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Research Article

Physical Degradation of Toli Shad Gillnet: Breaking Strength, Elongation, and Fisheries Implications

Ratu Sari Mardiah[1*], Subong Park[2], Yusrizal[1], Erick Nugraha[1], Rasdam[3], Ganang Dwi Prasetyo[3], Liya Tri Khikmawati[4], Fredi Febriyanto[5], Yuli Purwanto[1], and Khairudin Isman[6]

[1]Department of Fishing Technology Department, Polytechnic of Fisheries Business Experts, Jakarta. Indonesia.
[2]Division of Marine Production System Management, Pukyong National University. South Korea.
[3]Department of Fishing Technology, Polytechnic of Marine and Fisheries Kupang, East Nusa Tenggara. Indonesia.
[4]Department of Capture Fisheries m, Polytechnic of Marine and Fisheries Jembrana, Bali. Indonesia.
[5]Fishing Gear Laboratory, Polytechnic of Marine and Fisheries Dumai, Riau. Indonesia.
[6]Wakatobi Marine and Fisheries Community Academy, Wakatobi. Indonesia.

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*) Corresponding author:
E-mail: ratu.mardiah@kkp.go.id

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Abstract

Synthetic nets have high elasticity and are widely used for both aquaculture and marine fishing. However, as their technical age increases, their performance declines due to wear, reduced breaking strength, and decreased elongation caused by continuous exposure to the marine environment. Monitoring the technical age of nets is crucial to maintaining the effectiveness of Toli shad gillnets, minimizing losses, and ensuring optimal catch yields. This study aims to examine the physical degradation of synthetic gillnets used in Toli shad (Tenualosa macrura) fisheries based on their technical age. This study utilized gillnets targeting toli shad (Tenualosa macrura), with varying technical ages (control net, 1-year, 2-year, and 3-year nets), all made from polyamide (PA) monofilament. The differences in net dimensions were attributed to variations in their service life. The method used is purposive sampling, analyzed using descriptive statistics, correlation analysis, a Completely Randomized Design (CRD), and effectiveness evaluation. The results show that the structure of Toli shad gillnets consists of mesh sizes of 77.82–99.60 mm, thread diameters of 0.34–0.53 mm, and knot heights of 1.52–2.28 mm. The relationship between technical age and breaking strength has a correlation coefficient (r) of -0.972, an R^2 of 0.94, and a regression equation of $y = 9.85 - 1.31x$. The LSD test indicates a significant difference in breaking strength across treatments. The correlation between technical age and elongation has an r-value of -0.92, an R^2 of 0.86, with the equation $y = 20.11 - 0.34x$. The LSD test shows that the control net has significantly different elongation compared to others, but nets aged 1, 2, and 3 years show no significant differences. The study concludes that Toli shad gillnets remain effective for up to 3–4 years, with an effectiveness value of ≥50%. The implications of this study contribute to the efficient management of fishing nets by informing maintenance and replacement strategies based on the technical age and mechanical degradation of the gear. These findings suggest the importance of integrating net lifespan into gear management to enhance catch performance and sustainability in small-scale fisheries.

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1. Introduction

Synthetic Toli shad nets are one of the tools used to catch Toli shad fish (*Tenualosa* spp.) in the coastal areas of Riau. This commodity is one of the high-value fisheries commodities, especially in coastal areas such as Bengkalis Regency, Riau (Syahrian and Rahmat, 2023). The stable demand for this fish drives intensive fishing activities, where synthetic Toli shad nets serve as the primary fishing gear. The effectiveness of synthetic Toli shad nets in operation is highly influenced by their technical lifespan, which refers to the period of use determined by physical condition, wear level, and performance in optimally catching fish (Rahmadhani *et al.,* 2017; Cerbule *et al.*, 2023).

As the technical lifespan increases, synthetic Toli shad nets experience quality degradation due to various factors such as exposure to sunlight, friction with the seabed, water current pressure, and continuous use (Mardiah *et al.*, 2016; Azhar and Mon, 2022; Brinkhof *et al.*, 2023). Degradation manifests as tears, mesh deformation, and fibre weakening, primarily driven by prolonged exposure to UV light, water turbulence, and friction. These conditions can reduce the effectiveness of synthetic Toli shad nets in capturing fish, leading to suboptimal catches and increased operational costs due to the need for repairs or replacement of synthetic Toli shad nets. Additionally, ineffective synthetic Toli shad nets can negatively impact the aquatic ecosystem (Savina *et al.*, 2024; Karl *et al.*, 2025). Old Toli shad gillnets have the potential to increase bycatch and reduce selectivity for target species, such as Toli shad fish (Yani *et al.,* 2022). This not only causes economic losses for fishers but can also disrupt the sustainability of Toli shad stocks in these waters.

Relevant studies have been conducted on net design and structural characteristics with varying catch results (Dar *et al.,* 2017; Tri *et al.,* 2019; Thomas and Hridayanathan, 2006; Pravin *et al.*, 2009; Bonvechio *et al.*, 2012). Additionally, research on the development of monitoring system simulations for bottom nets has been carried out by Jin *et al.* (2019). Dwi *et al.* (2019) also studied modified nets with a hanging ratio of 55% and a net height of 5.9 m, which resulted in higher catches than conventional nets used by fishers. Relevant previous research was also conducted by Cerbule *et al.* (2022) regarding the comparison of the efficiency and modes of capture of biodegradable versus nylon gillnets in the Northeast Atlantic cod (*Gadus morhua*) fishery. Brakstad *et al.* (2022) stated The fate of conventional and potentially degradable gillnets in a seawater-sediment system. Loizidou *et al.* (2024) stated Bioplastic fishing nets as a sustainable alternative against ghost fishing: Results from the year-long testing among artisanal fishermen for operational effectiveness and social acceptance Bioplastic fishing nets as a sustainable alternative against ghost fishing: Results from the year-long testing among artisanal fishermen for operational effectiveness and social acceptance and Prihantoko *et al.* (2023) produced research on specifications and net construction of tilapia nets in Rawa Pening Lake. Other research was conducted by Le Gue *et al.* (2024a) regarding Degradation mechanisms in PBSAT nets immersed in seawater. Recent studies have emphasized the mechanical and structural factors influencing gillnet performance. Le Gué *et al.* (2024b) demonstrated that knot strength plays a critical role in the mechanical durability of biodegradable gillnets, with weakened knots reducing overall tensile strength, especially relevant for PA monofilament nets exposed to ageing and wear. Nsangue and Tang (2024) analyzed the structural response of gillnets under steady flow using a one-way coupling model, revealing that hydrodynamic forces deform net shapes and alter mesh size, impacting catch efficiency, particularly for agile species like toli shad. Shu *et al.* (2021) compared PLA biodegradable gillnets with conventional PA nets, finding that although biodegradable nets degrade faster, their flexibility may enhance selectivity for certain fish sizes. Together, these studies support the notion that net age, material properties, structural integrity, and interaction with water flow are key to optimizing gillnet effectiveness and sustainability in fisheries targeting species such as *T. macrura*. In this context, research on the physical degradation of synthetic Toli shad gillnets based on their technical lifespan is essential to provide a deeper understanding of how the structural and mechanical condition of the net affects fishing performance and the productivity of *Toli shad*. Ageing nets may undergo material fatigue, reduced flexibility, and knot loosening, all of which influence the mechanisms of capture and the net's ability to retain target species. This highlights the need for lifespan-based net evaluations to optimize gear selection, improve species-specific catch efficiency, and support sustainable fisheries management.

