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RESEARCH ARTICLE

Reproductive Biology Pattern and Size at Maturity of the Newly Reclassified *Sardinella pacifica* (Hata & Motomura, 2019) in Manila Bay, Philippines

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ABSTRACT

Manila Bay is a critical traditional fishing ground where the small pelagic *Sardinella pacifica* (formerly identified as *Sardinella fimbriata*) plays a vital socio-economic and ecological role. However, the population faces intense fishing pressure and overexploitation from unsustainable practices. Landed catch data from various fishing gears—including gillnets, stationary liftnets, ring nets, and otter trawls—were collected from January 2017 to December 2021. A total of 4,073 individuals were analyzed for sex ratio, body length and weight, gonadosomatic index (GSI), gonad maturity stages, length at first maturity (Lm_{50}), and length at first capture (Lc_{50}). The monthly sex ratio significantly deviated from the expected 1:1 (F: M) proportion, indicating female dominance. GSI values and gonad maturity stages showed that *S. pacifica* spawns year-round in Manila Bay. Spawning shows strong environmental resilience. The estimated length at first maturity (Lm_{50}) was 10.6–11.0 cm for females and 8.8–10.1 cm for males. These values are notably lower than the previously reported 2014–2015 baselines (12.25 cm for females and 12.75 cm for males). This marked reduction in Lm_{50} may reflect a shift toward earlier maturation at smaller sizes, potentially driven by high levels of fishing pressure. To address the critical knowledge gap surrounding this newly reclassified species, this study assessed its reproductive characteristics to provide scientific information for sustainable fisheries management.

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1. INTRODUCTION

Manila Bay, one of the Philippines' traditional fishing grounds, supports a multi-gear, multi-species fishery (Rivera et al. 2017). It also serves as one of the nation's busiest ports, both domestically and internationally (Cardos et al. 2023). Beyond its commercial importance, Manila Bay is a rich, dynamic ecosystem and a vital traditional fishing ground for numerous coastal communities (Trinidad et al. 2019; Bendaño et al. 2017). The bay's ecological structure is characterized by the dominance of small pelagic fishes (Bendaño et al. 2017). Earlier studies (Ronquillo et al. 1989; BFAR 1995) reported that the Bay was abundant in demersal fishes and invertebrates. However, more recent research has indicated a shift in species dominance toward pelagic species (Zaragoza et al. 2005; Rivera et al. 2017).

Historically, the most dominant small pelagic clupeid populations in Manila Bay were identified and recorded as the fringescale sardinella, *Sardinella fimbriata*. For decades, fish stock assessments and biological studies relied heavily on this morphological classification (Rivera et al. 2017). However, recent clupeid taxonomy has driven a fundamental reassessment of these species' populations, with a comprehensive taxonomic study identifying *Sardinella pacifica* as a distinct species (Hata and Motomura 2019). Their work showed that many specimens previously attributed to *S. fimbriata* in the Western Pacific, particularly those thriving in Philippine coastal waters, including Manila Bay, belong to this newly identified species. In line with this taxonomic reclassification, this study formally adopts the revised nomenclature, correcting the identification of the studied specimens from *S. fimbriata* to *S. pacifica* (Hata and Motomura 2019). This update is vital to the

integrity of our reproductive assessment and ensures that fisheries management strategies in Manila Bay align with *S. pacifica*'s specific biology.

However, *S. pacifica* populations in Manila Bay face several threats, primarily from overexploitation driven by unsustainable fishing practices. Increased catches of small and immature individuals using gill nets and other destructive fishing gear have placed the species under intense fishing pressure (Rivera et al. 2017). Unsustainable practices not only deplete fish stocks but also disrupt natural reproductive cycles, hindering population replenishment and long-term sustainability (Rivera et al. 2017). The lack of recent, comprehensive studies on the reproductive biology of *S. pacifica,* particularly the lack of reproductive data following its taxonomic reclassification, its reproductive pattern, information on the length at first maturity and length at first capture under prevailing fishing pressure within the bay, needs to be addressed for a more meaningful and comprehensive management strategy.

In this study, a thorough assessment of the reproductive patterns of *S. pacifica* is important to generate science-based fisheries management in Manila Bay, Philippines. Thus, this research aims to address the critical knowledge gap surrounding the reproductive biology of *S. pacifica* using multi-year landing data collected from 2017 to 2021 in Manila Bay, contributing to the development of sustainable fisheries management practices and ensuring the long-term health and productivity of this vital fish stock. Specifically, this study examines sex ratio, gonad maturity stages, gonadosomatic index (GSI), and length at first maturity (Lm_{50}) to describe the spawning patterns, reproductive size, and seasonality. In addition, the study assesses the relationship between length at first capture (Lc_{50}) and maturity size to determine the extent of fishing pressure on the stock.

2. MATERIALS AND METHODS

2.1 Study site

The study was conducted at selected fish landing sites in Manila Bay, the country's largest bay with a 190-kilometer coastline. Manila Bay is recognized as a vital body of water that supports food, livelihood, and recreation for millions while serving as the drainage area for Central Luzon, parts of Pangasinan and Nueva Vizcaya, most of CALABARZON, and Metro Manila.

