demersal and pelagic fish species. The study indicated that SAL not only increased catch quantity but also enhanced gear selectivity, thereby reducing the bycatch of immature fish. These findings underscore the role of SAL in promoting sustainable fishing by improving catch size distribution and supporting fish population conservation. The use of SAL was recommended as a cost-effective tool for enhancing the ecological and economic viability of small-scale fisheries.

KEYWORDS: Submersible light attractors (SAL); tidal trap; length at maturity (lm); sustainable fishing; small-scale fisheries

1. Introduction

Tidal trap (*gombang*) is a traditional fishing gear commonly used by fishermen to catch fish and shrimp in the waters of the Bengkalis Strait, Indonesia [1]. Its passive and static nature prevented the selection of the size and species of fish entering the net. The size of the catch was often problematic, as it tended to be small. This not only reduced the economic value of the catch but also threatened the sustainability of fish resources, as many fish that had not reached the legal size became trapped. Legal size, or Lm, was defined as the minimum body length of an individual organism of a species, particularly fish or marine invertebrates, at which it first reached sexual maturity and became capable of reproduction. Lm was an essential parameter in fisheries management, as it served as a benchmark to ensure the sustainability of fish stocks. The utility of Lm was to establish the minimum size of fish that could be caught, ensuring that fish could reproduce at least once before being captured [2]. Furthermore, Lm was used to determine the appropriate mesh size, allowing juvenile fish to escape and grow [3]. Another benefit of Lm was its role in evaluating the impact of fishing activities on fish population structure, particularly in identifying whether overfishing pressure occurred on individuals that had not yet matured reproductively [4]. Fisheries governance also utilized Lm to determine fishing seasons and locations to protect fish during spawning periods, ensuring that fish stocks remained naturally productive [5].

A previous study by [6] aimed to improve the operational method of tidal trap fishing by deploying SAL at night. The results showed that SAL significantly increased the tidal trap catch weight by 17.5% compared with traps operated without SAL. The present study builds upon that research. Study [7] further reported that fishers generally responded positively to SAL, with an 80% approval rate, and noted its long-term investment benefits for increasing catch yields. Nevertheless, the use of SAL may also have ecological and biological implications for tidal trap fisheries. Study [8] explained that one method to evaluate the effect of fishing on ecosystems was to examine legal size (Lm), maximum length (Lmax), and body-size distribution within the population. The use of SAL in tidal trap fisheries impacted Lm, both directly and indirectly. A deep understanding of legal size (Lm) and fish size distribution patterns was essential to guide future improvements. Further research was expected to focus on more selective catch methods for tidal trap fisheries, particularly regarding size. This study aimed to examine catch composition and the impact of Lm on tidal trap catches, both with and without the use of SAL.

Studies specifically focused on the distribution and size of Lm in tidal trap catches remained limited. The literature search found only two similar references related to the impact of using attractor lights (SAL) on legal size. According to [9], the species of fish caught with tidal traps were still below the first maturity size. Meanwhile, [10] stated that LED technology improved efficiency, but most of the fish caught were below the legal size, indicating potential risks to the sustainability of the fishery. This study filled the research gap by examining the impact of SAL on catch composition and Lm in tidal trap fisheries, an area that had been largely underexplored. Additionally, it developed a more selective fishing method aimed at improving catch size and supporting the sustainability of fish stocks in tidal trap fisheries.

2. Materials and Methods

The study was conducted in two main stages: the production of SAL and field testing. The first stage, SAL production, was carried out at the Fishery Gear Technology Laboratory, Faculty of Fisheries and Marine Sciences, IPB, in April 2023. The subsequent stage, the field trial, was conducted in the waters of Prapat Tunggal Village, Bengkalis District, Riau Province, from May to October 2023. The trial was conducted at two locations with different coordinates: 1°10′33.923″ N; 102°00′28.122″ E (referred to as P0/control) and 1°10′56.43″ N; 102°00′73.85″ E (referred to as P1). The locations of these points are visually presented in Figure 1. This study employed an experimental fishing method to collect primary data on catch composition, species, weight, and environmental parameters, including tides, currents, and temperature. Data were collected from two units of tidal traps: the control tidal trap (P0) and the tidal trap equipped with SAL (P1). Both units were operated simultaneously and were separated by approximately ±750 m to minimize bias. The number of replications was determined using the formula proposed by [11], which yielded a minimum of 16 replications. However, to improve data accuracy, 17 replications were conducted.