This study aims to offer both practical guidance and innovative perspectives for fisheries stakeholders and managers in Bengkalis and nearby regions. By examining the correlation between the physical deterioration, specifically, breaking strength and elongation, and the technical age of synthetic gillnets used for Toli shad, the research establishes a scientific basis for enhancing fishing gear performance. Determining the optimal service life of these nets enables more efficient fishing operations while contributing to the sustainable management of Toli shad populations in local waters. What sets this study apart is its interdisciplinary approach, bridging material science with fisheries management to deliver evidence-based recommendations for selecting more resilient net materials and developing maintenance protocols. Additionally, the proposed degradation model provides a potential tool for regulating gear usage, thereby promoting more adaptive and responsible fishing practices. This study aims to examine the physical degradation of synthetic gillnets used in Toli shad (*Tenualosa macrura*) fisheries based on their technical age. Specifically, it seeks to (1) analyze changes in key physical properties of gillnets, including breaking strength and elongation, (2) investigate the relationship between gillnet age and the technical performance of fishing gear, and (3) evaluate the implications of net aging on the operational efficiency of gillnets, with particular emphasis on sustainable fishing practices in Bengkalis and surrounding waters. In real-world applications, the implications of this research include improved cost-efficiency for fishers through planned gear replacement before performance significantly declines. The findings can also support decision-making by fisher cooperatives, local governments, and net manufacturers in the procurement, training, and distribution of fishing nets based on their technical lifespan. Thus, the outcomes of this study not only enhance fishermen's incomes through improved operations.

2. Materials and Methods

2.1 Materials

2.1.1 The equipment

The equipment used in this study includes a Breaking Strength Tester, two hooks, two clamps, a Vernier Caliper, scissors, a magnifying glass, a plastic bucket with a capacity of 20–50 litres, and a wooden beam approximately 2 meters in length. Additionally, a digital hanging scale with a capacity of around 150 kg, a nylon rope with a diameter of 5 mm, a plastic tube, and a measuring glass were also utilized. The function of each tool used is explained in Table 1.

2.1.2 The materials

The materials used in this study are 50-mesh gillnets with different technical lifespans, including new nets as a control and nets that have been used for 1, 2, and 3 years. The primary material used for the Toli shad gillnet by fishermen in Bengkalis is nylon or PA monofilament with a diameter of 0.40 mm, a mesh size of 3 inches (±76.2 mm), 140 meshes deep (MD), a length of 610 yards (±555 meters), and a TATE-type net. In this study, the structure of the Toli shad gillnet is identified based on three indicators: mesh size, net diameter, and knot height (Figure 1). The gillnets utilized in this study are representative of those commonly employed by local fishermen, sharing the same material type, brand, operational methods, and environmental conditions. The primary distinction among the nets lies in their duration of use, which has led to observable variations in mesh size, filament diameter, and knot height. Various types of materials were employed in this study, as outlined in Table 1, which provides a detailed account of all materials used during the research process.

2.1.3 Ethical approval

This study does not require ethical approval because it does not use experimental animals.

2.2 Methods

In this study, only primary data were used. The primary data include mesh size, net diameter, knot height, net elongation, and mesh breaking strength. Data were collected through observation and laboratory scale to evaluate gillnets of varying technical ages, including new nets (as a control), and nets aged 1, 2, and 3 years. Each treatment was replicated 25 times. The tensile strength testing followed the procedures outlined in SNI ISO 1805:2010, a standardized method for evaluating netting materials. The tensile test procedure consisted of several main stages. First, net samples were cut into standardized shapes and sizes in accordance with SNI ISO 1805:2010, with specimens collected from the central portion of each net panel to ensure consistent quality and minimize edge effects. Next, each specimen was firmly clamped at both ends within the tensile testing apparatus to guarantee consistent load application and avoid slippage. Prior to testing, the tensile testing machine was calibrated using certified reference standards to verify the precision and accuracy of force and elongation measurements, ensuring compliance with established testing protocols. A progressively increasing tensile load was then applied to the specimen at a controlled rate until specimen failure or the predetermined testing limit was reached. Throughout the test, applied force and specimen elongation were continuously recorded via integrated sensors and data acquisition systems. Finally, the collected data were analyzed to extract key mechanical properties, including tensile strength, elongation at break, and elastic modulus, facilitating assessment of material performance and degradation characteristics.

This methodology provides a reliable basis for assessing the structural integrity and performance degradation of gillnets over time. Table 2 presents the types and methods of data collection based on the research objectives. This research was conducted under controlled laboratory conditions.

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Tabel 1. Equipment and materials used

Type of Equipment	**Usage**
Breaking strenght tester	Measures the strength, elongation, and stability of net meshes.
2 hooks	Measures the elongation of net meshes.
2 clamps	Measures the elongation of net meshes.
Vernier Caliper	Measures net diameter and other constructions.
Scissors	Cuts the net.
Magnifying Glass	Analyzes the number of net fibers.
Plastic Bucket (20–50 liters)	Holds seawater.
Wood (±2 m length)	Supports the net.
Digital Hanging Scale (cap. ±150 kg)	Weighs research materials.
Nylon Rope (Ø 5 mm)	Ties the net.
Plastic Tube	Research container.
Measuring Glass	Measures water.
Type of Material	**Usage**
50 mesh gillnets of different sizes and service lives (1, 2, 3 years)	Research objects.

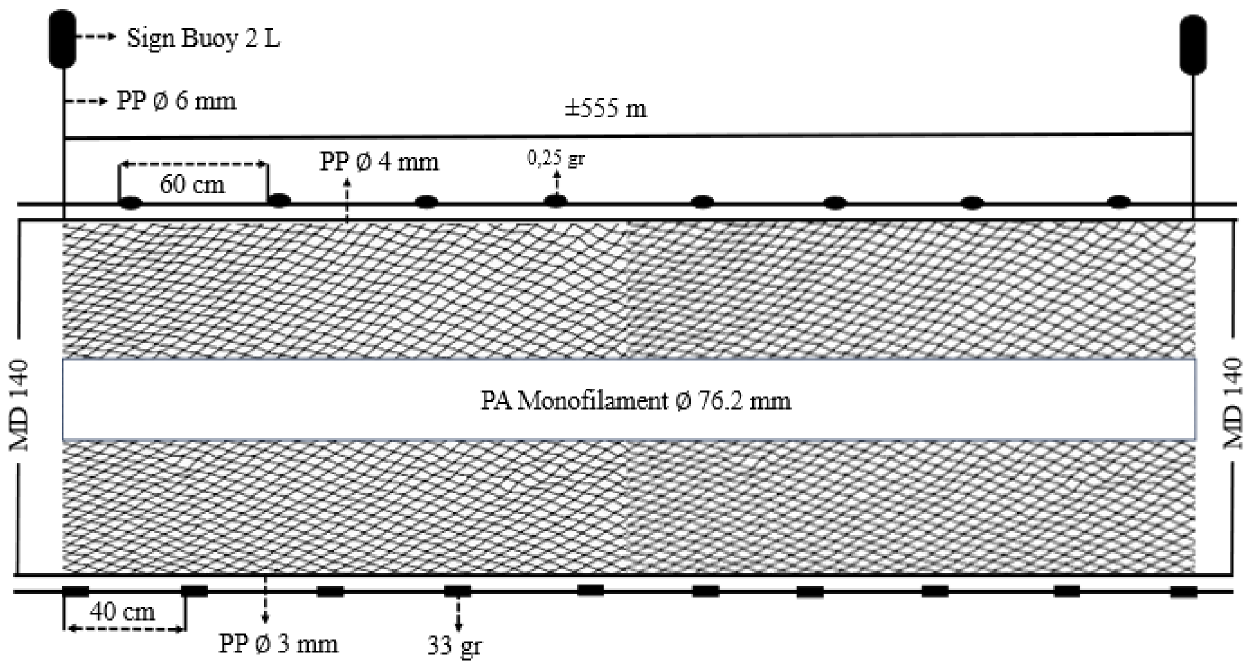

Figure 1. Toli shad Nets

Table 2. Types and methods of data collection based on research objectives

No	Objective	Data Type	Data Analysis
1.	Identify the structure of Toli shad nets	- Mesh size data - Net diameter data - Knot height data	- Descriptive statistics
2.	Analyze the relationship between technical age and breaking strength and elongation	- Elongation value - Breaking strength value	- Correlation analysis - Regression analysis - Completely Randomized Design (CRD) - Least Significant Difference (LSD)
3.	Determine the effectiveness level of Toli shad nets based on technical age	- Elongation value - Breaking strength value	- Prediction model using linear regression analysis - Effectiveness of technical age

2.3 Analysis Data

All tensile test data were statistically analyzed using IBM SPSS Statistics software. Descriptive statistics were first computed to summarize the central tendency and variability of mechanical properties, including tensile strength, elongation at break, and elastic modulus. To examine the influence of technical age on these properties, a one-way Analysis of Variance (ANOVA) was conducted, followed by post-hoc tests where necessary to identify significant differences between groups. In addition, regression analysis was employed to model the relationship between the technical age of the nets and their mechanical degradation, providing insights into predictive patterns and the rate of material decline over time.

