The Philippine Journal of Fisheries 2026 NSAP Special Issue: 129 - 146
DOI: 10.31398/tpjf/33.3.2025C0013
September 2026

RESEARCH ARTICLE

Reproductive Biological Performance of Selected Commercially Important Small Pelagic Fishes Landed in Region I, Northwestern Luzon, Philippines

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ABSTRACT

This study was conducted from 2016 to 2018 to determine the reproductive capacity of selected commercially important small pelagic species in Region I. This includes the determination of the sex ratio of females and males, seasonal patterns of gonadal maturity development, gonado-somatic index (GSI), comparative values of length at first maturity (L_m), length at full captivity (L_{50}), mean length of catch and length at full selectivity (L_c), spawning potential ratio (SPR), and length ranges of species caught by various fishing gears with their corresponding length at first maturity (Lm) using the National Stock Assessment Program standard data gathering and gonad identification. A total of 16,097 samples were collected, and the male-to-female sex ratio was 1:1. *Decapterus macarellus* spawns year-round, and its performance indicators fall within the target reference points except for exploitation rate (0.70). All gears catching this species show a high frequency of catch for mature individuals. *Rastrelliger brachysoma* and *Rastrelliger kanagurta* spawn from April to November. The length at full captivity (L_{50}) of these species is near the computed L_m, indicating a high probability of capturing first-time spawners. Additionally, gillnet (GN) and trawl (T) catches show a high frequency of mature and immature sizes, while beach seine (BS) captures a high frequency of smaller sizes for *R. brachysoma*. The SPR of *R. kanagurta* is near the threshold of limit reference points. BS, GN, and hook and line (H&L) obtained a wide range of mature sizes and a high frequency of sizes near L_m, while T, GN, and H&L recorded a high frequency of immature sizes. *Selar boops* spawns from February to October, while *Selar crumenophthalmus* spawns from April to December. Moreover, L_m and L_{50} were almost the same for both species. For *S. boops*, the mean length is smaller than the L_m. Furthermore, *S. crumenophthalmus* caught by T has a high frequency of catch near the Lm, while *S. boops* is recorded at smaller sizes. GN extracts smaller sizes, while H&L catches bigger sizes than L_m.

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Received: *April 23, 2025*
Accepted: *June 29, 2026*

Keywords: *small pelagics, reproductive biology, length at first maturity, length at first capture*

1. INTRODUCTION

Landings of small pelagic fish provide much of the employment and are mostly used for local consumption. Small pelagic fish species contain all the elements of a healthy and nutritionally optimal food source for humans and are an important contributor to the food and nutritional security of many poor, low-income households in developing countries (Isaacs 2016). Small pelagic fish groups include roundscads, anchovies, sardines, mackerels, round herrings, bigeye scads, flying fishes, and halfbeaks (Zaragoza et al. 2004).

Region I is located in the northwestern section of Luzon Island in the Philippines, which covers four provinces (Ilocos Norte, Ilocos Sur, La Union, and Pangasinan) and has six fishing grounds (Pasaleng Bay, Bangui Bay, Ilocos Coast/North West Philippine Sea, Lingayen Gulf, Dasol Bay, and Scarborough Shoal). The fisheries resources in these fishing grounds contribute significantly to the income, employment, and nutrition of resident fishers. According to Gaerlan and Buccat (2018), in terms of catch composition by fish group, the highest catch in Region I came from small pelagics, totaling 2,366 MT. *Decapterus macarellus,* a small pelagic species, is

commonly processed and marketed as smoked fish in the region. However, local fishers said that, over time, catches of various small pelagics have been lower than in previous years. Therefore, it is imperative to study why local fishers' catches are declining and to examine the reproductive biology of small pelagic species to identify and propose solutions that prevent population collapse. Also, Gaerlan et al. (2018) recommend conducting a reproductive biology study on small pelagic fish species to determine spawning seasons as an additional basis for recommending fisheries management initiatives for stock conservation and protection.

Fish reproductive biology (onset and duration of spawning, sex ratio, maturity stages, length and age at maturity, and fecundity) is vital in fisheries research, stock assessment, and management (Tsikliras et al. 2013). Gaerlan et al. (2018) recommended conducting reproductive biology studies of small pelagic fish species to determine spawning seasons for stock conservation and protection.