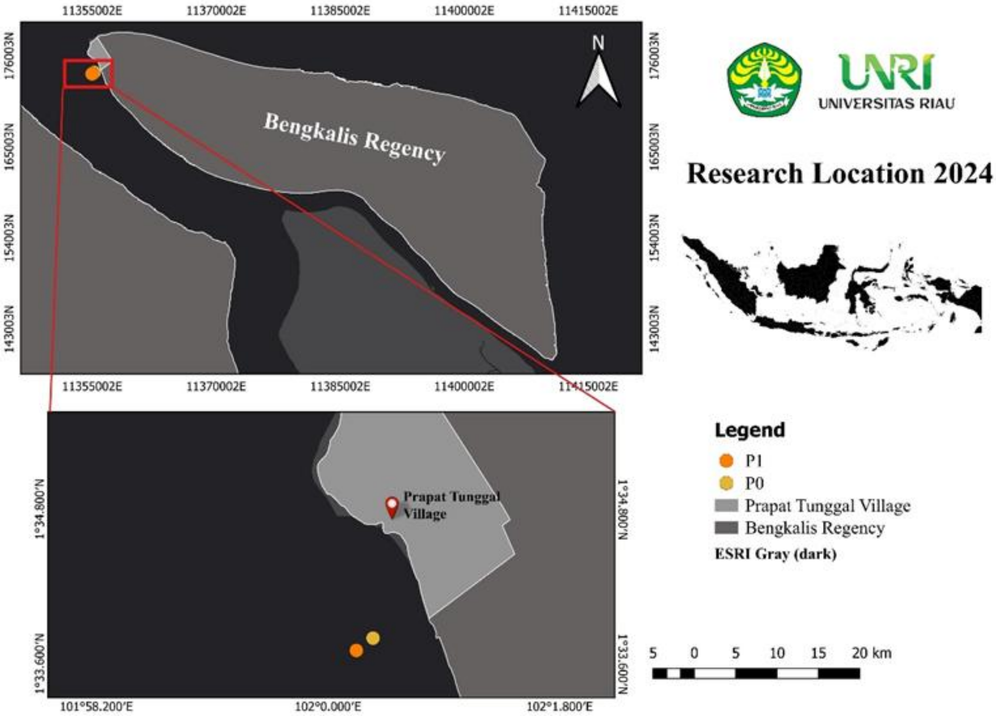

Figure 1. Research the location of SAL.

The equipment used in the study consisted of batteries, a metal frame, a measuring tape, calipers, rulers, a whiteboard, a camera, a current meter, a lux meter, a stopwatch, a thermometer, a bucket, a GPS (Global Positioning System) tracker, and two units of tidal trap fishing gear, including a control tidal trap and an experimental tidal trap. The system also included light-emitting diodes (LEDs) with a maximum light intensity of 300 lux and a uniform horizontal light distribution around the light source. The reduction in light intensity was evenly distributed at all angles as the power from the dry batteries decreased. The SAL was placed in front of the tidal trap mouth and suspended by the leader net. The tidal trap design incorporating a leader net was developed by [1], who reported a 30% increase in catch. The materials used included catch samples, acrylic materials, and LED strips. The construction of the SAL is shown in Figure 2, while the illustration of SAL placement during tidal trap operation is presented in Figure 3.

Figure 2. Construction of SAL.