2.3.1 Descriptive statistical analysis

Descriptive statistics refer to statistical methods that use data from a group to describe or draw conclusions about that group (Nasution, 2017). The descriptive statistics used in this study involve a simple mean or average formula (Hanifah *et al*., 2025), as follows:

$X = (\sum x) / n$ ....(i)

Where :

$\sum x$ = sum of all values,

n = number of data points.

2.3.2 Correlation coefficient analysis

The correlation coefficient is a numerical value that measures the strength of the relationship between two or more variables and determines the direction of the relationship (Yusuf, 2018). In this study, correlation coefficient analysis was employed to evaluate the strength and direction of the relationship between the technical age of the gillnet (x), considered as the independent variable, and the net's mechanical properties, specifically breaking strength or elongation (y), as the dependent variables. The correlation coefficient (r) was calculated using the formula adapted from Nasution (2017).

$$r = \frac{n(\sum xy) - (\sum x.\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}} \quad ....(ii)$$

Where :

n = number of data points,

x = independent variable,

y = dependent variable.

The correlation value ranges from -1 to +1, with the direction indicated as positive (+) or negative (-). The correlation level is interpreted based on the strength of the relationship between x and y. Table 3 presents the correlation levels and the strength of the relationships based on the data analysis results.

Table 3. Correlation level and strength of relationship

No	Correlation Value	Strength of Relationship Level
1	0.00 - 0.19	Very weak
2	0.20 - 0.39	Weak
3	0.40 - 0.59	Moderate
4	0.60 - 0.79	Strong
5	0.80 - 1.00	Very Strong

2.3.3 Simple linear regression analysis

The simple linear regression equation is a model that describes the relationship between one independent/predictor variable (x) and one dependent/response variable (y). This relationship is typically represented by a straight line, as illustrated in Figure 2.

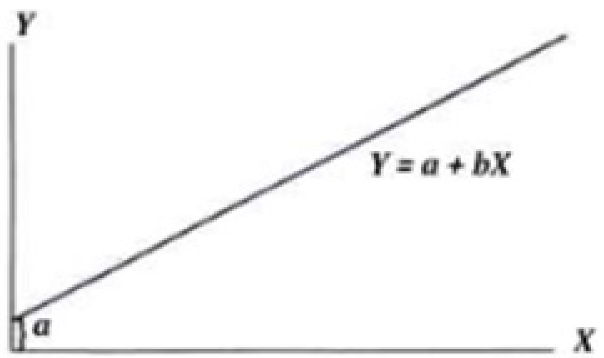

Figure 2. Illustration of linear regression line

The simple linear regression equation is mathematically expressed using the following formula (Efendi *et al*., 2020):

$y = a + bx$..(iii)

Where:

y = dependent/response variable,

x = independent/predictor variable,

a = intercept (constant),

b = regression coefficient (slope), which indicates the rate of change in y for each unit increase in x.

Where y is the regression line, a is the constant (intercept) where it intersects the vertical axis, b is the regression coefficient (slope), and x is the independent/predictor variable. The values of constants a and b are determined using the following equations:

$$a = \frac{(\sum Y_i)(\sum X_i^2) - (\sum X_i)(\sum X_i Y_i)}{n\sum X_i^2 - (\sum X_i)^2}$$

$$b = \frac{n\,(\sum X_i Y_i) - (\sum X_i)(\sum Y_i)}{n\sum X_i^2 - (\sum X_i)^2}$$

..............(iv)

2.3.4 Net elongation and breaking strength

The study employed a Completely Randomized Design (CRD), in which the treatment variable was the technical age of the gillnets. Four treatment groups were established: new nets (serving as the control), and nets with one, two, and three years of technical use. The collected data were then analyzed using a one-way Analysis of Variance (ANOVA) to assess the statistical significance of differences in mechanical performance among the treatment groups. Each treatment group consisted of 25 replicates. Tensile strength testing was conducted in accordance with the procedures outlined in SNI ISO 1805:2010 to assess the mechanical performance of the nets. Prior to further analysis, a normality test was performed using the Kolmogorov-Smirnov method to determine the distribution pattern of the data. If the p-value exceeded the significance level (α), the data were considered normally distributed; conversely, if the p-value was less than α, the data were considered not normally distributed. Following the normality assessment, the data were statistically analyzed using CRD, where net age was treated as the main factor with four levels representing the different durations of net usage. The calculation uses the formula from Steel and Torrie (1980), namely:

$Yij = \mu + \tau_i + \beta_j + \varepsilon_{ij}$.......................................(v)

Where :

Y_{ij} = data from the j-th group receiving the i-th treatment,

μ = overall mean,

τi = effect of the i-th treatment,

βj = effect of the j-th group,

϶ij = experimental error in the j-th group receiving the i-th treatment.

The hypotheses are:

- H_0 : τi = τj; for all i ≠ j and H1 : τi ≠ τj ;

- H0 : βi = βj ; for all i ≠ j and H_1 : βi ≠ βj.

The decision rule is if $F_{count} > F_{\alpha(adp,dbs)}$: reject H_0; and if $F_{count} < F_{\alpha(adp,dbs)}$: fail to reject H_0. When successful, push H_0, followed by determining eye elongation, eye strength, and node stability using linear regression. To find out whether the treatment has a significantly different effect on the response, a Least Significant Difference Test (LSD) is carried out.

2.3.5 Technical age effectiveness of nets based on breaking strength and elongation

The formula used is to adopt the catch effectiveness formula in the article Olii *et al.* (2024) and Fridman (1986), that is:

$$Effectiveness_{\ technical\ life} = \alpha^t/\alpha_0 \times 70\% + b^t/b_0 \times 30\% \ldots(vi)$$

Where:

α^t = Value of breaking strength of the net at a certain time (*t*);

α_0 = Initial net breaking strength value (*control condition*);

b^t = Elasticity value at a certain time (*t*);

b_0 = Initial mesh ductility value (*control condition*).

The effectiveness of net use was also analyzed using predictions from linear regression and compared with established standards, namely SNI ISO 1805:2010 concerning fishing equipment made from nets: determining breaking force and breaking force of net thread knots. The standards are presented in Table 4.

Table 4. Standard breaking strength and elongation of monofilament (SNI ISO 1805:2010)

Thread Diameter (mm)	Breaking Strength (kgf)	Elongation (%)
0.2	3 - 5	15 - 25
0.3	6 - 8	15 - 20
0.5	10 - 15	10 - 15
1.0	30 - 50	5 - 10

The effectiveness of the gillnet was assessed from a technical perspective using a standardized scoring system designed to evaluate mechanical performance and structural integrity. A net receiving a score between 80 and 100 is considered highly effective, demonstrating optimal mechanical performance such as strong tensile strength, sufficient elongation, and secure knot integrity, making it well-suited for continued use in the targeted fishing operations. Nets that fall within the 60 to 79 range are classified as effective, performing adequately for their intended use but showing minor technical limitations that may benefit from further optimization. Scores between 40 and 59 indicate moderate technical performance, suggesting that certain structural or material improvements are needed to maintain operational efficiency. When a net scores between 20 and 39, it is considered technically poor, as multiple deficiencies significantly reduce its effectiveness and reliability in the field. Nets receiving a score from 1 to 19 are deemed ineffective for their intended purpose, failing to meet the minimum technical requirements and requiring either replacement or substantial rehabilitation. This scoring framework provides a quantitative basis for evaluating the technical lifespan of gillnets and offers guidance for maintenance and gear replacement strategies in sustainable fisheries management.