Similar studies were also conducted in South Sulawesi, Indonesia, from March 1996 to July 1997 on the maturation process of the short mackerel, *Rastrelliger brachysoma*, based on seasonal changes in GSI and histological observation of the gonads. The study revealed that short mackerel are multiple spawners with asynchronous oocyte development, and the minimum size at maturation was about 140 mm (fork length). Individuals that reached maturation were considered to repeat the process from the developing stages to the resting stages. However, spawning and post-spawning occurred throughout the year, and clear seasonal changes were not observed in either area (Suyama et al. 2000).

A study of the fishery, biology, and stock status of Indian mackerel, *Rastrelliger kanagurta*, landed along the northeast coast of India from 2011 to 2014 found that trawlers, gillnetters, and seiners contributed roughly equally to the catch. Length at first maturity varied between 18.32 and 18.86 cm (Ghosh et al. 2016), while the length at first maturity (L_m) on the Arabian Sea coast of Mahout, Oman, was estimated at 25.2 cm for males and 25.7 cm for females (Zaki et al. 2016). Gonad maturity in Indian mackerel in Makassar coastal waters, South Sulawesi, Indonesia, occurred year-round, peaking between July and August (Kantun et al. 2018), similar to results from Takalar Coastal Waters, South Sulawesi, Indonesia (Kasmi et al. 2017). The peak spawning season was July-October and February-April (Ghosh et al. 2016). Females were more dominant than males in the catches, and the annual sex ratios differed significantly (Zaki et al. 2016). Length at first capture and estimated lifespan were 12.78 cm and 2.48 years, respectively. Natural mortality, fishing mortality, and total mortality were 2.06, 3.69, and 5.75, respectively, with an exploitation rate of 0.64. Peak recruitment was found to be during September-October (Ghosh et al. 2016).

In a reproductive biology study of the mackerel scad, *D. macarellus*, from Cabo Verde, the samples comprised 284 females (20–36 cm fork length [FL]) and 85 males (21–35 cm FL). The reproductive season occurs from March to October, with two spawning peaks, one in March and another from July to October (Costa et al. 2020). Meanwhile, *D. macarellus* matures at about 24.5 cm SL, and in Hawaii spawning occurs from April through August (Clarke et al. 1995). The species was abundant in April, May, and June in Moro Gulf, Philippines (Calvelo 1997). The sizes at first maturity were estimated for females and males at 24.1 cm FL and 26.6 cm FL, respectively (Costa et al. 2020).

Furthermore, the biology of bigeye scad (*Selar crumenophthalmus*) was studied from commercial fishery catches around Reunion Island. The sex ratio remained constant month by month, and there was no predominance of males or females, even in the larger size classes. Fish matured by April, and the proportion of mature fish increased progressively until November, when gonad indices were highest. The size at first maturity (L_{50}) was reached at 21.5 cm FL (Roos et al. 2007). The spawning season is from April through September or October (Clarke et al. 1995).

In general, this study was conducted to determine the reproductive capacity of selected commercially important small pelagic species in Region I. Specifically, the study aimed to determine the sex ratio of females and males, seasonal pattern of gonadal maturity development, gonado-somatic index (GSI), comparative values of length at first maturity (L_m), length at full captivity (L_{50}), mean length of catch and length at full selectivity (L_c), spawning potential ratio (SPR), and length ranges of species caught by various fishing gears with their corresponding length at first maturity (L_m).

2. MATERIALS AND METHODS

Small pelagic fisheries assessment of Region I is a continuing activity up to the present. This is an additional and supporting study of the published literature titled "A Review on the Status of Small Pelagic Fish Resources in the Lingayen Gulf for the Year 2009-2013" (Gaerlan et al. 2018).

This paper presents a reproductive biology study that lasted from 2016 to 2018. The results presented and analyzed in this paper cover 2 1/2 years, or 288 data collection events, from June 2016 to December 2018, with data collection at selected landing sites conducted every other two days, regardless of Saturdays, Sundays, and holidays.

2.1. Study area

Sampling was conducted from 42 landing sites (Figure 1). Two enumerators conducted catch recording, species identification, gonad stage identification, and gear used at each landing site. However, gonad samples depended on the landed catch. Before sampling, the enumerators were trained in fish species identification, fish dissection, and gonad stage and sex identification (Table 1).

