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Effect of hauling and soaking time of stationary lift nets on fish aggregation using a hydroacoustic monitoring approach

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ABSTRACT

This study aimed to determine the effect of hauling and soaking time of stationary lift nets on the pattern of fish aggregation in the Banyuasin waters, South Sumatra, Indonesia using a hydroacoustic monitoring approach. The fish aggregations were monitored using the SIMRAD EK-15 single beam (200 kHz) during hauling, and the transducer was mounted on the side of the fishing gear. Furthermore, data were collected before (17:00–23:59) and after midnight (24:00–05:00) at four different soaking times (S_1, S_2, S_3, and S_4). The data obtained were then analyzed using pairwise comparisons (nonparametric tests). The pairwise test (p = 0.25 > 0.05) showed that there was no significant difference between the acoustic mean densities obtained before and after midnight (292.2 and 178.9 g/m^3), but the total values for both periods varied widely (6,797 and 3,507 g/m^3). Dunn's post hoc tests (p = 0.001 < 0.05) revealed that there were significant differences in the acoustic mean densities between S_1 (1–16 min) and S_2 (17–32 min). Based on the results, the optimum soaking time was 17–32 min, which was recommended for improving the effectiveness of the stationary lift nets. Furthermore, fish aggregation began to spread out of the catchable area when the soaking time was over 32 min.

Introduction

Banyuasin coastal waters in the province of South Sumatra, Indonesia, hold strategic and significant potential for fishery activities. One of the prominent fishing gears employed in this region is the stationary lift nets, also known as "shore-operated stationary lift nets", as classified by FAO (He et al., 2021). These nets are extensively used for capturing anchovies and play a vital role in the anchovy fishery of Banyuasin coastal waters. Septifitri et al. (2010) also highlighted that they were one of the prominent fishing gears in South Sumatra Province. However, a significant challenge lies in their effectiveness in attracting the target species and minimizing unintended bycatch (Fauziyah et al., 2021).

The stationary lift nets are usually operated from fixed installations located in coastal waters along the shore (He et al., 2021). Based on the Code of Conduct for Responsible Fisheries (CCRF), these nets are categorized as eco-friendly fishing gear, as they have been accepted by the communities and do not cause harm to protected biota (Limbong et al., 2022). Krumme et al. (2013) also stated that they are widely used in several Asian countries, including Indonesia, Malaysia, Thailand, Philippines, VietNam, and China. In this study, the lifting system consists of a conveyor pulley with spherical roller bearings, while the traditional kerosene lamp was applied for attracting the target species (Fauziyah et al., 2021).

In terms of fishing operations, the fishermen rely solely on kerosene lamps (artificial light) as a means of attracting and aggregating the target fish within the catchable area. The optimal soaking time of this gear has been reported to be closely related to the duration it takes the target fish to be attracted to the artificial light and enter the catchable area. This indicated that the soaking and hauling time have a significant effect on fishing efficiency. Over the years, fishermen determined the hauling and soaking time solely based on their inherited knowledge and experience. However, direct observation of the target fish behavior in the catchable area is very limited due to the high level of turbidity in these waters. In this context, employing hydroacoustic technology provides a viable solution to this problem.

Hydroacoustic observation of target fish behavior on the stationary lift nets has been carried out in various Indonesian waterbodies, including Takalar Waters (Angreni et al., 2020a), Pangkep Waters (Angreni et al., 2020b), Makassar Strait (Kurnia et al., 2015, 2016; Salman et al., 2015; Sulaiman et al., 2006), Seribu Is-

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lands (Priatna and Mahiswara, 2009; Sugandi et al., 2019), and Morotai Island (Alwi et al., 2021). Several studies have also explored hydroacoustic monitoring in other countries, such as France, Switzerland (Girard et al., 2020), Korea (Min et al., 2021), California (Kaltenberg and Benoit-Bird, 2009), United Kingdom (Draštík et al., 2017), China (Lin et al., 2020; Wu et al., 2022), and Oregon (Rasmuson et al., 2022). For example, Pujiyati et al., (2022) have used hydroacoustic technology to detect plankton distribution in Yos Sudarso Bay of Jayapura. Consequently, these techniques are increasingly being used to monitor fish populations, distribution, and behavior. They also provide reliable information for fish assessment without interfering with behavioral components (Martignac et al., 2021). The main advantages of acoustic technology include non-intrusive sampling of fisheries, quantitative measurements, rapid processes, and being synoptic (Girard et al., 2020; Martignac et al., 2015; Simmonds and MacLennan, 2005). However, one of the main challenges associated with these methods is fish species identification (Martignac et al., 2015). To address this challenge, a good knowledge of fish behavior in the monitored fishing gear can facilitate indirect species identification and increase fishing efficiency.