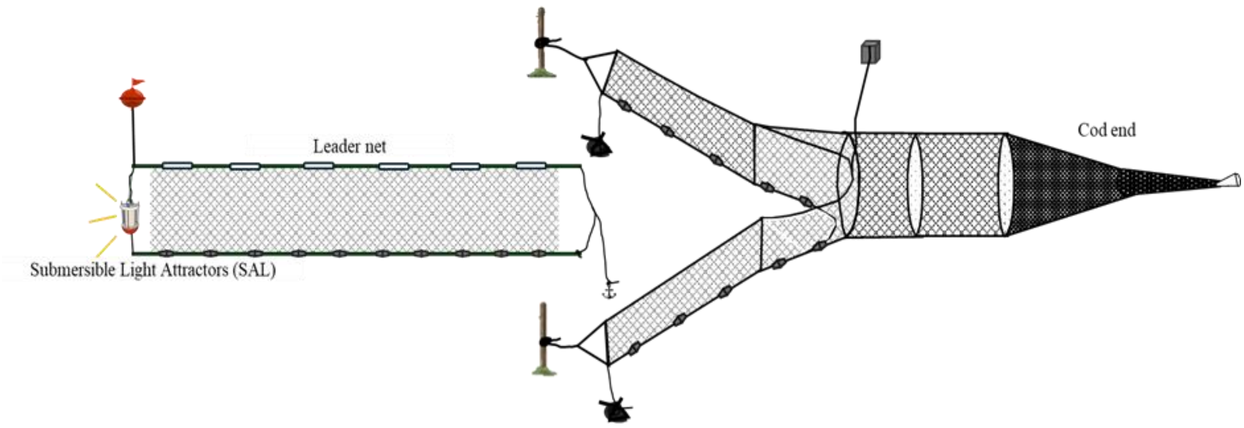

Figure 3. Illustration of SAL placement during tidal trap operation.

2.1. Catch composition and legal size (length at maturity) analysis.

Catch composition was analyzed descriptively. All catch results were presented as catch composition diagrams following the method described by [12]. The legal-size analysis was also conducted descriptively. The legal size (length at maturity) analysis included all fish species that showed a 60% increase in total catch when using SAL. Legal sizes were then compared between catches obtained with SAL and without SAL. Legal size was determined based on available data from FishBase for each fish species.

2.2. Statistical analysis.

Data analysis included descriptive statistics and nonparametric tests, namely the Mann–Whitney U Test or the Wilcoxon Rank-Sum Test. Descriptive analysis was used to describe fish species composition and the weight of fish caught using SAL and without SAL during nighttime fishing. Nonparametric testing was applied to compare two groups [13, 14]. The analysis procedure involved combining both data samples and ranking them from smallest to largest. Each value in the combined dataset was assigned a rank, with the smallest value receiving rank 1, the second-smallest rank 2, and so on. These ranks were then allocated to each data group, namely tidal traps without SAL and tidal traps with SAL, based on the predetermined order in the combined dataset. The final step involved calculating the sum of ranks for each group. The sum of ranks for the tidal traps without SAL was denoted as R1, while the sum of ranks for the tidal traps with SAL was denoted as R2. This procedure allowed for a comparison between the two groups based on rank distributions.

The Mann–Whitney U Test or Wilcoxon Rank-Sum Test used the following formulas:

$$U1 = R1 - (n1(n1 + 1)/2) \quad (1)$$
$$U2 = R2 - (n2(n2 + 1)/2) \quad (2)$$

Where R1 represented the sum of ranks for the first group, R2 represented the sum of ranks for the second group, n1 represented the number of observations in the first group, and n2 represented the number of observations in the second group.

The U statistic used in the test was the smaller value between U1 and U2, expressed as

$$U = \min(U1, U2). \quad (3)$$

When necessary, U values were converted to Z values to approximate a normal distribution, particularly when the sample size was large (n > 20), using the following formula:

$$Z = (U - \mu U) / \sigma U \quad (4)$$

In this equation, μU was defined as (n1n2)/2, and σU was defined as √[n1n2(n1 + n2 + 1)/12]. Statistical decisions were made by examining the p-value of the U statistics. If the p-value was smaller than the significance level (p = 0.05), the null hypothesis (H0) was rejected, indicating a significant difference between the two groups.