2.2. Data collection

Data were collected at selected landing sites every other two days, including Saturdays, Sundays, and holidays. This was done throughout the month, resulting in 20 sampling days (10 days per landing site). In months with 31 calendar days, the first landing site was sampled for 11 days. All pertinent data on the landed catch were recorded: name of fishing ground, landing center, date of sampling, species weight (grams), length measurements (fish length), fish identification and name, and signature of samplers or recorders. The species recorded were classified according to taxonomic identification and verified as correct using FishBase.

A total of 16,097 samples were collected, sorted per species, measured, dissected, and analyzed. Samples were dissected to determine sex, and the five-point scale (Işmen 2003) was used to identify gonad stages

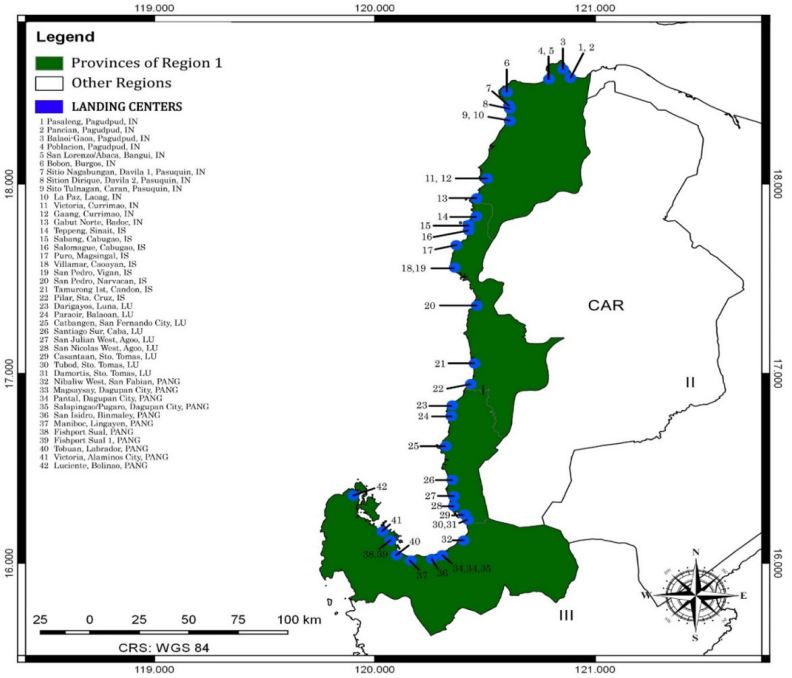

Figure 1. Map of fish landing centers in Region 1.

Table 1. Five-point scale of female gonadal maturity (İşmen 2003).

Maturity Stages	Classification	Distinguishing Characteristics
Stage I (FI)	Immature/Virgin	Young individuals have not yet engaged in reproduction; gonads are very small.
Stage II (FII)	Developing/Maturing	Sexual products have not yet begun to develop; gonads are very small; eggs are not distinguishable to the naked eye.
Stage III (FIII)	Mature/ Ripening	Female - Eggs are distinguishable to the naked eye; gonads rapidly increase in weight. Male - testes change from transparent to pale rose color.
Stage IV (FIV)	Gravid and Spawning	Sexual products are ripe; gonads have achieved their maximum weight; sexual products are extruded in response to light pressure on the belly; weight of the gonads decreases rapidly from the start of the spawning to its completion.
Stage V (FV)	Spent or Resting	The sexual products have been discharged; the genital aperture is inflamed; gonads have the appearance of deflated sacs; the ovaries contain a few leftover eggs and the testes had some residual sperms. And finally, in the resting stage, inflammation on the genital aperture has subsided; gonads are very small; and the eggs are not distinguishable to the naked eye.

(Table 1). The individual gonads were then extracted for weighing, and data were recorded in grams.

2.3. Data processing

During data encoding, all information provided on the specified forms was entered into a designed Excel format. We also checked, edited, and filtered the data using Microsoft Excel's pivot table routine to generate graphs by converting tabular data into graphical representations of catch data, length at first maturity (L_m), sex ratio, and length ranges.

2.4 Sex ratio

The sex ratios were expressed as the proportion of females to the total number of males (Sheng-Ping Wang et al. 2003) :

Sex Ratio = Fn/n

Where Fn is the monthly count of females, and n is the monthly total number of samples.