3. Results and Discussion

3.1 Results

3.1.1 Identification of toli shad gillnet structure

The identification of Toli shad gillnet structure is essential for understanding how its physical characteristics, such as material type, mesh size, and filament diameter, affect performance and durability. This section outlines the key structural features of the net, forming the basis for analyzing the relationship between net design, technical age, and fishing efficiency. Mesh size refers to the size of the net's openings, which fishermen use to determine their catch (Vincent *et al.*, 2022). The size is adjusted based on the target species. In Bengkalis, fishermen use a mesh size of 3 inches (±76.2 mm) for catching terubuk. The study found that the average mesh size was 77.82 mm for the control net, 86.64 mm for the 1-year-old net, 99.60 mm for the 2-year-old net, and 63.14 mm for the 3-year-old net. The 2-year-old net had the largest mesh size, likely due to continuous use, which caused the mesh to expand. However, the 3-year-old net had a reduced mesh size, as it was no longer frequently used. The net diameters varied slightly, with the 1-year-old net having the highest diameter at 0.53 mm, followed by the control net at 0.40 mm, the 3-year-old net at 0.35 mm, and the 2-year-old net at 0.34 mm. Figure 3 presents the average mesh size according to usage duration. The knot height is measured to determine the mesh depth and mesh length within the net's mesh size (Ayunda *et al.*, 2017). The values vary across different treatments. The control net had a knot height of 1.53 mm, followed by the 3-year-old net at 1.63 mm, the 2-year-old net at 1.66 mm, and the highest value observed in the 1-year-old net at 2.28 mm.

This study employed gillnets constructed from polyamide (PA) monofilament with varying filament

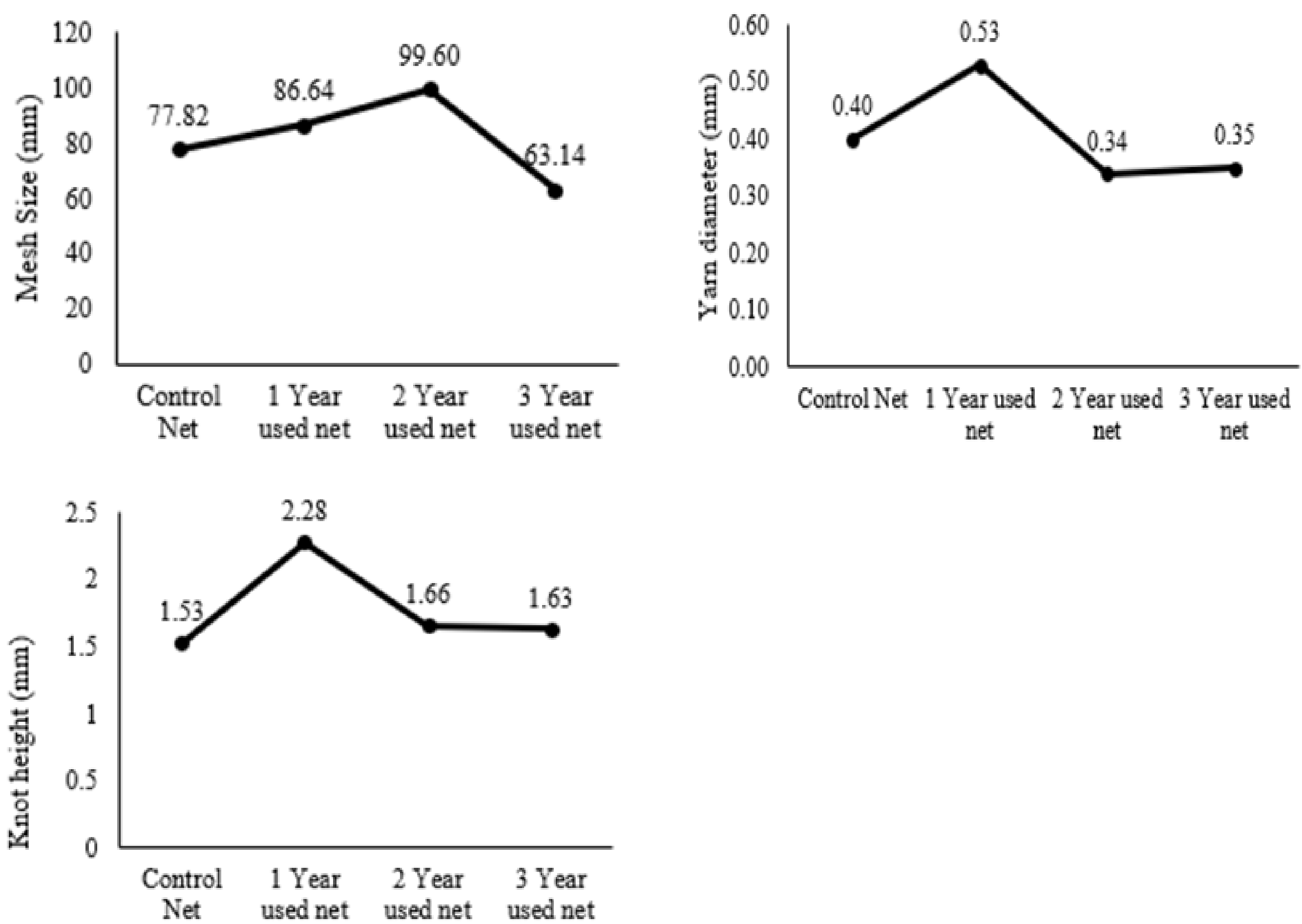

Figure 3. Identification of toli shad net structure based on technical age.

diameters: 0.53 mm, 0.4 mm, 0.35 mm, and 0.34 mm. The mesh sizes recorded were also variable, namely 77.82 mm for the control net, 86.64 mm for the 1-year-old net, 99.60 mm for the 2-year-old net, and 63.14 mm for the 3-year-old net. These discrepancies suggest both physical degradation over time and potential inconsistencies in the initial specifications of the netting materials. The variation in mesh size is primarily attributed to the mechanical and environmental responses of PA monofilament, a material known for its flexibility and elasticity but also susceptible to permanent deformation under prolonged stress (Sharif and Mon, 2021). In the coastal waters of Bengkalis, nets are regularly exposed to intense ultraviolet (UV) radiation, fluctuating tidal currents, and saline conditions, all of which contribute to gradual material deterioration. These factors likely lead to knot slippage and fibre elongation, resulting in enlarged mesh dimensions in nets aged 1 to 2 years.

Conversely, the decrease in mesh size observed in the 3-year-old net may be indicative of material fatigue, knot tightening due to structural collapse, or shrinkage caused by long-term exposure. Such behavior is characteristic of synthetic polymers that have exceeded their mechanical lifespan, particularly under dynamic marine conditions. Furthermore, differences in filament diameter significantly influence the net's tensile properties. Thinner monofilaments (e.g., 0.34 mm) are more prone to elongation and deformation under load compared to thicker filaments (e.g., 0.53 mm), potentially leading to inconsistent performance and altered mesh geometry. These results suggest that the nets tested may not have originated from a single standardized production batch, underscoring the importance of quality control in manufacturing. Although tensile strength testing using a Universal Testing Machine (UTM) provides reliable data on the material's breaking strength, it does not fully capture the complex mechanical interactions and environmental stressors that occur in situ. Thus, laboratory findings may only partially represent the actual field conditions experienced by the gillnets.

3.1.2 Correlation between breaking strength, elongation, and net technical age

The correlation value is a statistical measure that describes the strength and direction of the relationship between two variables. The correlation values range from -1 to 1, where each value indicates the degree and type of relationship between the variables. Table 5 presents a detailed correlation analysis of breaking strength, elongation, and net technical age based on the given treatments.