2.2 Fish sampling and data collection

A total of 4,073 fish samples were purchased and randomly selected from eight (8) fish landing sites covered (two in Metro Manila, two in Bataan, and four in Cavite) operated by fishers in Manila Bay (Figure 1). The samples were placed in ice-filled coolers to maintain quality and then transported to the NFRDI laboratory for reproductive biology analysis.

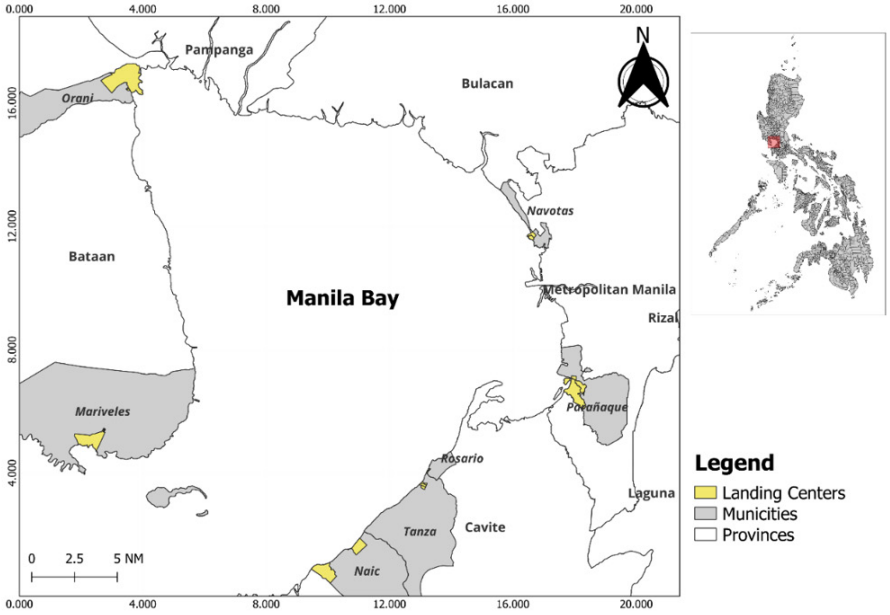

Figure 1. Map of the selected fish landing sites in Manila Bay, Philippines.

2.3 Fish gonad extraction and identification

The samples were randomly collected from various fishing gears, including gillnets, stationary lift nets, ring nets, and trawls. Prior to dissection, the total length (cm) and body weight (g) of each sample were recorded. Dissection was performed by opening the abdominal cavity to determine the sex and gonad maturity stage through visual examination of the samples following the NFRDI guidelines. Gonads in Stages II to IV were removed and weighed to the nearest 0.01 g. For each sex, the maturity stages were grouped into juvenile or virgin (Stage I), immature, maturing virgin, and recovering spent (Stage II), maturing, developing, and developed (Stage III), matured, gravid, and spawning (Stage IV), spent or resting (Stage V), and undetermined "U," which were removed from the analysis (Holden and Raitt 1974). Figure 2 shows the Gonadal maturity and classification by Holden and Raitt (1974).

2.3.1 Sex ratio

The proportion of female to male individuals was calculated monthly to determine the sex ratio. A chi-square (χ^2) test was then applied to assess whether the observed ratios significantly deviated from the expected theoretical sex ratio of 1:1 (Al-Jufaili 2013), using the following formula:

$$X^2 = \sum \frac{(O-E)^2}{E}$$

Where O is the observed frequency, and E is the expected frequency. All essential information, such as the date of collection, fishing gear used, species, total length, weight, gonad weight, and stages, was recorded.

2.3.2 Gonad frequency

Seasonal distribution of gonads by maturity stages was determined monthly, and the overall percentage frequencies observed were used to indicate the seasonal distribution of the gonad maturity stages. The average spawning season duration was defined as the time when at least 50% of the adult population had reached maturity.

2.3.3 Gonadosomatic Index (GSI)

The gonadosomatic index (GSI) indicates the percentage of fish weight used for egg production. The