3. Results and Discussion

3.1. Catch composition of tidal trap with SAL and without SAL.

The catch composition of tidal traps, both with and without SAL, consisted of 12 species categorized into three major groups: crustaceans, pelagic fish, and demersal fish. The crustacean group included acetes shrimp (*Acetes* sp.), red shrimp (*Penaeus monodon*), and black tiger shrimp (*Sculpilis* sp.). The pelagic fish group included longjaw thryssa (*Ilisha* sp.), dried gangetic anchovy (*Thryssa setiostris*), gold stripe sardinella (*Dussumieria acuta*), and narrow bar (*Scomberomorus brasiliensis*). The demersal fish group included wolf herring (*Chirocentrus* sp.), croaker fish (*Johnius trachycephalus*), hairtail (Trichiurus lepturus), Bombay duck fish (*Horpodon neherus*), and cuttlefish (Sepia sp.). The total weight of the catch reached 3,721.14 kg. A detailed breakdown of the catch composition is presented in Figure 4.

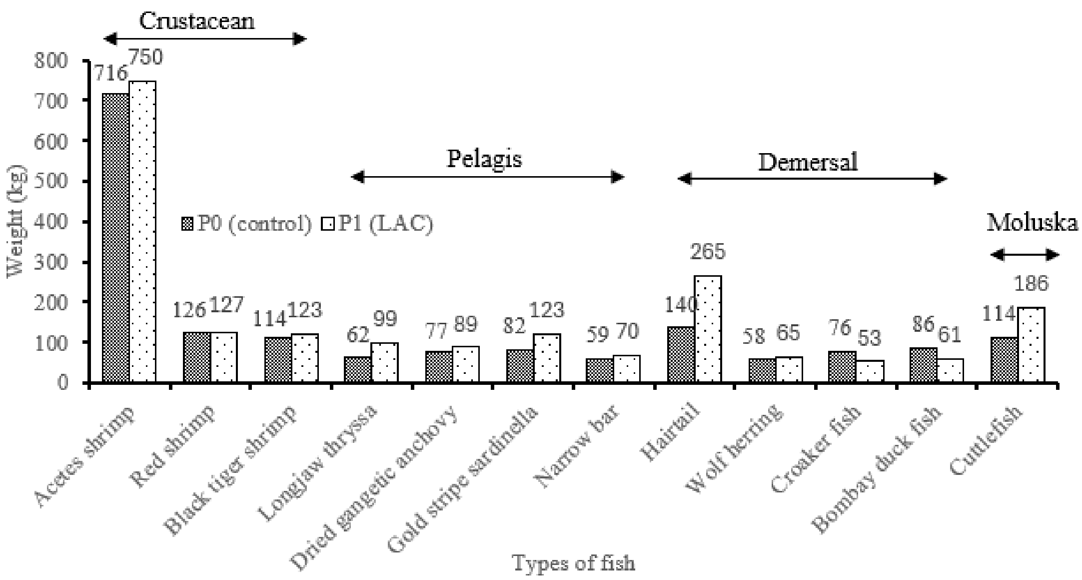

Figure 4. Catch composition of tidal trap with SAL and without SAL.

Figure 4 showed that almost all catch types increased with the use of SAL, except for croaker fish and Bombay duck fish. The greatest increases in catch with SAL were observed for hairtail and cuttlefish. The tidal trap with SAL (P1) caught 2,010.32 kg, which was 17.5% higher than the tidal trap without SAL (P0), which caught 1,710.76 kg of the total catch. Additionally, Figure 4 indicates that crustaceans were the primary catch of tidal traps, both with and without SAL. SAL effectively attracted crustaceans such as acetes shrimp by concentrating plankton as a food source using a 45-watt LED light with an optimal intensity of approximately 300 lux. The effectiveness of SAL was further supported by mangrove habitats, which served as natural ecosystems for crustaceans [15, 16]. At night, the vertical migration of plankton to the surface further attracted crustaceans to illuminated areas, thereby increasing catch opportunities [17, 18].

The demersal group was the second most abundant catch. As nocturnal predators, demersal species actively foraged at night. The use of SAL increased demersal catch by 33%, not due to direct attraction to light, but rather due to increased plankton concentrations around the light source. Similar to crustaceans, demersal fish relied on plankton in neritic waters as a primary food source; therefore, illumination from SAL supported their presence and increased catch opportunities [19−23].