2.5 Gonadal frequency pattern

Gonadal frequency patterns were tabulated as the count of females per stage. These counts were converted to percentages for the relative frequency distribution per stage.

2.6 Gonado-Somatic Index

Gonadosomatic Index (GSI) was calculated using the equation (Daban et al. 2020):

GSI=GW/BW X 100

Where:

GW is the total wet weight of gonads

BW is the total wet body weight

2.7 Length at first maturity

Length at which 50 % of all individuals were sexually mature (L_m) was estimated from the proportion of mature individuals in each of the 5 cm length class intervals and the fitted logistic curve (Sparre and Venema 1992) as follows:

$$P = \frac{1}{1 + \exp(S1 + S2 * L)}$$

where P is the proportion of mature individuals within a length class, S1 is the intercept, S2 is the slope, and L is the midpoint length.

2.8. Population parameters

Growth parameters were initially estimated by determining the asymptotic length (L_∞) using the Powell–Wetherall method (Wetherall 1986), as implemented in the FAO-ICLARM Stock Assessment Tools (FiSAT) (Gayanilo and Pauly 1997). The method is based on the equation of Beverton and Holt (1956): $Z = k ((L_\infty - L) / (L - L'))$, where Z is the total instantaneous mortality, k is the growth coefficient, L is the mean length, L_∞ is the asymptotic length, and L' is the initial length of the sample.

The estimated value of L_∞ was further processed in ELEFAN I (ELectronic LEngth Frequency ANalysis) (Gayanilo and Pauly 1997) to verify L_∞ and k. Analysis of the estimation of growth parameters and mortality used the von Bertalanffy (1938) growth equation: $Lt = L_\infty (1–e–k(t-to))$, where Lt is the length of fish at age t, e is the base of the Napierian logarithm, and to is the hypothetical age the fish would attain at length zero.

Mortality and exploitation rate were then calculated using the equation: Z = M+F, where Z is the instantaneous total mortality, M is the instantaneous natural mortality due to predation, aging, and other environmental causes, and F is the instantaneous fishing mortality caused by fishing.

Furthermore, M was estimated using Pauly's (1984) empirical formula: Log M = 0.654 Log k – 0.28 Log L_∞ + 0.463 LogT, where L_∞ and k are the Von Bertalanffy Growth Function (VBGF) growth parameters, and T is the annual mean habitat temperature (°C) of the water in which the stock in question lives.

Expanding the mortality equation leads to the exploitation rate: E = F/Z, where E is the exploitation rate. Using the equation from growth parameters and mortalities, prediction of recruitment patterns and virtual population analysis could be estimated using the routines found in FISAT programs (Gayanilo et al. 1997).

Recruitment patterns were derived by backward projection of length-frequency data onto the length axis. The steps were: a) projection of frequencies onto the time axis after division by Δt (time to grow through a length class), producing narrower peaks; b) summation of adjusted frequencies for each month, regardless of year; c) subtraction of the lowest monthly sum to standardize the minimum to zero; and d) estimation of monthly recruitment as a percentage of annual recruitment.

Probability of capture is estimated by extrapolating the descending limb of a catch curve

to infer expected catches. The ratio of observed to expected numbers (Ni) provides the probability of capture: Pi = ln (Ni/Δt)/ ln(Nai/Δt), where Pi refers to the points for probabilities of capture, Ni is the number of observed catch or the population size, and Nai is the number of available catch, and Δt is the change in time.

Virtual Population Analysis was used to estimate the catch and to draw inference or a quantity that cannot be readily estimated: the population that produces such catches, which follows the equation: Ci/ Ni+1 = (Fi/Zi) x (e Zi-1), where Ci is the catch from a population during a unit time period (i), Ni is the population size at the beginning of the time period, Fi/Zi is the fraction of deaths caused by fishing, and e Zi – 1 is the fraction of total deaths.