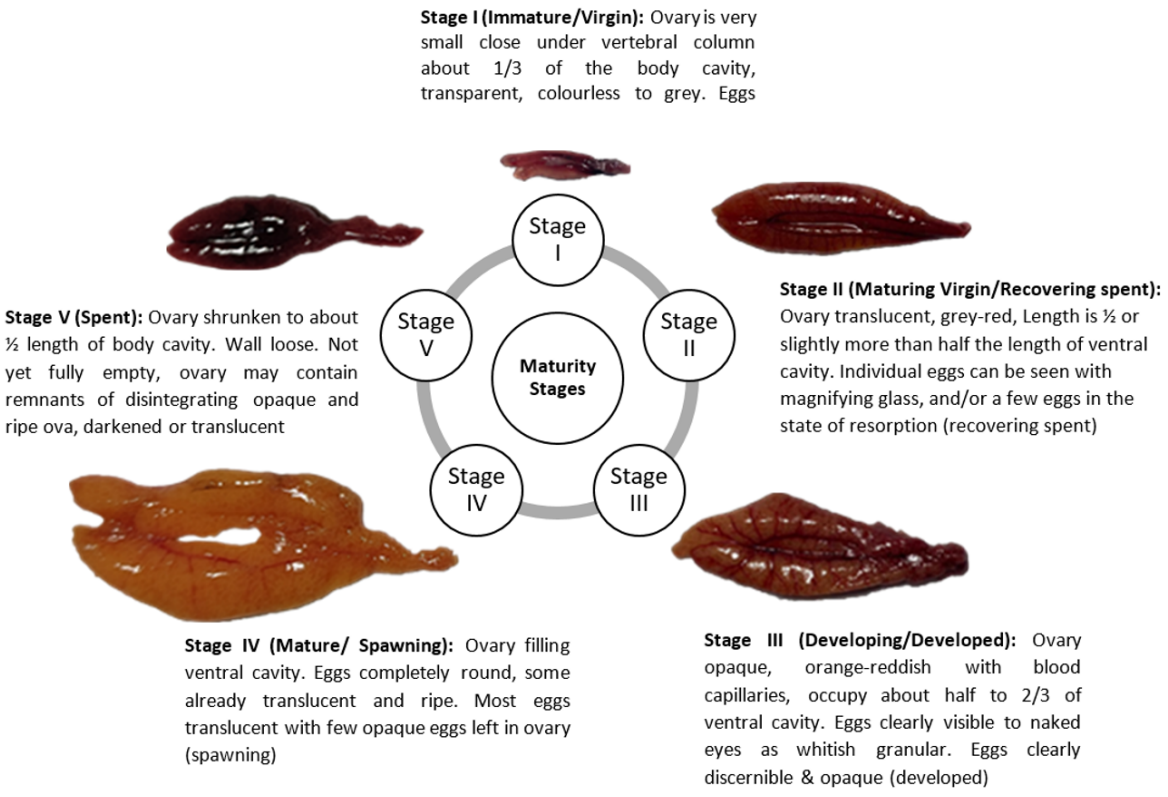

Figure 2. Gonadal maturity and classification by Holden and Raitt (1974).

analysis used only female gonads in stage IV (mature/spawning) to verify spawning strength during the biological months. The GSI was computed as follows:

$$GSI = \frac{Gonad\ Weight\ (g)}{Fish\ Weight\ (g)} \times 100$$

2.3.5 Length at first maturity

Fish gonads in stages III and IV were considered mature and were used to calculate the length at first maturity (Lm_{50}). The length at which 50% of all individuals were sexually mature (Lm_{50}) was estimated from the proportion of mature individuals in each 0.5 cm length-class interval, fitted to a logistic curve (Somerton 1980; Roa et al. 1999) using the RStudio "sizeMat" package (Torrejon-Magallanes 2020)

2.3.6 Length at first capture

The optimum catch size was estimated using the length-converted catch curve implemented in the FiSAT II tool. This method allowed for the calculation of the probability of length at first capture (Lc_{50}), which is defined as the length at which 50% of individuals are captured, alongside the lengths at the 25% and 75% capture probabilities (Pauly 1984)

2.4 Statistical analysis

Descriptive and inferential data analyses were done using statistical software. Descriptive statistics summarized key biological parameters, including sex ratio and gonadosomatic index (GSI). Mean values, ranges, and percentages were computed to provide an overview of the dataset. We used the chi-square test to determine whether the observed sex ratio significantly deviated from the expected 1:1 female-to-male ratio. The gonadosomatic index (GSI) was calculated to evaluate reproductive condition and spawning activity. A logistic regression model implemented in R software (SizeMat Package) was used to estimate the length at first maturity. Length-based analysis was performed using FiSAT II software to estimate the length at first capture.

3. RESULTS

3.1 Sex ratio

In this study, we analyzed 4,073 *S. pacifica* samples, of which 62.19% were female and 37.81% were male. The chi-square test revealed that the abundance of females and males over the sampling period of the study significantly differs from the expected ratio of 1:1. The differences was observed in 2017 (1.56:1 (F: M), $\chi2$= 47.33), 2018 (1.81:1 (F: M), $\chi2$= 78.11), 2019 (1.84:1 (F: M), $\chi2$= 69.14), 2020 (1.57:1 (F: M), $\chi2$= 32.99), and 2021 (1.63:1 (F: M), $\chi2$= 40.48) in favor of females. Table 1 presents these results.

3.2 Monthly distribution of gonad maturity and frequency

The observation of gonad frequency revealed significant changes over the five-year study period. For *S. pacifica*, mature and spawning individuals were consistently present in both sexes throughout the study, with the spawning peak initially occurring in the last quarter of 2017 and then shifting to the first quarter of 2018–2019. Although no catch was available from March to May 2020, spawning individuals were still observed during that year, and in 2021 spawning activity was observed continuously across the sampling period. (Figure 3).