At present, there are no studies on the observation of fish behavior on the stationary lift net in Banyuasin waters using a hydroacoustic approach. The existing reports in the region have only focused on identifying the different types of bottom sediments (Fauziyah et al., 2020; Ningsih et al., 2021) and plankton abundance (Hasan et al., 2021). For example, a previous study compared the effect of different LED lamp intensities on the catch composition from the stationary lift net in these waters (Fauziyah et al., 2021). Therefore, this study aims to analyze the pattern of fish aggregation based on the hauling and soaking time from the stationary lift net using a hydroacoustic monitoring approach. The results are expected to provide scientific information on the best setting and hauling times for operating the stationary lift net in the Banyuasin waters.

Material and method

Study area

This study was carried out in the Banyuasin waters of South Sumatra, Indonesia (Fig. 1) and sampling was performed from the 3rd-12th of November 2019, throughout the waxing crescent to full moon phases. Furthermore, the sampling procedures were carried out about 7 nm from the fishing base of Banyuasin. The Musi River inflows highly influenced the coastal waters, which tended to have a diurnal tide.

Data collection

Data was collected using one unit of stationary lift net operated by local fishermen. Furthermore, the data included the acoustic density and aggregation pattern of fish obtained from hydroacoustic monitoring for 10 days during each fishing operation. Several fish species created social aggregations due to the need for defense, reproduction, and food acquisition (Partridge, 1982). Hauling time was divided into before (T_1 = 17:00–23:59) and after midnight (T_2 = 24:00–05:00). The numbers of hauls including the soaking time were obtained using data on fishermen's habits. During the observation, a total of 50 hauls were conducted in the study location. Soaking time was divided into four groups, namely S1 (1–16 min), S2 (17–32 min), S3 (33–48 min), and S4 (49–64 min).