The pelagic group also showed a 36% increase in catch with SAL. Small pelagic species, which fed on plankton, tended to approach the light. However, the presence of demersal predators, which were also attracted to the light, often caused small pelagic fish to migrate away to avoid predation. This created a dynamic in which pelagic fish migrated to deeper or shallower waters, depending on their need to avoid demersal predators. Nevertheless, pelagic species continued to utilize plankton concentrated under the light, which remained their primary food source [24, 25].

The increase in catch associated with SAL use was closely related to trophic food-chain dynamics. SAL illumination attracted plankton, crustaceans, and small fish, which in turn attracted larger predators, creating species aggregation in illuminated areas and increasing catch opportunities [26, 27]. This finding was consistent with [28], who conducted a comprehensive review of behavioral and physiological interactions between fish aggregation and fishing gear. That study emphasized the role of external stimuli, such as light, electric fields, and hydrodynamic disturbances, in shaping fish responses to fishing gear. Three interaction zones the influence zone, action zone, and retention zone, were identified as key determinants of capture effectiveness. Fish responses varied according to phototaxis, electroreceptive abilities, and schooling behavior, which ultimately affected gear selectivity and efficiency. The use of underwater lighting, particularly in passive and semi-active fishing gear such as bagan and ring nets, was shown to significantly increase fish aggregation and catch rates. Similar effects were observed in the engineering application of SAL in tidal traps. The study further argued that adaptive fishing gear designs integrating fish behavioral knowledge could enhance selectivity and reduce bycatch, thereby supporting more sustainable fisheries management.

3.2. The catch increased significantly with the use of SAL.

The use of SAL in tidal trap fisheries focused on fish species that responded to light. The introduction of SAL aimed to increase catches of pelagic, demersal, and mollusk species, as fishermen had traditionally focused mainly on crustaceans. Based on the research findings, tidal traps that showed significant catch increases (>60%) included hairtail, longjaw thryssa, gold stripe sardinella, and cuttlefish.

3.2.1. Hairtail.

Hairtail (*Trichiurus lepturus*) had a gonochoric reproductive system with a batch-spawning pattern. Female fish released eggs periodically during the spawning season. Hairtail eggs were pelagic and floated in the water column until hatching, after which larvae developed in open waters. First gonadal maturity generally occurred at sizes of 25–40 cm, with females maturing more slowly than males. Environmental factors such as temperature (24–28°C), salinity (30–35 ppt), and food availability significantly affected spawning success [29−31]. The application of SAL in tidal trap operations had a significant effect on hairtail catches. Based on Figure 5, the length distribution of hairtail that did not meet the legal size (Lm < 30 cm) was dominated by individuals measuring 22–28 cm, which were predominantly caught without SAL (P0). In contrast, hairtail meeting legal size (Lm ≥ 30 cm) were more commonly captured when SAL was used (P1). This pattern indicated a reduction in juvenile hairtail capture. SAL improved gear selectivity by attracting larger hairtail, thereby directly reducing the exploitation of fish below the minimum reproductive size.