3.3 Gonado Somatic Index (GSI)

Monthly variation in the gonadosomatic index (GSI) over the study period showed that reproductive activity in *S. pacifica* is year-round, with multiple peaks (Figure 4). Females recorded the highest values in 2017 in February (6.67 ± 0.80) and November (5.40 ± 0.47). In 2018, peaks shifted, with females exhibiting the highest values in October (6.01 ± 0.43) and April (4.43 ± 0.35), while males peaked in January (4.84 ± 0.56) and April (4.88 ± 0.46). In 2019, both sexes peaked in February and June, with GSI values of 5.29 ± 0.57 and 5.37 ± 0.45 for females and 5.36 ± 0.43 and 6.34 ± 0.47 for males. Fluctuating patterns were observed in 2020, with recorded peaks in July (5.90 ± 0.64) and September (5.12 ± 0.63) for females, and in June (4.75 ± 0.28) and August (5.29 ± 0.32) for males. In 2021, multiple peaks occurred, with females recording high values in February (5.22 ± 0.34), July (5.03 ± 0.46), November (5.57 ± 0.57), and December (5.04 ± 0.21), while males peaked in March (5.21 ± 0.25), April (5.82 ± 0.35), and December (4.84 ± 0.29).

Table 1. Monthly sex ratio with the corresponding chi-square (x2) values, percentage of mature individuals of Sardinella pacifica from Manila Bay, Philippines, from 2017 to 2021 (pooled data), n = 4,073.

2017					2019				
Month	**Female**	**Male**	**Sex ratio**	**χ2**	**Month**	**Female**	**Male**	**Sex ratio**	**χ2**
Jan	28	23	1.22:1	0.49	Jan	34	21	1.62:1	3.07
Feb	39	28	1.39:1	1.81	Feb	43	17	2.53	11.27*
Mar	65	28	2.32:1	14.72*	Mar	37	16	2.31:1	8.32*
Apr	56	69	0.81:1	1.35	Apr	33	22	1.5:1	2.20
May	51	27	1.89:1	7.38*	May	25	31	0.81:1	0.64
Jun	79	37	2.14:1	15.21*	Jun	28	27	1.04:1	0.02
Jul	74	23	3.22:1	26.81*	Jul	63	26	2.42:1	15.38*
Aug	53	34	1.56:1	4.15*	Aug	47	28	1.68:1	4.81*
Sept	25	25	1:1	0.00	Sept	69	20	3.45:1	26.98*
Oct	43	49	1.14:1	0.39	Oct	47	23	2.04:1	8.23*
Nov	52	31	1.68:1	5.31*	Nov	39	26	1.5:1	2.60
Dec	35	21	1.67:1	3.50	Dec	48	22	2.18:1	9.66
Total	600	395	1.56:1	47.33*	Total	513	258	1.84:1	69.14*
*P<0.05 = 3.84					*P<0.05 = 3.84				
2018					2020				
Month	**Female**	**Male**	**Sex ratio**	**χ2**	**Month**	**Female**	**Male**	**Sex ratio**	**χ2**
Jan	19	32	2.23:1	6.10*	Jan	44	24	1.83:1	5.88*
Feb	36	25	1.44:1	1.98	Feb	52	34	1.53:1	3.77
Mar	43	17	2.53:1	11.27*	Mar	-	-	-	-
Apr	35	25	1.4:1	1.67	Apr	-	-	-	-
May	53	24	2.21:1	10.92*	May	-	-	-	-
Jun	64	13	4.92:1	33.78*	Jun	30	20	1.5:1	2.00
Jul	33	37	0.89:1	0.23	Jul	63	32	1.97:1	10.12*
Aug	27	39	0.69:1	2.18	Aug	29	31	0.94:1	0.07
Sept	101	58	1.74:1	11.63*	Sept	57	27	2.11:1	10.71*
Oct	53	11	4.82:1	27.56*	Oct	24	32	0.75:1	1.14
Nov	78	23	3.39:1	29.95*	Nov	64	33	1.94:1	9.91*
Dec	30	32	0.94:1	0.06	Dec	43	25	1.72:1	4.76*
Total	572	304	1.84:1	78.11*	Total	406	234	1.57:1	32.99
*P<0.05 = 3.84					*P<0.05 = 3.84				

2021				
Month	**Female**	**Male**	**Sex ratio**	**χ2**
Jan	31	16	1.94:1	4.79*
Feb	51	4	12.7:1	40.16*
Mar	22	23	0.67:1	2.20
Apr	29	26	1.12:1	0.16
May	40	36	1.11:1	0.21
Jun	41	11	3.73:1	17.31*
Jul	41	19	2.16:1	8.07*
Aug	35	16	2.19:1	7.08*
Sept	19	36	0.53:1	5.25*
Oct	53	35	1.51:1	3.68
Nov	41	19	2.16:1	8.07*
Dec	39	21	1.86:1	5.40*
Total	442	246	1.63:1	40.48*
*P<0.05 = 3.84				

3.4 Length at first maturity (Lm_{50}) and length at first capture (Lc_{50})

The estimated length at first maturity (Lm_{50}) of *S. pacifica* showed variations throughout the study period. In 2017, females reached maturity at 10.9 cm and males at 8.8 cm. In 2018, female maturity length remained the same, while males increased to 10.1 cm. In 2019, females reached maturity at 11.0 cm, while males decreased to 8.2 cm. Female maturity size continued to decline in 2020 (10.6 cm), while males increased to 9.9 cm. In 2021, female maturity size returned to 11.0 cm, while males decreased slightly to 9.6 cm. Figure 5 show the results.

The length at first capture was estimated at 10.4 cm in 2017 (Figure 6). However, in 2018, the value decreased to 9.36 cm. In the following study period, length at first capture increased gradually to 11.3 cm in 2019, 11.4 cm in 2020, and 11.7 cm in 2021.