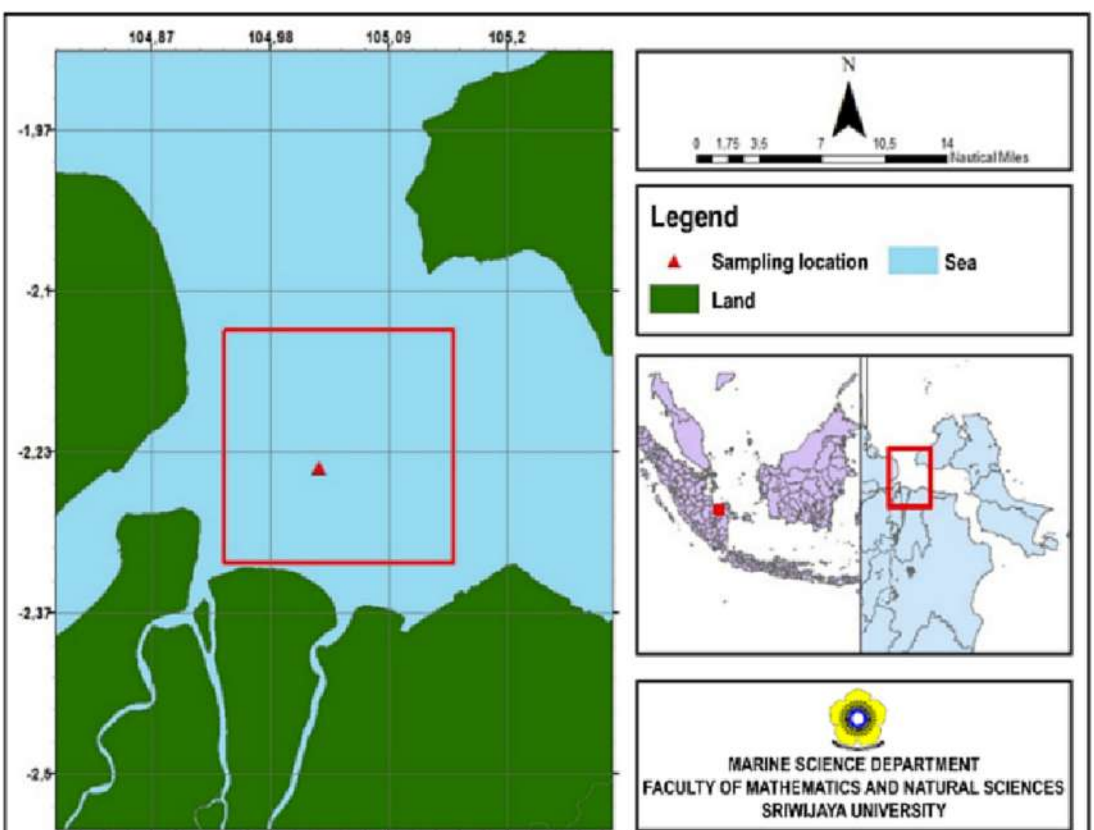


Fig. 1. Map of sampling site in the Banyuasin waters of South Sumatra, Indonesia.

In the experiments, a Simrad EK15 echosounder and a single transducer were employed for horizontal observations, as shown in Fig. 2. The echosounder was equipped with a sphere ball, transducer, processing unit, and PC software. Furthermore, it operated at a frequency of 200 kHz with a 26° angle of coverage. The Simrad EK15 device was calibrated using a 38.01 mm spherical isotropic reflector before the hydroacoustic observation. The transducer position was installed horizontally at 1 m below the water surface during the lowest tide, and it was mounted on one pole of the stationary lift net on the side of the fishing gear operation. The acoustic data recording was simultaneously performed in stationary and operating modes (night to morning) from setting to hauling. Trends in fish distribution and abundance were obtained through visual observation of the echograms (Thorne et al., 1989).

Data processing

Hydroacoustic data were processed using the Sonar-5 Pro software for visualization and extraction. Microsoft Excel was also used for editing and calculating data. Furthermore, the Sonar-5 Pro generated two kinds of echograms (Balk and Lindem, 2015), namely amplitude (AMP-echogram) and single echo-detection (SED-echogram) echograms. The AMP-echogram was used for image analysis, while the SED-echogram was used to detect and trace a single echo (Tao et al., 2009). The fish density (acoustic density) in units of area (fish/ha) and units of volume (fish/m^{-3}) were provided by the software. Sonar-5 Pro also facilitated the estimation of acoustic density (g/m^3) by inputting the conversion equations between length-weight and TS-length into the program, as well as the mean weight of the detected fish (Orduna et al., 2021).

The fish density was calculated using the SV/TS scaling method (Simmonds and MacLennan, 2005). Based on the mean TS value (Manik and Nurkomala, 2016), the size could be divided into three groups, namely small (-70 to −61 dB), medium (-60 to −49 dB), and large (-48 to −34 dB). This method used mean target strength (TS) and volume back-scattering strength (S_V) for calculating fish density. The volume backscattering strength was estimated based on echo integration (EI). The EI extended the S_V application for various distributions and provided more precise results by introducing the average S_V (Furusawa, 2021).

The TS data were one of the important outputs generated from the sonar-5 pro software. However, the TS value could not be directly used for species identification in multispecies fisheries. The value only indicated the reflection intensity recorded during one full rotation of the fish body (Frouzova et al., 2005). The relationship between TS and fish length (L) could be modeled using a simple empirical formulation as follows (Simmonds and MacLennan, 2005):

$$TS_i = b_i + m_i log(L)$$

where m_i and b_i are constants for the i^{th} species, assumed to be known from experimental evidence.

According to Fauziyah et al., (2021), the composition of the main catch for the stationary lift nets in this study location was anchovies, which reached 58%. Sobradillo et al., (2021) stated that the TS formulation for anchovies at 200 kHz was expressed as:

$$TS = 20log_{10}(SL) - 70.4dB$$

where SL is a standard length of anchovy. In this study, the TS value of anchovies was not estimated because it was not the study's focus.

Simmonds and MacLennan, (2005) stated that the TS was the backscattering cross-section (σ_{bs}) expressed in decibels, referring to the following formula:

$$TS = 10log_{10}(\sigma_{bs})$$

The value of (σ_{bs}) and average backscattering cross-section ($<\sigma_{bs}>$), which was equivalent to a given target strength was calculated using the following formula (Manik et al., 2018; Simmonds and MacLennan, 2005):

$$\sigma_{bs} = 10^{\frac{TS}{10}}$$

$$<\sigma_{bs}> = \frac{1}{n}\sum_{i=1}^{n}\sigma_{bs}$$

where n is the number of data.