Table 5. Correlation of breaking strength, elongation, and technical age of nets

	Technical Age	Breaking Strength (Kgf)	Elongation (%)
Technical Age	1		
Breaking Strength (Kgf)	-0.97	1	
Elongation (%)	-0.92	0.98	1

A strong inverse relationship was observed between net age and mechanical properties, with correlation coefficients of –0.972 for breaking strength and –0.92 for elongation.

3.1.3 Relationship between net technical age, breaking strength, and elongation

The relationship between the technical age of the net and its breaking strength and elongation is very strong, as both factors play a crucial role in determining the durability and effectiveness of the net throughout its lifespan. Figure 4 illustrates the relationship between the technical age of the net (x-axis) and its breaking strength (y-axis). The regression equation y = 9.85 – 1.31x and the R^2 value of 0.94 indicate that the breaking strength of the net decreases linearly as the technical age increases.

As the net ages (higher x values), its breaking strength (y) declines. The R^2 value of 0.94 suggests that 94% of the variability in breaking strength can be explained by changes in the net's technical age, while only 6% is influenced by other factors, such as net material, frequency of use, or environmental conditions (Hasly *et al.*, 2017).

The interpretation of breaking strength based on technical age is as follows (1) A new net has a breaking strength of 9.85 kgf. (2) After 1 year, the breaking strength decreases to 9.85 – 1.31(1) = 8.54 kgf. (3) After 3 years, the breaking strength further declines to 9.85 – 1.31(3) = 5.92 kgf. Even after approximately 3 years, the breaking strength remains above 5 kgf, although the decline becomes more significant over time.

The relationship between the net's technical age and its elongation shows a negative linear trend. As the net is used for a longer period (increasing technical age), its elongation gradually decreases. The R^2 value of 0.85 (85.75%) indicates that 85.75% of the variation in net elongation can be explained by the net's technical age, while 14.25% is influenced by other factors such as environmental conditions, net material, or usage patterns (Srimahachota *et al.*, 2020).

According to the linear regression equation, a new net has an elongation of 20.11%. For each additional year of use, elongation decreases by 0.34%. This reduction in elongation can affect net performance, especially under high tension during fishing operations. Older nets become more prone to physical damage due to loss of flexibility, making them less capable of withstanding high pulling forces (Kanehiro, 2004).

3.1.4 Comparison analysis of net technical age and breaking strength

Breaking strength refers to the maximum force required to break a material under tension, typically measured in kgf. The Completely Randomized Design (CRD) analysis of breaking strength across four treatments showed that $F_{calculated} > F_{table}$, leading to the rejection of H_0. This indicates a significant difference between treatments. A further Least Significant Difference (LSD) test yielded a value of 5.506, meaning that each net treatment had significantly different values. The comparison analysis results are presented in Figure 5, showing the differences in breaking strength across various net ages.

Based on the Least Significant Difference (LSD) test, there is a significant difference in breaking strength among all tested treatments. This difference is mainly due to net usage over time. Nets that have been used for a specific period (1 year, 2 years, or 3 years) experience wear and tear due to environmental exposure such as seawater, UV radiation, friction, and mechanical load during operation. These factors lead to a gradual decrease in breaking strength as the net fibres become more brittle or undergo structural changes (Dagli *et al.*, 1990). In contrast, control nets (unused) do not undergo wear or degradation from environmental exposure, thus generally having a higher breaking strength. However, in some cases, control nets might show lower breaking strength due to suboptimal manufacturing processes.

3.1.5 Comparative analysis of net service life and elongation

Net elongation refers to the increase in length of a material when subjected to tension, typically expressed in centimeters or millimeters. It is one of the

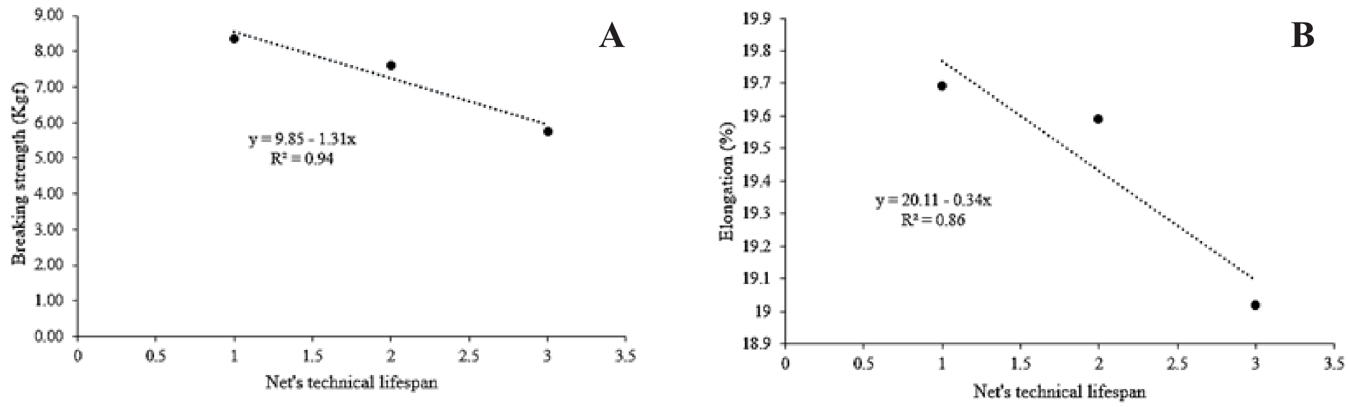

Figure 4. Relationship between net technical age and breaking strength (a) and elongation (b).

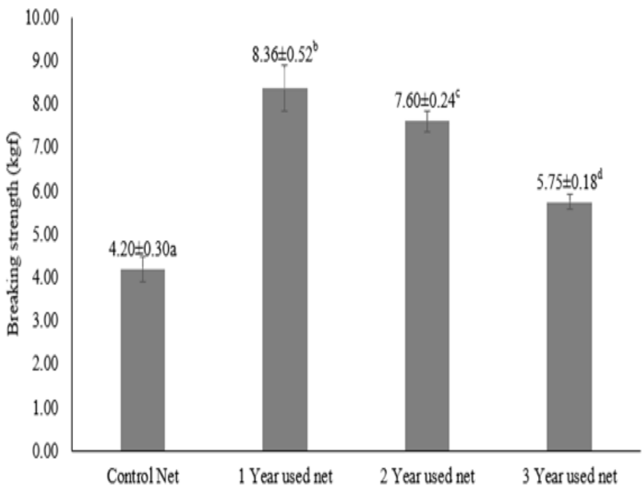

Figure 5. Breaking strength value of gillnet.

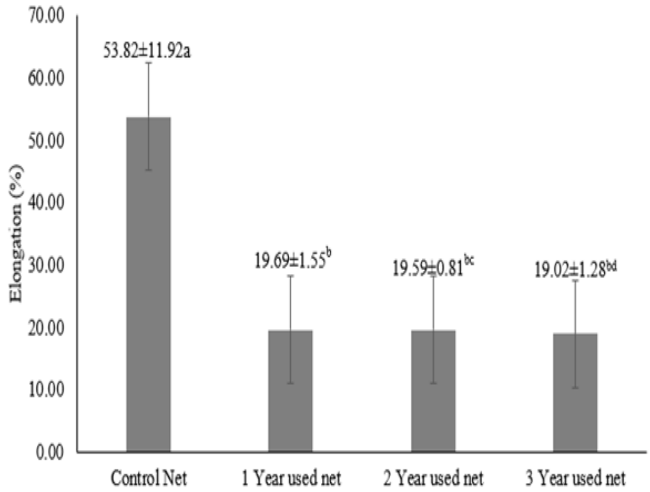

Figure 6. Elongation value of gillnet.

physical properties of net fibres, used to assess the elasticity of the netting material. CRD analysis of net elongation across four treatments showed a statistically significant difference ($F_{calculated} > F_{table}$), leading to the rejection of H_0. This indicates a notable difference among treatments. Consequently, LSD test was conducted, yielding a value of 3.023. As a result, each treatment had distinct values and superscripts, as shown in Figure 6. The control net (unused net) exhibited a significantly different elongation compared to the other nets. However, the 1-year-old and 3-year-old nets did not show a significant difference, as their superscripts indicated no notable variation. This is because new or unused nylon has high elasticity, strength, and lightweight properties, which are characteristic features of synthetic fishing nets.