4. DISCUSSION

The yearly sex ratio differs significantly from the expected 1:1 ratio. The chi-square value exceeded the critical value of 3.84, confirming significant differences between the sexes. Monthly pooled data for *S. pacifica* between females and males showed differences dominated by females (Table 1). The overall sex ratio of *S. pacifica* per year was 1.56:1 for 2017; 1.81:1 for 2018; 1.84:1 for 2019; 1.57:1 for 2020; and 1.63:1 for 2021, which shows similar results from other related studies examining both historical Manila Bay stocks (Rivera et al. 2017) and closely related *S. fimbriata* populations in other regions (Kudale and Rathod 2016). The predominance of female sardines among the sampled individuals suggests an imbalanced sex ratio, which could significantly affect reproductive success and future population dynamics (Alheit et al. 2019; Samba et al. 2021). The female-biased sex ratio could result from capturing a more dominant sex; sex-ratio differences may also reflect seasonal differences in mortality and other behavioral patterns between females and males (Kudale and Rathod 2016; Qasim 1957). Thus, information on the sex ratio of *S. pacifica* may be used to manage fishery resources sustainably. Specifically, by improving the interpretation of Spawning Potential Ratio (SPR) and guiding the regulation of gear mesh size to ensure the long-term sustainability of the stock (Willems et al. 2023)

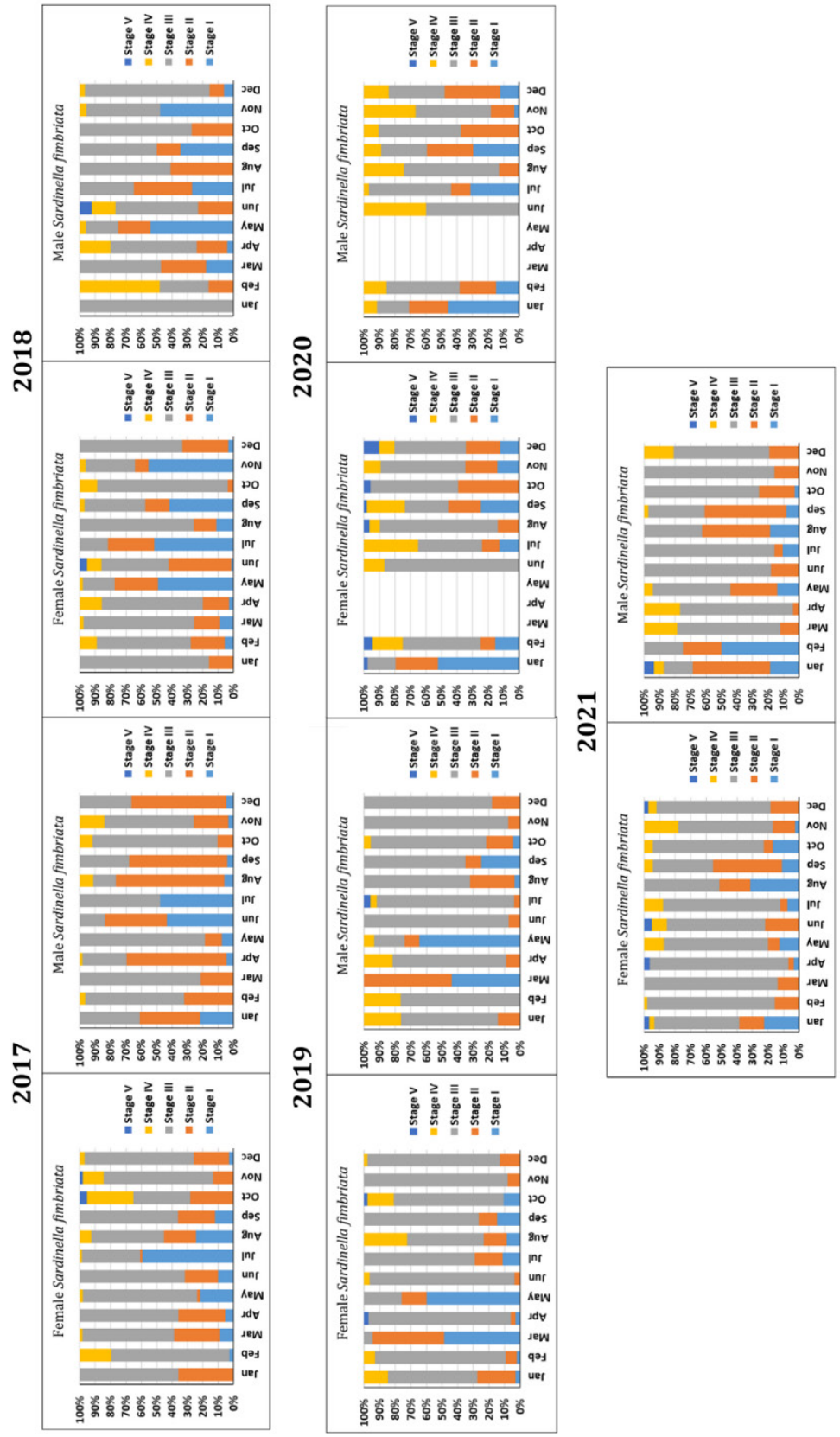

Figure 3. Gonadal development of *Sardinella pacifica* from 2017 to 2021 in Manila Bay, Philippines.