The equations for measuring volume backscattering strength (S_V) and volume backscattering coefficient (s_v) could be expressed as (MacLennan et al., 2002; Parker-Stetter et al., 2009; Simmonds and MacLennan, 2005):

$$S_V = 10\log s_v$$

$$s_v = \Sigma\sigma_{bs}/V$$

where V is the sampling volume.

Fish density (ρ) was calculated from the volume backscattering coefficient (s_v) divided by the average backscattering cross section (MacLennan et al., 2002; Parker-Stetter et al., 2009), and the formula was expressed as:

$$\rho = s_v / <\sigma_{bs}>$$

The fish density was automatically calculated by the sonar-5 pro software (Fig. 2b), and it was the most important data for further analysis.

Statistical analysis

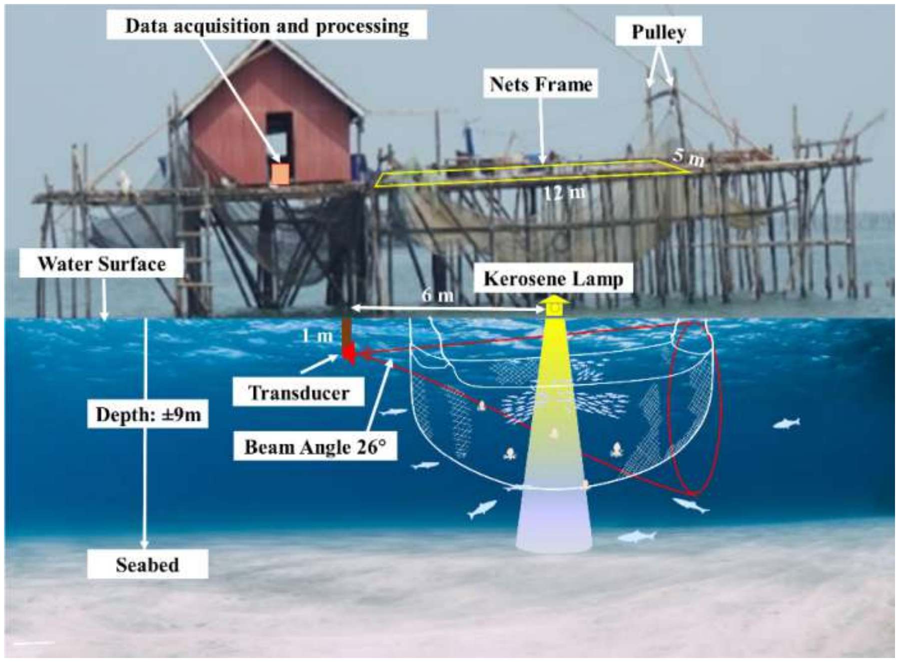
Non-parametric pairwise tests were used in this study to compare at least two independent samples from the subgroups of acoustics densities obtained at different times and durations. The statistical significance was tested at the probability (p) level of<0.05. The two-sample Kolmogorov-Smirnov test was performed to quantitatively compare the acoustics density data before and after midnight. Furthermore, differences in the densities between the soaking times were determined using the Kruskal-Wallis test. When the Kruskal-Wallis test indicated a significant difference, the Dunn-Bonferroni post hoc test was performed. All data were processed using the statistical software SPSS version 21.0.