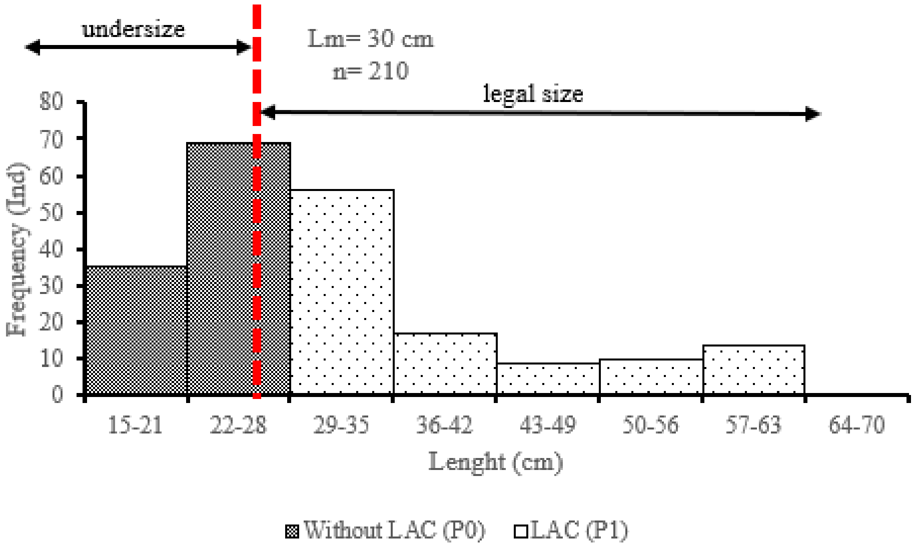

Figure 5. Length distribution of Lm hairtail without SAL and with SAL.

3.2.2 Longjaw thryssa.

The trial using SAL in tidal traps showed a significant impact on the catch of longjaw thryssa (*Ilisha* sp.). Based on the histogram in Figure 6, most longjaw thryssa caught by tidal traps without SAL (P0) were within the size range of 7.3–16.3 cm, which did not meet the legal size (Lm = 15 cm). This size distribution indicated low selectivity of tidal traps without SAL, resulting in the capture of many juvenile fish. With the use of SAL (P1), the catch distribution shifted toward larger size classes, with a significant increase observed in the 17–26 cm size range.

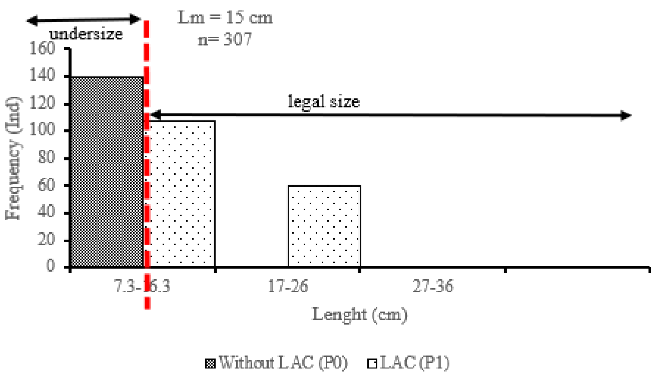

Figure 6. Length distribution of Lm longjaw thryssa without SAL and with SAL.

The results indicated that SAL improved fishing gear selectivity by attracting larger fish, reducing the exploitation of juvenile individuals, and increasing the catch of longjaw thryssa that met the legal size. The application of SAL in tidal traps for longjaw thryssa demonstrated that most of the captured fish met the legal size (≥15 cm). Thus, SAL not only supported selective fishing practices but also played an important role in maintaining population balance, supporting the sustainability of longjaw thryssa fisheries, and ensuring future population regeneration.

3.2.3. Cuttlefish.

The use of SAL in tidal traps showed a significant impact on cuttlefish catches. Based on the histogram in Figure 7, tidal trap operations without SAL (P0) predominantly captured cuttlefish with mantle lengths ranging from 2.8 to 11.8 cm, which fell into the undersized category because their lengths were below the legal size (Lm < 7 cm). This result reflected the low selectivity of tidal traps without SAL, leading to a high proportion of small cuttlefish being caught. In contrast, the application of SAL (P1) resulted in a reduction in the capture of small cuttlefish. Additionally, larger mantle length classes, ranging from 12.8 to 21.8 cm, began to appear and increased in frequency. Cuttlefish exhibit strong attraction to light, and the selection of appropriate light sources and SAL intensities that align with their retinal adaptations to dim or low-light environments was crucial [32]. The results of this study confirmed that SAL improved fishing gear selectivity by increasing the capture of larger cuttlefish.