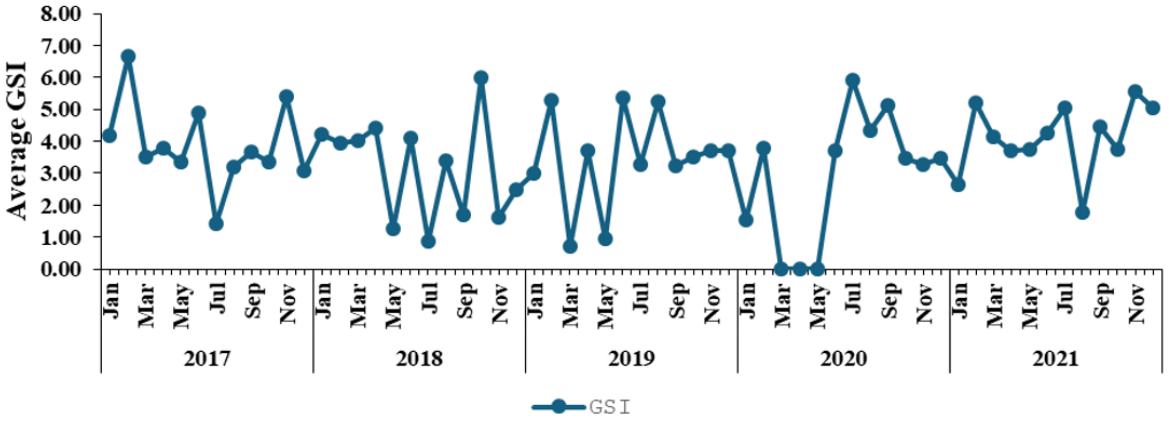

Figure 4. Monthly gonadosomatic index values indicating the peak spawning season (with the highest value) of *Sardinella pacifica* from 2017 to 2021 in Manila Bay, Philippines

Table 2. Comparative Analysis of Length at first maturity and Length at first capture for *Sardinella pacifica* in Manila Bay (2017–2021).

Year	L_{m50} (Female)	L_{c50}	Status	Spawning Window
2017	10.9 cm	10.4 cm	$L_c < L_m$	-0.5 cm
2018	10.9 cm	9.36 cm	$L_c < L_m$	-1.54 cm
2019	11.0 cm	11.3 cm	$L_c > L_m$	+0.3 cm
2020	10.6 cm	11.4 cm	$L_c > L_m$	+0.8 cm
2021	11.0 cm	11.7 cm	$L_c > L_m$	+0.7 cm

The peak spawning of *S. pacifica* was indicated by the presence of mature and spawning gonads, as supported by the highest calculated GSI during the study period. The monthly distribution of gonad frequency and the gonadosomatic index (GSI) is vital for understanding reproductive potential and informing effective management and conservation strategies. Monthly gonad stages of *S. pacifica* show mature and spawning individuals throughout the study period, with sizes ranging from 8.5 cm to 23.0 cm TL, weights from 9.65 g to 77.67 g, and gonad weights from 3.0 g to 12.03 g. Spawning occurred in the first quarter, peaking in February, with a minor peak in the last quarter of the year. This result aligns with Ghosh et al. (2013) and Rivera et al. (2017), but contrasts with Vicente and Palla (2025), which reported a spawning peak in April. In addition, Musel et al. (2022) report a spawning season from March to June. Overall, variation in peak spawning periods and the presence of mature individuals throughout the study indicate year-round reproductive activity in *S. pacifica*, characterized by partial spawning. This may be attributed to a combination of environmental and anthropogenic factors, including water temperatures, dissolved oxygen, salinity, climate change, stress, habitat destruction, pollution, and fishing pressure (Cushion 2010; Hunnam 2021; Canosa and Bertucci 2023).

The Length at first maturity, where 50% of the fish reached sexual maturity of *S. pacifica* recorded was 10.6 cm – 11.0 cm for females and 8.2 cm - 10.1 cm for males which was relatively lower than the value reported from the previous study by Rivera et al. (2017) in Manila Bay, which recorded a maturity size of 12.25 cm for females and 12.75 for males for specimens they identified at the time as *Sardinella fimbriata* (now recognized as *S. pacifica)*. The observed decline in length at first maturity suggests a survival response to long-term overfishing in Manila Bay. In this process, the fish may adapt by reaching sexual maturity earlier, which often leads to a smaller and less resilient population over time. Furthermore, earlier maturation may occur as both a genetic and adaptive response to fishing pressure (de Roos et al. 2006; Yang et al. 2023). Moreover, the length at first capture (Lc_{50}) is an essential indicator, in comparison with length at first maturity (Lm_{50}), to indicate the health status of the fishery resources (Gulland 1983; Froese 2004). The estimated length at first capture in 2017–2018 was significantly lower than the length at first maturity, suggesting that fishing predominantly targeted immature fish. However, in 2019 – 2021, the length at first capture was significantly higher than the length at first maturity, indicating that most fish had spawned at least once before being caught, thereby supporting the sustainability of the fishery