Results

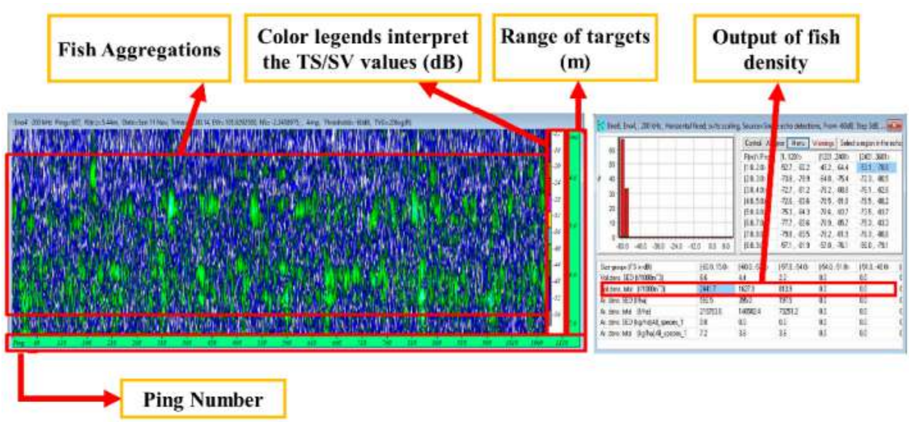
Acoustic fish density

During the observations, 50 samples with their fish acoustic densities were obtained, as shown in Table 1 and Fig. 3. The results indicated significant variability ranging from 14.0 to 2,347.2 g/m^3 with a mean value of 206.1 g/m^3. The total and mean acoustic density obtained from 38 hauls at 17:00–23:59 (T_1) were 6,797 and 292.2 g/m^3, respectively. Meanwhile, the total and mean acoustic density obtained from 12 hauls at 24:00–05:00 (T_2) were 3,507 and 178.9 g/m^3, respectively. The results showed that the values obtained from T_1 and T_2 were not statistically different (Kolmogorov–Smirnov, p = 0.25 > 0.05).

The lowest acoustic density (14.0 g/m^3) was obtained from the T_1 hauling time with a soaking time of 1–16 min (S_1), while the highest (2,347.2 g/m^3) was recorded in T_2 hauling time with a soaking time of 33–48 min (S_3). Based on the total acoustic density, the lowest value (164 g/m^3) was obtained when soaking time was performed for 17–32 min at 24:00–05:00 (S_2T_2). Meanwhile, the lowest (76.9 g/m^3) was recorded when the soaking was carried out for 1–16 min at 17:00–23:59 (S_2T_1) based on the mean value.



(A)



(B)

Fig. 2. An experimental study schematic on the stationary lift nets: (a) echosounder installation and construction, and (b) example of an echogram display and fish density output generated from the sonar-5 pro software.

Table 1
Hydroacoustic observation results. Fish density (g/m^3) was estimated according to different soaking and hauling times.

Hauling Time (T)	Soaking times (S) in minutes	Descriptive statistics of acoustic density (g/m^3)					
		Min	Mean	Max	SD	N_h	Total
T_1 (17:00–23:59 PM)	S_1	14.0	76.9	620.4	133.9	26	2,000
	S_2	208.5	613.7	1,319.7	452.6	7	4,296
	S_3	83.4	85.8	88.3	3.4	2	172
	S_4	37.1	109.8	215.7	93.9	3	329
	Total	14.0	178.9	1,319.7	299.6	38	6,797
T_2 (24:00–05:00 AM)	S_1	16.3	125.7	384.5	155.4	6	754
	S_2	34.5	82.1	129.7	67.3	2	164
	S_3	43.8	647.1	2,347.2	1,134.1	4	2,588
	Total	16.3	292.2	2,347.2	656.6	12	3,507
All Samples (17:00–05:00)	S_1	14.0	86.1	620.4	136.9	32	2,755
	S_2	34.5	495.6	1,319.7	457.3	9	4,460
	S_3	43.8	460.0	2,347.2	925.0	6	2,760
	S_4	37.1	109.8	215.7	93.9	3	329
	Total	14.0	206.1	2,347.2	408.6	50	10,304

Note: S_1: 1–16 min, S_2: 17–32 min, S_3: 33–48 min, S_4: 49–64 min, N_h: number of hauls, SD: standard deviation.