The control net has a significantly higher elongation compared to the used nets, indicating that new nets have better elasticity. A new net exhibits high elongation because its material properties are still in optimal condition and have not undergone degradation due to use or environmental exposure. In the initial state, these fibres can stretch well when subjected to tension, resulting in a high elongation value. Additionally, the control net does not have microscopic damage or permanent deformation in its fibres. The fibre structure remains intact, allowing the net to stretch to its maximum capacity before breaking (Grimaldo *et al.*, 2020).

The 1-Year Net has higher elongation compared to the 2-Year Net and 3-Year Net, although the decrease is not significant. The reduction in elongation in Toli shad nets does occur, but it is not as pronounced as in other materials. This type of net also has a flexible polymer structure that allows it to return to its original shape after stretching, making it more resistant to permanent deformation compared to other synthetic materials (Charter, 2022). This characteristic helps the net maintain its elasticity for a longer period. The polymer net has long molecular chains with strong bonds, making it more resistant to structural changes due to ageing compared to other synthetic materials.

Additionally, the net has the ability to distribute stress evenly across the fibres, preventing pressure concentration that could cause significant damage at specific points (Farah *et al.*, 2021).

3.1.6 Effectiveness of net technical lifespan based on breaking strength and elongation

The effectiveness of Toli's shad net usage is highly influenced by its technical lifespan, which refers to the optimal duration a net can be used before experiencing a significant decline in quality. The effectiveness of Toli's shad net usage is analyzed from two aspects: breaking strength and elongation. The graphical representation is shown in Figure 7.

with effectiveness dropping from 77.12% to 61.50%, a decrease of approximately 15.62%. The decline continues but at a slower rate in older nets, such as from year 6 (18.22%) to year 7 (12.13%).

The minimum effectiveness threshold is observed between years 5–7, where effectiveness drops below 30%, indicating that the net is no longer technically viable or efficient. Based on this data, nets are only effective for up to 3–4 years, with effectiveness remaining above 50%. After 4 years, effectiveness drops below 40%, suggesting the net is no longer optimal for practical use. Regular gear assessments are recommended, with net replacement advised after

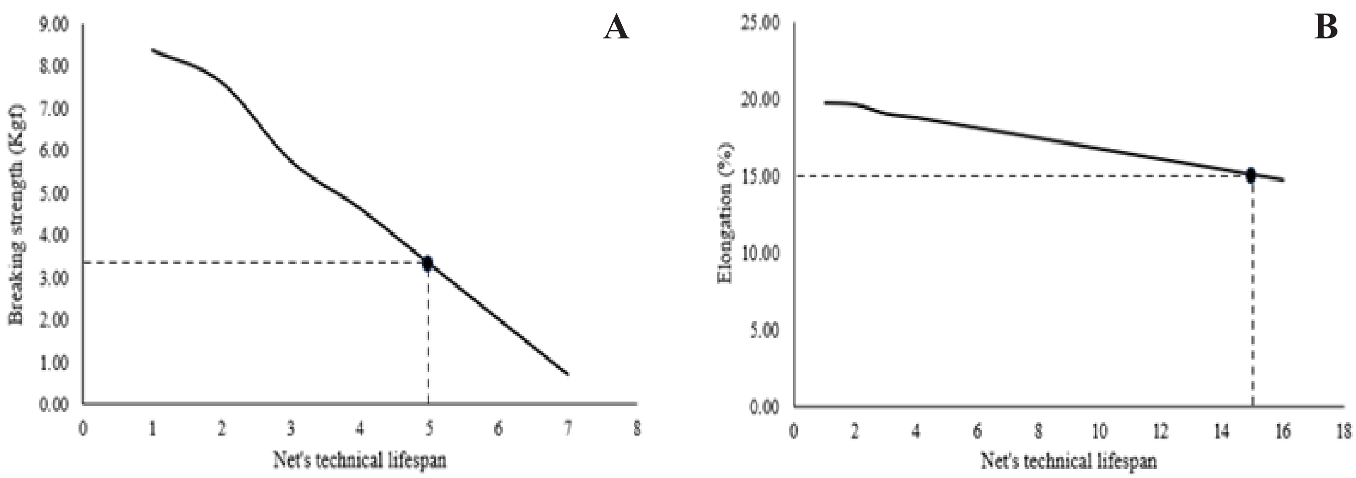

Figure 7. Net effectiveness based on breaking strength (a) and elongation (b).

Based on the breaking strength standard from SNI ISO 1805:2010, Toli shad nets can be optimally operated up to the 5th year, with a breaking strength value of 3.32 kgf. However, when considering elongation, the net can be used optimally until the 15th year, with an elongation value of 15.06. The decline in elongation occurs more gradually than the decline in breaking strength due to several factors related to material properties and mechanisms of thread degradation. Elongation measures how much the thread can stretch, which makes it less susceptible to structural damage. Even though elongation decreases over time, the thread can still stretch before breaking, despite a reduction in its load-bearing strength (Radhalekshmy and Nayar, 1973).

Net effectiveness is also calculated based on its formula. The results show a negative relationship between the net's technical lifespan and effectiveness. The highest effectiveness is observed in 1-year-old nets, with a value of 77.12%, while the lowest effectiveness is 12.13% at year 7. The most significant decline occurs in the early years of use (1–2 years), 3-4 years to ensure optimal catch performance and reduce the risk of operational failure. The results are described in Figure 8.

Variations in the construction of monofilament yarns used in gillnets lead to notable differences in their mechanical performance, particularly in tensile strength and elongation at break. Monofilament yarns with larger diameters generally possess greater tensile strength due to their increased cross-sectional area; however, this also results in increased stiffness and reduced elongation capacity. Conversely, smaller-diameter yarns tend to be more elastic and flexible, exhibiting higher elongation at break but lower tensile strength. These physical characteristics must be carefully considered when evaluating the technical lifespan of gillnets, as they directly influence the net's operational performance and suitability for specific fishing conditions (Sharif and Mon, 2021).

In relation to the effectiveness of gillnets in capturing *Toli shad* (*Tenualosa macrura*), the findings indicate that gillnets with approximately one year of usage offer superior catch efficiency, especially for

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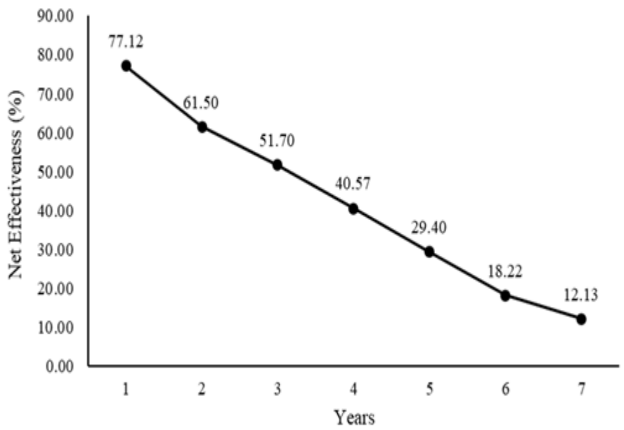

Figure 8. Effectiveness of Toli shad net based on technical age.

smaller and more agile individuals. This is primarily due to the net's retained mechanical integrity at this age, which offers an optimal balance between strength and flexibility factors that enhance the entanglement efficiency of the gear. On the other hand, gillnets used for two to three years exhibit noticeable material fatigue, including decreased flexibility and reduced elongation capacity, which may compromise their ability to effectively capture active or smaller fish (Sari *et al*., 2017). Although older nets may still perform adequately in capturing larger fish, their overall efficiency tends to decline due to cumulative wear and degradation.