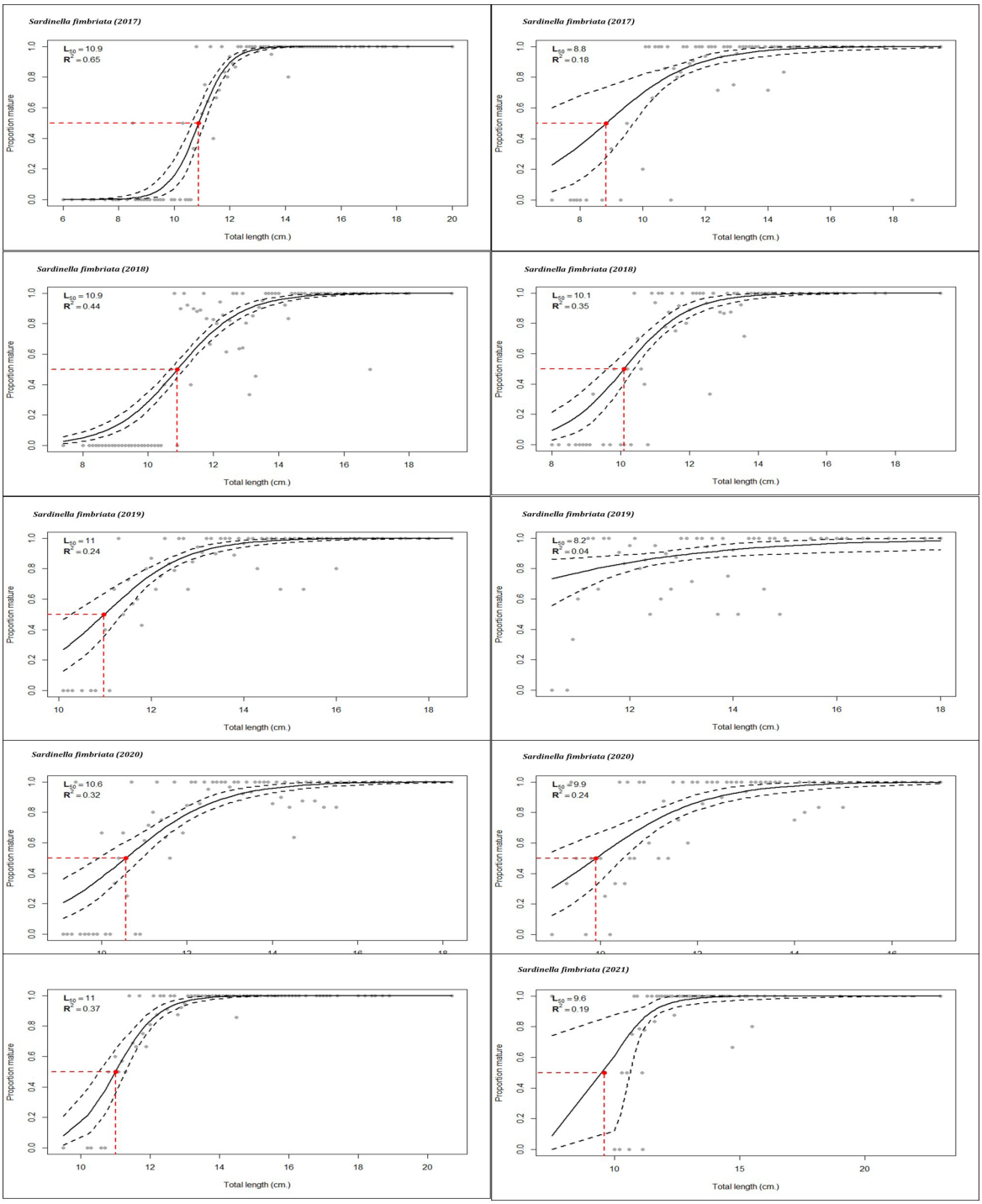

Figure 5. Length at first maturity of female and male *Sardinella pacifica* in Manila Bay, Philippines.