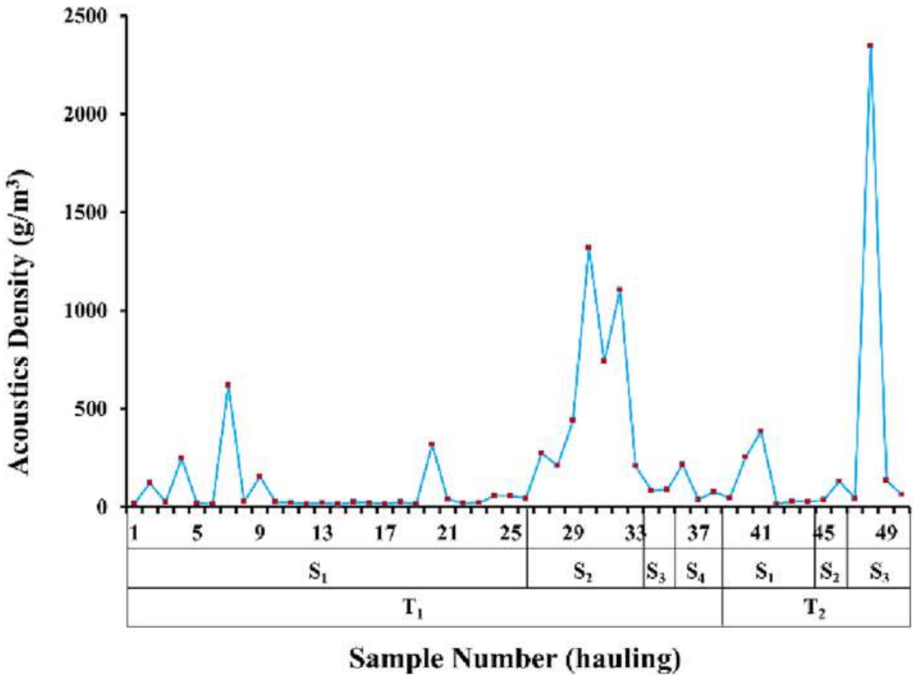


Fig. 3. Acoustic density data for individual samples by the groups of soaking (S_1-S_4) and hauling time (T_1 and T_2).

The highest acoustic mean density (647.1 g/m^3) was obtained when the soaking was performed for 33–48 min at 24:00–05:00 PM (S_3T_2). Based on the total acoustic densities, the highest value (4,296 g/m^3) was obtained from S_2T_1.

The acoustic mean densities obtained from different soaking times also varied from 86.1 to 495.6 g/m^3, as shown in Table 1. Therefore, the Kruskal-Wallis test was performed to determine whether the different soaking times affected the acoustic density. The result showed that there was a statistically significant difference in the values obtained between the different soaking times, as shown in Table 2, (Kruskal-Wallis, $p = 0.001 < 0.05$). Dunn's post hoc tests with Bonferroni correction showed a significant difference in the acoustic mean densities between S_1 and S_2 (Dunn, $p = 0.001 < 0.05$). These results indicated that the hauling conducted at 17–32 min (S_2) gave the best results.

Fish behavior under acoustics monitoring

The total acoustic densities estimated during T_1 were almost 3 times greater than T_2. Meanwhile, the mean value obtained during T_2 was almost 2 times greater than T_1, as shown in Fig. 4a. The total acoustic densities at S_2 showed the maximum values among the soaking times, followed by S_1, S_3, and S_4, as shown in Fig. 4b. The mean values were also higher in S_2 compared to others. These patterns provided strong evidence that the optimal soaking time was 17–32 min.

The total/mean acoustic density value between the two hauling times showed the same aggregation pattern, as shown in Fig. 5. In the S_1-S_2 interval at T_1, the level of fish aggregation tended to increase, it started declining as the soaking time was increased. During T_2, the level tended to fall in the S_1-S_2 interval, but it increased along with the hauling time. Based on these patterns, the optimal soaking time for T_1 and T_2 was 17–32 min and 33–48 min, respectively.

In line with Fig. 5, Fig. 6a illustrated the fish aggregation patterns within the catchable area. This pattern was indicated by the increasing acoustic densities in the soaking time interval of 1–32 min. Furthermore, Fig. 5b showed that the fish aggregation began to spread out of the catchable area, as indicated by the decreasing acoustic densities in the soaking time interval of 33–64 min.

Discussion

Based on the perspective of local fishermen, lighting kerosene lamps was used until a sufficient number of target species were aggregated in the catchable area, followed by hauling. In this study, the fish aggregations within the catchable area of the stationary lift net were monitored. Furthermore, the acoustic monitoring results showed that the sampled densities at 17:00–23:59 and 24:00–05:00 were not statistically significant. This finding was inconsistent with a previous study, that the hauling time variable (before and after midnight) significantly affected the catches (Boesono et al., 2020; Prasetyo et al., 2023). During night and dawn periods, the fish were evenly distributed throughout the aggregation, leading to the presence of similar density in most of the area (Hanchet et al., 2000). Although the hauling time before and after midnight had no significant effect on the acoustic densities, the total densities obtained before midnight was 3 times greater compared to the dawn period. This finding was inconsistent with a previous report

Table 2
The summary results of Kruskal-Wallis and Dunn's post hoc tests presented the significant differences in the acoustic density between two groups of soaking times (S).

Kruskal-Wallis test	The p-values of Dunn's post hoc test						
Chi-sq.	p-value	S_1 vs S_2	S_1 vs S_3	S_1 vs S_4	S_2 vs S_3	S_2 vs S_4	S_3 vs S_4
16.72	0.001^S	0.001^S	0.181 ^{NS}	1.000 ^{NS}	1.000 ^{NS}	1.000 ^{NS}	1.000 ^{NS}

Chi-sq. = Chi-square, ^{S} = significant difference, ^{NS} = no significant difference, S_1 = 1–16 min, S_2 = 17–32 min, S_3 = 33–48 min, and S_4 = 49–64 min.