To ensure continued effectiveness and sustainability in fishing operations, regular mechanical assessment of gillnets, such as tensile testing using a Universal Testing Machine (UTM) is recommended. These evaluations support the development of evidence-based guidelines for determining the optimal technical lifespan of polyamide monofilament gillnets. Additionally, integrating net condition into fishing strategies, including adjustments to site selection, soak time, and deployment scheduling, can enhance gear performance and contribute to more responsible and efficient fisheries management (Pfeiffer *et al.*, 2022).

3.2 Discussion

3.2.1 Identification of Toli shad net structure

Changes in mesh size are caused by forces exerted on the net, such as water currents, catch weight, and the process of hauling the net onto the boat during fishing operations (Sala and Lucchetti, 2011). Environmental factors like friction with the seabed and repeated use also contribute to damage. Friction weakens the fibres, and continuous use wears down the mesh and knots, loosening them and enlarging the mesh openings. Degradation is further accelerated by sunlight exposure, which weakens the fibres, stretches the material, and affects knot performance, leading to larger mesh openings (Mardiah *et al.,* 2021). Additionally, seawater contains salts that speed up material degradation. If the net is exposed to certain chemicals (such as net coatings or cleaning agents), the fibres weaken over time, making the mesh more likely to expand.

Manual repairs to damaged nets can also result in inconsistent mesh sizes. Improper adjustments may cause some mesh openings to become larger than their original size. Another factor is the elasticity of the net material. With prolonged use, the material stretches but does not fully return to its original size, leading to an increase in mesh size (Shakiba *et al.,* 2021).

The knot height (mesh height) is influenced by several factors related to net design, usage, and environmental conditions. The main factors affecting knot height include mesh size, as larger mesh sizes result in higher knot heights when the net is fully extended. The elasticity of the net material also plays a role, as materials tend to stretch over time, affecting the overall height of the knots. Another factor is the method of net installation, whether the net is set up vertically or horizontally, which can influence the knot height when the net is under tension (Mardiah and Pramesthy, 2019). Changes in knot height can impact fishing activities in several ways. They may alter the net's selectivity for target fish species (Maroneze *et al*., 2014). Additionally, excessive knot height due to stretching can reduce net durability and increase the risk of damage. It also affects the stability and efficiency of net operations, potentially reducing their effectiveness over time.

3.2.2 Correlation between breaking strength, elongation, and net technical age

Net materials naturally degrade over time due to their technical age and tend to weaken due to environmental factors such as exposure to seawater, sunlight, or chemicals that weaken the fibre structure of the net (Thomas and Sandhya, 2019). Another cause is mechanical damage resulting from friction, repeated loads, or intensive use. Nets that are frequently pulled over rough surfaces experience fibre damage. Repeated friction accelerates wear as the fibre structure weakens cumulatively. Some rough surfaces that damage nets include rocks or coral on the seabed, boat parts or fishing gear, captured objects such as logs or debris in the sea, and rough surfaces in storage areas or during operation (Sala *et al.,* 2004).

The friction process generates abrasive forces that cause fibre erosion, micro-breakage, and increased stiffness. There are three stages of net damage: (1) initial damage: The outer fibre layer wears down, usually without immediate visible signs. (2) microstructural damage: small cracks begin to appear in the fibres, weakening strength and elasticity. (3) material failure: after cumulative damage, fibres break permanently, leading to a reduction in breaking strength and elongation (Kim and Ko, 1993). This means that as the technical age increases, the breaking strength and elongation values tend to decrease, and vice versa. This indicates material degradation after years of use. Several factors contribute to the decline in breaking strength and elongation with increasing net age, including material ageing, mechanical damage, and environmental factors (Eriksen *et al*., 2024).

3.2.3 Comparison analysis of net technical age and breaking strength

Interestingly, the control net had the lowest breaking strength, while the 1-year-old net had the highest. This phenomenon occurs because used nets (e.g., 1-year-old or 2-year-old nets) may undergo material compaction or reinforcement during use, making the fibers temporarily stronger and more resistant to tensile forces compared to unused control nets. However, as the net ages further, breaking strength gradually declines, with the 3-year-old net experiencing the most significant drop.

In this study, it was observed that previously used gillnets, specifically those with one to two years of usage, demonstrated higher tensile strength than the unused control nets. At first glance, this finding appears counterintuitive, as material degradation is typically expected with prolonged use (Chamas *et al*., 2020). However, this phenomenon can be scientifically explained as a form of temporary mechanical reinforcement that occurs in polymer-based materials such as polyamide (PA) monofilament. A key mechanism underlying this phenomenon is strain-induced hardening or work hardening. During usage, the net fibres are continuously subjected to tensile stress caused by ocean currents, catch loads, and friction between knots (Le Gué *et al*., 2024b; Loizidou *et al.,* 2024). These repeated mechanical forces induce microplastic deformation in the polymer structure, whereby polymer chains become increasingly aligned in the direction of the applied stress. This molecular rearrangement enhances the local stiffness and tensile strength of the fibres through improved molecular orientation and intermolecular bonding (Mi *et al*., 2024; Gupta *et al.*, 2024).

Additionally, repeated cycles of drying, common in artisanal fisheries after exposure to seawater, contribute to fibre compaction and densification. As absorbed seawater evaporates, microstructural contraction and knot tightening occur, which results in a denser and less elastic net structure (Zou *et al*., 2024; Ghiassinejad *et al*., 2024). This compaction effect temporarily improves the mechanical performance of the net and reduces deformation under tensile testing, such as that conducted with a Universal Testing Machine (UTM). This temporary increase in strength is also associated with structural relaxation within the polymer (Jeong and Baig, 2020). Following repeated loading cycles, the polymer chains tend to settle into a new equilibrium configuration, marked by reduced entropy and increased intermolecular order. While this state improves mechanical resistance temporarily, it gradually deteriorates due to prolonged exposure to chemical and mechanical degradation factors such as UV radiation, oxidation, and micro-abrasion (Wypych, 2020; Andrady *et al.,* 2022).

Several key factors contribute to material wear, degradation, and environmental impact. Ultraviolet (UV) Exposure: UV rays damage the molecular structure of synthetic fibres like nylon, causing them to become brittle and less elastic, leading to reduced breaking strength over time (Orasutthikul *et al.,* 2017). Extreme Temperature Fluctuations: High temperatures (direct sunlight or warm seawater) can weaken fibres, while low temperatures make materials rigid and prone to breaking (Skvorčinskienė *et al.,* 2019). Repeated Mechanical Stress: Older nets have undergone multiple tension cycles (fishing operations, net hauling, and stretching), reducing fibre elasticity and durability. This process leads to permanent deformation, making the net more susceptible to breaking. Microscopic Fibre Breakdown: Over time, repeated pulling, friction, and material changes cause microscopic damage, progressively weakening the net's tensile strength. In 3-year-old nets, this microscopic damage has become widespread, leading to a significant drop in breaking strength.

3.2.4 Effectiveness of net technical lifespan based on breaking strength and elongation

Breaking strength is more influenced by external factors such as friction, abrasion, and mechanical stress. During use, net threads frequently experience friction against rough surfaces (such as rocks or sharp objects), which can cause structural damage to the fibres and significantly reduce breaking strength (Kim *et al.,* 2016). Over time, net strength declines due to factors such as wear and tear, UV exposure, friction, and seawater exposure, which directly impact the net's ability to catch fish efficiently. Initially, nets have optimal breaking strength and elongation, making them highly effective for catching Toli shad fish. However, as the technical lifespan increases, net effectiveness declines because elasticity and strength deteriorate, making the net prone to tearing or losing functionality (Sari *et al*., 2017).