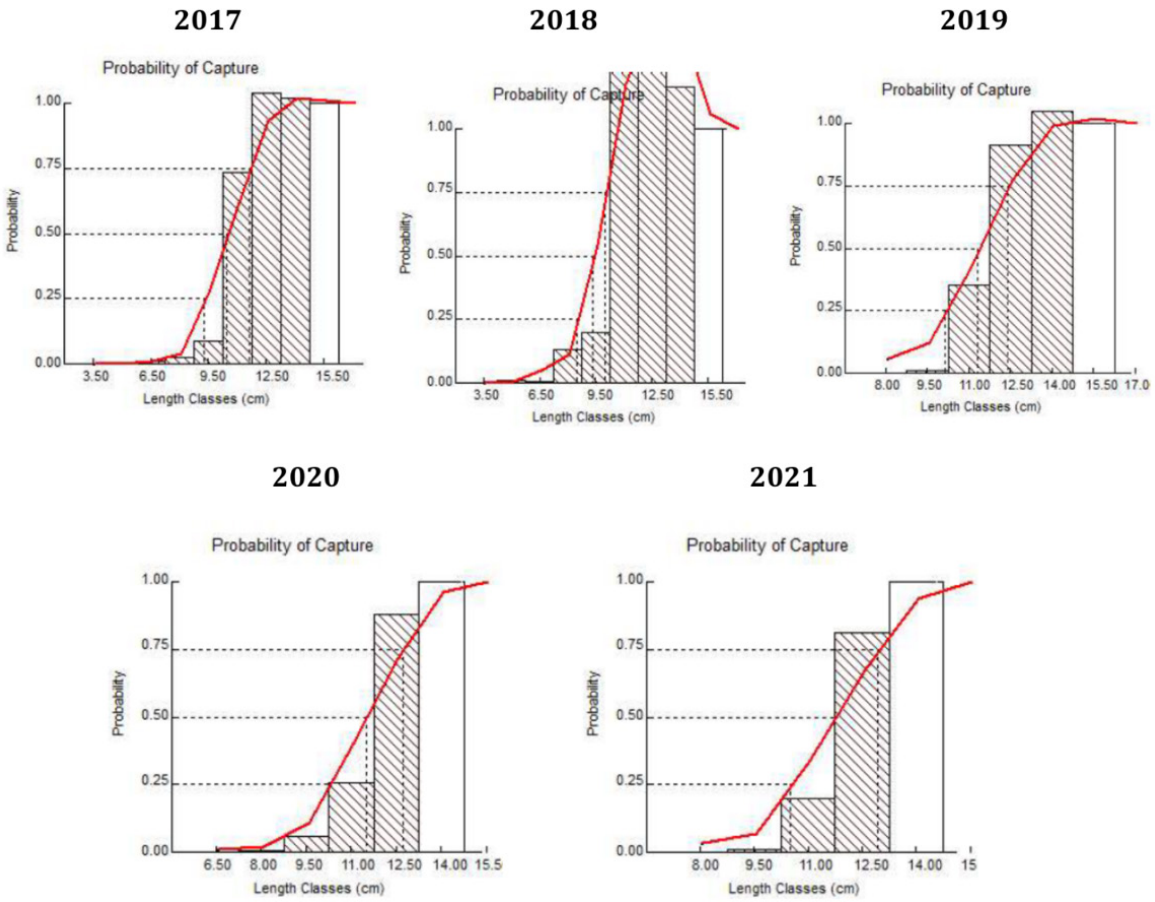

Figure 6. Length at first capture of *Sardinella pacifica* in Manila Bay, Philippines.

(Froese 2004). The observed decline in size raises concerns about the population status and long-term sustainability of the sardine stock in the bay. Therefore, to sustain the positive trend observed in 2019 – 2021, it is recommended that the minimum size for *S. pacifica* in Manila Bay be strictly maintained above 11.8 cm. This ensures the current spawning window remains open, preventing a return to the recruitment overfishing seen in 2018.

5. CONCLUSION

This research study focused on the reproductive biology pattern and size at maturity of *Sardinella pacifica* in Manila Bay covering the five years data collection. Results showed a female-dominated sex ratio and variations in peak spawning periods, indicating year-round reproductive activity in *S. pacifica* (partial spawning). The reproductive of *S. pacifica* in Manila Bay is characterized by high environmental resilience rather than dependence on environmental triggers. The estimated length at first maturity (Lm_{50}) of *S. pacifica* was notably lower than the values reported for this species (previously identified as *S. fimbriata*) by Rivera et al. (2017) (12.25 cm for females; 12.75 cm for males). Findings showed declining maturity sizes, suggesting potential impacts of increased fishing pressure. Moreover, length at first capture (Lc_{50}) indicates fishing sustainability. These findings highlight *S. pacifica*'s adaptability to Manila Bay's environmental conditions but also indicate potential stress on its populations.

Current size limits and fishing-effort controls may need reassessment to prevent further stock depletion. Establishing a minimum catch size regulation of at least 11.8 cm total length for *S. pacifica* and reducing fishing pressure during peak spawning periods may help to enhance stock recovery and sustainability. Furthermore, improving gear selectivity and strictly enforcing existing fisheries policies are recommended to reduce the harvest of immature individuals. These measures are critical to ensure the long-term viability of *S. pacifica* populations in Manila Bay and their continued socio-economic benefits to coastal communities.

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AUTHOR CONTRIBUTIONS

Dicdiquin NRB: Writing-Original Draft, Supervision, Validation, Investigation, Data curation, Writing - Review & Editing. **Lopez GDV:** Supervision, Project administration, Validation. **Torres FSB:** Supervision, Validation, Writing - Review & Editing. **Abad JL:** Investigation, Writing-Review. **Perez JEG:** Data curation, Data analysis, Visualization, **Ruado MA:** Investigation, Data analysis. **Loyola CM:** Investigation, Data analysis. **Sucgang R:** Investigation, Data analysis. **Pendre JEG:** Formal analysis

CONFLICTS OF INTEREST

The authors declare no actual, potential, or perceived conflict of interest for this study.

ETHICS STATEMENT

The authors affirm that all international, national, and institutional guidelines for the care and use of laboratory animals have been diligently followed and adhered to throughout this study.

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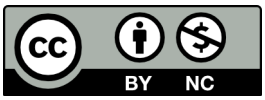

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