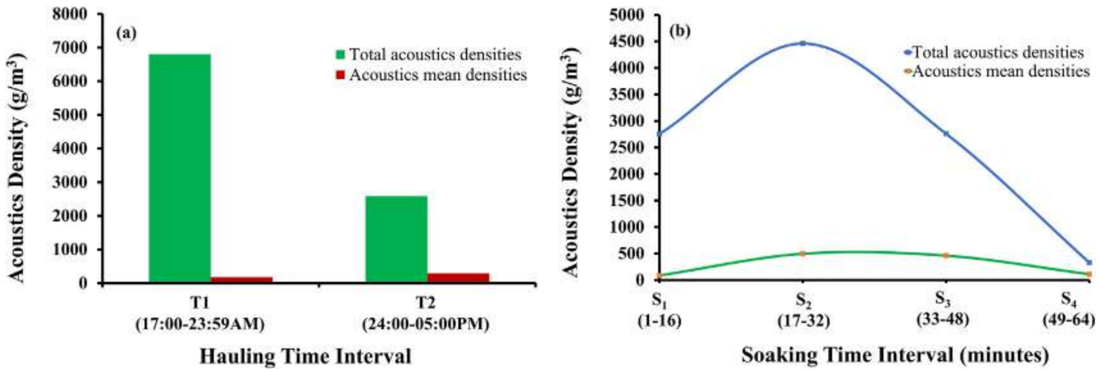


Fig. 4. Fish aggregation pattern under acoustic monitoring on the Stationary lift net from Banyuasin Waters of South Sumatra: (a) aggregation pattern based on acoustic densities and hauling time interval, (b) aggregation pattern based on acoustic densities and soaking time interval.

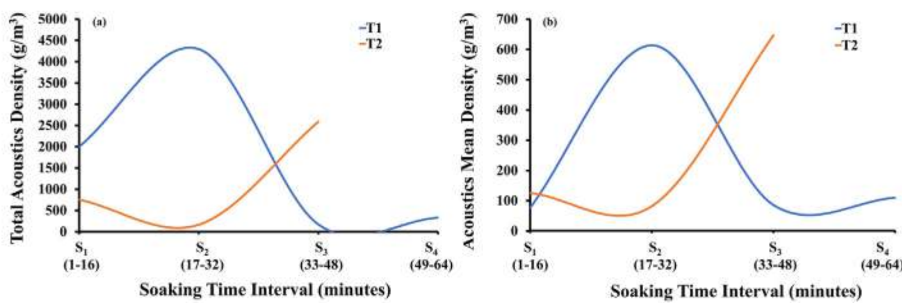


Fig. 5. Fish aggregation pattern under acoustic monitoring on the Stationary lift net from Banyuasin Waters of South Sumatra: (a) aggregation pattern based on total acoustic densities and soaking times interval, (b) aggregation pattern based on acoustic mean densities and soaking times interval.

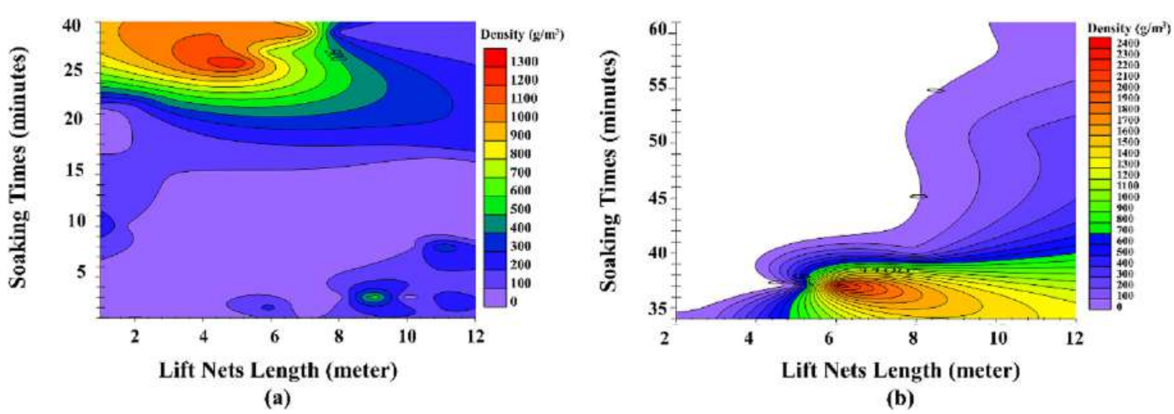


Fig. 6. Fish Aggregation Patterns on the Stationary lift net in Banyuasin Waters: (a) Aggregation concentrated within the catchable area (1–32 min); (b) aggregation began to spread out of the catchable area when the soaking time was over 32 min.