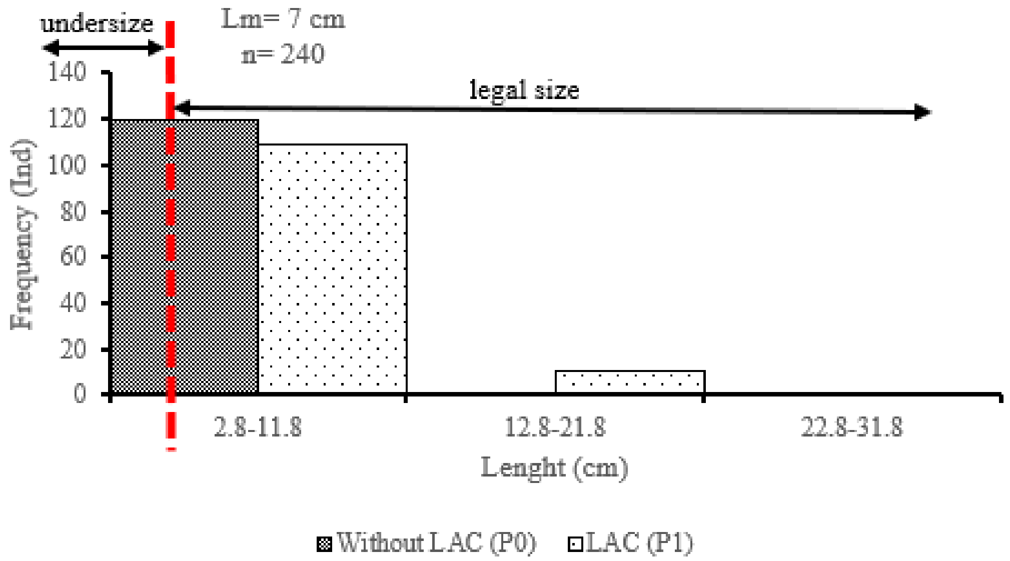

Figure 7. Length distribution of Lm cuttlefish without SAL and with SAL.

3.2.4. Gold stripe sardinella.

Gold stripe sardinella (*Dussumieria acuta*) showed an increase in catch with the use of SAL. A positive trend toward larger, adult, or legal-size individuals accompanied this increase. Based on the histogram in Figure 8, tidal traps without SAL (P0) predominantly captured gold stripe sardinella within the 5.5–13.5 cm size range, which fell into the undersized category. The low selectivity of tidal traps without SAL resulted in the dominance of small-sized fish in the catch. In contrast, the application of SAL (P1) significantly reduced the number of gold stripe sardinella captured below the legal size. The size distribution of the catch shifted toward the 14.5–22.5 cm size group, which fell within the legal-size category. The use of SAL resulted in most gold stripe sardinella being within the legal-size range (Lm ≥ 12 cm). This shift reduced the number of individuals in the 12–14 cm size range that had not yet reached the minimum reproductive size (≥14 cm). The increase in gold stripe sardinella catch associated with SAL use was attributed to their attraction to light, as this species is known to form schools during the day and forage at night [24]. Gold stripe sardinella typically inhabits neritic waters, with a swimming layer ranging from 10 to 20 m.

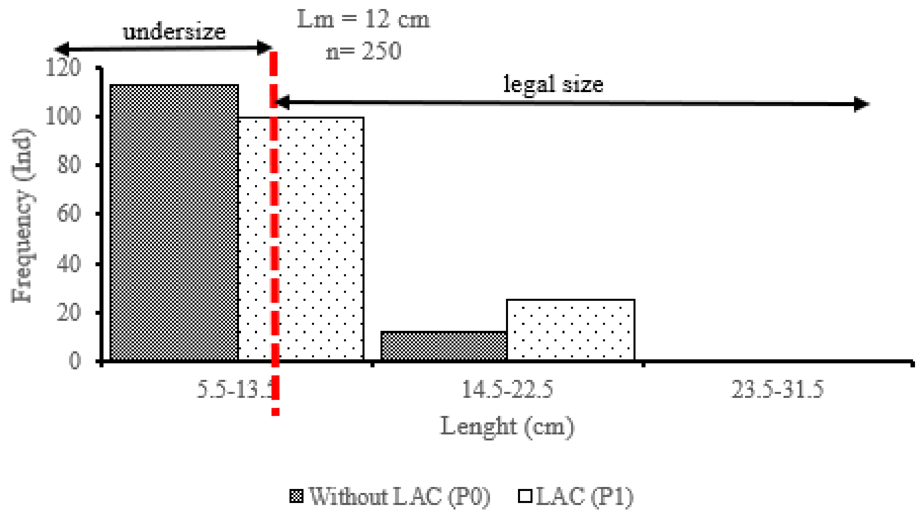

Figure 8. Length distribution of Lm gold stripe sardinella without SAL and with SAL.