Nets that are well-maintained and used under moderate conditions experience a gradual reduction in strength, typically around 5–10% per year. However, this rate may vary depending on several factors, such as the selection of high-quality materials, regular maintenance, and the use of protective covers to shield the net from direct sunlight when stored. Proper storage in a dry and sheltered environment also plays a crucial role in preserving the net's durability, as does ensuring that the net is used within its recommended load capacity to prevent mechanical damage (Moezzi *et al*., 2020; Mahato *et al*., 2018).

Based on the technical lifespan of the net, several recommendations can be made to maintain its effectiveness. During the first year, fishermen can continue using the net while conducting regular maintenance and monitoring its condition to ensure optimal performance (Jeong and Baig, 2020). By the second and third years, it is advisable to start considering the possibility of net replacement or to implement intensive maintenance measures, such as recoating the net to provide additional protection against UV exposure and abrasion. As the net reaches its fourth and fifth years of use, an evaluation of its condition becomes essential, as its effectiveness has likely declined significantly, increasing the risk of operational failure (Burkey *et al.,* 2022). By the sixth and seventh years, net replacement is strongly recommended, as its effectiveness has reached critically low levels, making it unsafe and inefficient for fishing operations (Pfeiffer *et al*., 2022).

Data indicates that net effectiveness consistently declines as its technical lifespan increases, primarily due to material degradation, wear and tear, and environmental factors. To ensure safe and effective fishing operations, it is essential to conduct routine monitoring of the net's condition based on its age, perform maintenance and repairs when feasible to extend its usability, and replace the net at critical stages typically between three to five years to maintain both efficiency and safety. Understanding the relationship between the net's lifespan and its effectiveness provides valuable insights for fisheries management (Gebremedhin *et al*., 2021). This knowledge aids in making informed decisions regarding net maintenance and replacement, ultimately enhancing productivity and reducing the risk of ghost fishing, which can have detrimental effects on marine ecosystems (Thomas *et al*., 2023; Do and Armstrong, 2023).

The catch performance of hilsa shad demonstrates a strong correlation with the age of the gillnet. Younger nets (approximately 1 year old) tend to be more effective in capturing smaller and more agile individuals due to their optimal balance of tensile strength and material flexibility. In contrast, older nets (2–3 years old) may be more suitable for capturing larger fish; however, the reduction in flexibility and elongation properties associated with material ageing can negatively impact overall capture efficiency (Thomas and Sandhya, 2019). Therefore, selecting gillnets based on their service age and the behavioral and morphological characteristics of the target species is essential for optimizing fishing operations and improving capture efficiency in sustainable fisheries management (Mardiah and Pramesthy, 2019).

The interaction between gillnets and toli shad is influenced by a combination of the net's physical properties and the morphological characteristics of the target species. Gillnets operate based on passive selectivity mechanisms, where fish are captured through three primary modes: gilling (caught by the gill covers), wedging (snagged around the body), and entangling (entwined in the netting) (Mardiah *et al.,* 2016; Nsangue and Tang, 2024). The effectiveness of these mechanisms depends greatly on the compatibility between mesh dimensions, mechanical properties of the netting material, and the size and shape of the fish (Maroneze *et al*., 2014). Toli shad has a laterally compressed, elongated body, with relatively moderate body depth and easily detached scales. Its pointed head and rigid operculum make it highly sensitive to mesh size and elasticity. When swimming into the gillnet, the likelihood of being captured depends on whether parts of the fish's body, such as the operculum, jaw, or fins, become engaged with the net (O'Keefe *et al*., 2023; Reavis *et al.,* 2025).

In nets that are relatively new (approximately one year of use), polyamide (PA) monofilament retains a high degree of flexibility and elongation (Karl *et al*., 2025). This elasticity allows the mesh to deform upon contact with the fish's body, increasing the chances of capture, especially through gilling, which is most effective for fish of moderate size. Additionally, the net's elasticity helps absorb the escape attempts of the fish, reducing the likelihood of the fish breaking free and minimizing physical damage. In contrast, nets aged two to three years undergo mechanical and chemical degradation, leading to decreased deformability and increased rigidity. As a result, interactions with fish become less dynamic and the capture mode shifts more toward entanglement, particularly for larger individuals that cannot pass through the mesh. For smaller or more agile fish, however, this rigidity results in a higher escape rate, as the mesh fails to conform adequately to their body contours (Jin *et al.*, 2019; Hasly *et al.*, 2017).

Another important factor is the surface condition of the netting. Abrasion and repeated use cause surface roughness, which may lead to scale loss in the toli shad. This not only compromises the fish's market quality but also reduces frictional engagement with the mesh, lowering capture efficiency (Dwi *et al.*, 2019; Dar *et al.*, 2017). Therefore, the interaction between gillnets and toli shad is significantly influenced by net age, filament diameter, and the material's mechanical behavior. Selecting nets with appropriate specifications and service life is essential to maximize catch efficiency, optimize species selectivity, and maintain the quality of the catch (Brinkhof *et al.*, 2023; Azhar and Mon, 2022; Cerbule *et al.*, 2023).

4. Conclusion

This study provides a comprehensive evaluation of the physical degradation and operational performance of Toli shad (*Tenualosa macrura*) gillnets based on their technical age. First, the structural characteristics of the gillnets, consisting of mesh sizes ranging from 77.82 mm to 99.60 mm, thread diameters between 0.34 mm and 0.53 mm, and knot heights from 1.52 mm to 2.28 mm, vary depending on the duration of use. These structural variations influence the physical behavior and mechanical performance of the nets over time. Second, the analysis of changes in physical properties demonstrates a strong negative correlation between technical age and both breaking strength ($r = -0.972$; $R^2 = 0.94$; $y = 9.85 - 1.31x$) and elongation ($r = -0.92$; $R^2 = 0.86$; $y = 20.11 - 0.34x$). The statistical analysis reveals significant differences in breaking strength among all age groups, while elongation differences are primarily observed between the control group and the aged nets. These results confirm that aging significantly reduces the mechanical integrity of the nets. Third, the technical performance and operational effectiveness of the gillnets remain within an acceptable threshold (≥50%) for up to three to four years of use. However, the decline in tensile strength and elasticity over time may affect the net's ability to effectively capture smaller and more agile Toli shad, emphasizing the importance of aligning net selection with both material condition and target species morphology. From a fisheries management perspective, this research highlights the need for regular evaluation of net physical properties as a basis for optimizing gear performance and supporting sustainable fishing practices in Bengkalis and surrounding waters. It is recommended that future studies focus on developing standardized maintenance protocols based on net age and investigate material enhancement strategies, such as additive treatments to extend net lifespan while maintaining capture efficiency and environmental compatibility.

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Authors' Contribution

Ratu Sari Mardiah was responsible for conceptualizing the study, drafting the original manuscript, and supervising the research process. Subong Park contributed to the methodology, data analysis, and manuscript review. Yusrizal conducted the investigation, collected data, and participated in manuscript editing. Erick Nugraha was involved in validation, visualization, and reviewing the manuscript. Rasdam contributed to data curation, formal analysis, and manuscript editing. Ganang Dwi Prasetyo played a key role in software development, statistical analysis, and reviewing the manuscript. Liya Tri Khikmawati conducted the literature review and contributed to the original draft writing. Fredi Febriyanto was responsible for data collection and manuscript editing. Yuli Purwanto provided supervision, secured funding, and participated in manuscript review. Khairudin Isman was responsible for project administration, managing resources, and reviewing the manuscript. All authors have read and approved the final version of the manuscript.

Conflict of Interest

This research was conducted without any commercial or financial relationships that could be interpreted as a potential conflict of interest.

Declaration of Artificial Intelligence (AI)

The author(s) acknowledge the use of ChatGPT and Grammarly for language refinement and grammatical correction in preparing this manuscript. All AI-generated content was rigorously reviewed, edited, and validated to ensure accuracy and originality. Full responsibility for the manuscript's final content

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rests with the author(s). To ensure transparency and support the review process, a comprehensive delineation of the tool's application is furnished in the "Introduction" or "Materials and Methods" section of this manuscript in compliance with the publisher's ethical guidelines.

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