on the lift nets in Pangandaran Waters (West Java), where the total catches were greater when the hauling was conducted after midnight (Dwipayana et al., 2018).

Compared to the hauling time, there were significant differences in the effect of soaking time. The Dunn post hoc test showed that the two soaking times used in this study had different effects on the acoustic mean densities. Furthermore, these differences were due to variations in lighting durations of the kerosene lamp used on the stationary lift net, which was linked to the fish behavior (aggregations or dispersed individuals) during the hauling. This finding was consistent with a study on the stationary lift nets in the Morodemak Waters of Central Java (Oktafiandi et al., 2016), where there was an interaction effect between light intensity and soaking time on the anchovies catches. Artificial light stimuli had been reported to have the ability to affect fish behavior (Marchesan et al., 2005). Aggregation and moving toward artificial light sources were common reactions of fish, and these behaviors helped in enhancing feeding efficiency and avoiding predators (Ben-Yami, 1991; Pitcher and Parrish, 1993). The reactions of fish to artificial light were driven by their adaptive mechanisms, including positive phototaxis, preference for specific optimal intensity, aggregation, investigatory orientation, disorientation, feeding on prey attracted toward the light, or curiosity (Ben-Yami, 1991; Marchesan et al., 2005; Nguyen and Winger, 2019).

During observations, the pelagic fish exhibited some adaptivity mechanisms, such as aggregation and swimming toward the illuminated field within the catchable area when the soaking time ranged from 1 to 16 min (S_1). However, when hauling at a long soaking time (above 32 min), the presence of predatory fish within the illuminated field increased. This made the anchovies move out of the area to avoid their predators. Based on these findings, a better fish adaptation for these conditions possibly occurred at the soaking time of 17–32 min (S_2), leading to optimal acoustics densities. The results of this study were consistent with previous reports on the lift net in the Demak waters, that the soaking time of 20–27.5 min yielded more catch compared to 27.6–35 min (Boesono et al., 2020). The larger fish, including predators, had a slower response toward lighting compared to the smaller species (anchovies) (Priatna and Mahiswara, 2009). Prey-predator interactions were observed between anchovies and squids. Moreover, the use of kerosene lamps on the stationary lift net generated catch compositions of these species, reaching 3:1 (Fauziyah et al., 2021). Other predator fish, such as short mackerel, yellow stripe scad, and sardines were moving toward the illuminated field due to the availability of anchovies. The presence of predators in the area could cause changes in aggregation behavior (Hölker et al., 2007), thereby influencing the estimated acoustics densities (Girard et al., 2020).

The anchovies were the target species for the stationary lift net in Banyuasin Waters. The anchovy's schools were dispersing at nighttime, avoiding predators, reforming into discrete schools rapidly at sunrise, and keeping aggregation behavior during daylight hours (Kaltenberg and Benoit-Bird, 2009). Furthermore, they could maintain their aggregation at deficient levels of light (O'Connell, 1963). The selection of fish for dispersing or aggregating was based on the combination of various factors, including individual energy requirements of fish, light, and prey density (Kaltenberg and Benoit-Bird, 2009).

Based on these findings, fish resource management must be implemented properly in line with the established management principles. One of such management principles involved ensuring a balance between the operated fishing gear and the fish resources available in the waters. Hydroacoustics was an instrument used for decoding faunal acoustic signals into resource density in an aquatic ecosystem, making it effective and efficient in biomonitoring fishery resources.

Conclusions

The estimation of acoustic densities using data from 50 samples showed that the optimal soaking time was 17–32 min for the stationary lift net in Banyuasin waters. During this duration, the fish aggregation patterns were optimally concentrated within the catchable area but tended to spread out of this region beyond 32 min. Therefore, this soaking time was considered optimal, as it allowed the target species to aggregate effectively within the catchable area and adapt to the existing predator density.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical clearance statement

Not applicable.

Acknowledgments

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