3.3. The impact of SAL on length at maturity.

The results of the statistical analysis showed that the increase in tidal trap catches with SAL was supported by the Mann–Whitney U test. The obtained p-value was 0.0413, which was lower than the significance level of 0.05. Therefore, the null hypothesis (Ho) was rejected, indicating a statistically significant difference between the catches of tidal traps without SAL (P0) and those with SAL (P1). The use of SAL was proven to have a significant impact on increasing both the quantity and diversity of catches in tidal traps. Almost all catch types showed an increase, particularly the four main species that responded most strongly to SAL application: the demersal group (hairtail and cuttlefish) and the pelagic group (longjaw thryssa and gold stripe sardinella). These four species recorded catch increases of more than 60% when SAL was used.

The study indicated that the effect of SAL was not solely due to the visual attraction of light to fish but was largely attributed to increased plankton concentrations around the illuminated area. Light emitted by SAL attracted zooplankton and phytoplankton, which subsequently attracted small fish and crustaceans. The presence of this prey then attracted demersal predators, such as hairtail and cuttlefish, toward the light source, increasing their likelihood of capture [19−23].

Pelagic fish, such as longjaw thryssa and gold stripe sardinella, also approached the light because plankton constituted their primary food source. However, ecological interactions emerged due to the presence of demersal predators in the illuminated area. Under these conditions, small pelagic fish tend to migrate away from the light source to avoid predation, either moving to deeper or shallower water layers. Nevertheless, they continued to utilize plankton concentrated around the light source as their main food resource [24, 25]. This interaction created a complex spatial distribution between prey and predators but ultimately enhanced the effectiveness of the fishing gear.

The study further revealed that SAL use not only increased total catch weight but also influenced the size of captured fish. Average fish size tended to increase, with many individuals reaching or exceeding length at maturity. This effect was likely due to SAL attracting fish of various sizes, including larger adult individuals that actively preyed on organisms aggregated around plankton concentrations [33−37]. This process reflected trophic food-chain dynamics, beginning with primary producers such as plankton, followed by consumers such as shrimp and small fish, and ultimately higher-level predators. According to [28], fishing gear design should integrate knowledge of fish behavior to improve size selectivity and reduce bycatch. Therefore, SAL uses enhanced not only catch quantity but also biological quality, with important implications for economic value and sustainable fisheries management.

4. Conclusions

The use of SAL in tidal trap fisheries resulted in a significant increase in both catch quantity and quality. This study found that SAL increased total catch weight by 17.5%, particularly for demersal and pelagic fish species. The positive impact of SAL was also evident in improved fishing gear selectivity, as shown by a reduction in the number of fish that had not yet reached Lm. This indicated that SAL contributed to capturing fish at sizes closer to reproductive maturity. By attracting larger fish and reducing the capture of sexually immature individuals, SAL supported the sustainability of fish stocks. Overall, SAL not only improved fishing efficiency but also contributed to more sustainable fisheries management practices.

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Author Contribution

The contributions of each author to the research are as follows: conceptualization was performed by Muhammad Natsir Kholis and Gondo Puspito; methodology was developed by Muhammad Natsir Kholis, Budy Wiryawan, and Wazir Mawardi; data collection was carried out by Muhammad Natsir Kholis, Erliantina Arridhaty Akita, and Muhamad Yogi Prayoga; data analysis was conducted by Muhammad Natsir Kholis, Mohammad Imron, and Erliantina Arridhaty Akita; writing of the manuscript was done by Muhammad Natsir Kholis, Irwan Limbong, and Amraini Fitri; supervision was provided by Gondo Puspito, Budy Wiryawan, Mohammad Imron, and Wazir Mawardi; and funding was secured by Muhammad Natsir Kholis..

Competing Interest

All authors should disclose any financial, personal, or professional relationships that might influence or appear to influence their research.

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