Beverton and Holt's (1957) models were used to estimate relative yield per recruit and biomass per recruit. The yield model evaluates mesh size effects using length-based parameters, while the biomass model estimates average survivor biomass as a function of fishing mortality, linked to catch per unit effort. The prediction models use the equations:

$(Y/R)' = E^*U\ M/k\ (1\text{-}3U/1+m + 3U2\ /1+2m - U\ 3\ /1+3m)$

$(B/R) = \exp(-M^*(Tc\text{-}Tr))\ ^*W_\infty\ ^*\ (1/Z - 3S/Z+k + 3S2\ /Z+2k - S\ 3\ /Z+3k)$

eqn. 14

where: $m = 1\text{-}E = k/Z\ M/k$

$U = 1 - L_c/L_\infty$

$E = F/Z$

Tc – Age at first catch

Tr – Age at first recruitment

W – Weight at infinity

2.9. Mean Length

$$\frac{(ML * \text{Frequency Count per ML})}{\text{Total Fequency (N)}}$$

L_c is the length at full selectivity, determined from length-frequency data as the length with the highest catch (the mode).

3. RESULTS

The study was conducted from CY 2016–2018 to determine the reproductive performance of the selected commercially important small pelagic species in Region I. A total of 16,097 individuals were sampled from various landing centers where the National Stock Assessment Program (NSAP) conducted stock assessments. Table 2 shows the minimum and maximum lengths, along with the mean and standard deviation (SD). The measured length (TL) for *D. macarellus* ranges from 14.5 cm to 37 cm, with a mean of 33 cm and a standard deviation of 15.91. *R. brachysoma* size ranges from 12.5 cm to 32 cm, with a mean of 28.50 cm and a standard deviation of 13.79, while *R. kanagurta* length ranges from 14.6 cm to 32 cm and a mean of 30.60 and a standard deviation of 12.30. *S. boops* length ranges from 11 cm to 29.2 cm, with a mean of 25.60 and a standard deviation of 12.87, while *S. crumenophthalmus* has a size range of 12.5 cm to 28.7 cm, with a mean of 26.85 and a standard deviation of 11.46.

3.1 Sex ratio

Table 3 shows the sex ratio of selected commercially important small pelagic species in Region 1 (Figure 2). *D. macarellus* recorded a sample of 3,773 individuals, while *R.brachysoma* and *R. kanagurta* recorded samples of 1,450 and 2,098 individuals, respectively. *S. boops* recorded a sample of 1,354, and *S. crumenophthalmus* had the highest number of samples, with 7,422 individuals.

Table 2. Minimum and maximum length of selected commercially important small pelagics in Region 1.

Scientific Name	Min. Length (cm)	Max. Length (cm)	Mean	STDEV
Decapterus macarellus	14.5	37	33.00	15.91
Rastrelliger brachysoma	12.5	32	28.50	13.79
Rastrelliger kanagurta	14.6	32	30.60	12.30
Selar boops	11	29.2	25.60	12.87
Selar crumenophthalmus	12.5	28.7	26.85	11.46

Table 3. Sex ratio of selected commercially important small pelagics in Region 1.

Species	Female	Male	N	Ratio
Decapterus macarellus	1802	1971	3773	1:1
Rastrelliger brachysoma	851	599	1450	1:1
Rastrelliger kanagurta	1228	870	2098	1:1
Selar boops	725	629	1354	1:1
Selar crumenophthalmus	3885	3537	7422	1:1

	Decapterus macarellus (Cuvier, 1833) Mackerel scad
	Rastrelliger brachysoma (Bleeker, 1851) Short mackerel
	Rastrelliger kanagurta (Cuvier, 1816) Indian mackerel
	Selar boops (Cuvier, 1833) Oxeye scad
	Selar crumenophthalmus (Bloch, 1793) Bigeye scad

Figure 2. Selected commercially important small pelagics in Region I.

3.2 Gonadal frequency distribution

Figures 3a-e show the monthly gonadal frequency distribution of *D. macarellus, R. brachysoma, R. kanagurta, S. boops,* and *S. crumenophtalmus.* As shown in the figure, FI (Immature/Virgin), FII (Developing/Maturing), and FIII (Mature/Ripening) are the dominant stages in all months for all species.

D. macarellus spawns year-round, but the highest frequency can be seen in July-October, while the gonadal distribution for stage I is highest in February and March. Stage V, or the resting/spent stage, is seen from June to November.

For *R. brachysoma,* stage IV, or when eggs are extruded, is seen from April to September, with the highest peak in May-June. For *R. kanagurta*, spawning occurs from April to October, with the highest frequency in May and October. The resting stage can be seen in the months of April-November.

The spawning season of *S. boops* will start in February and continue through October, and the months of February to March show the highest

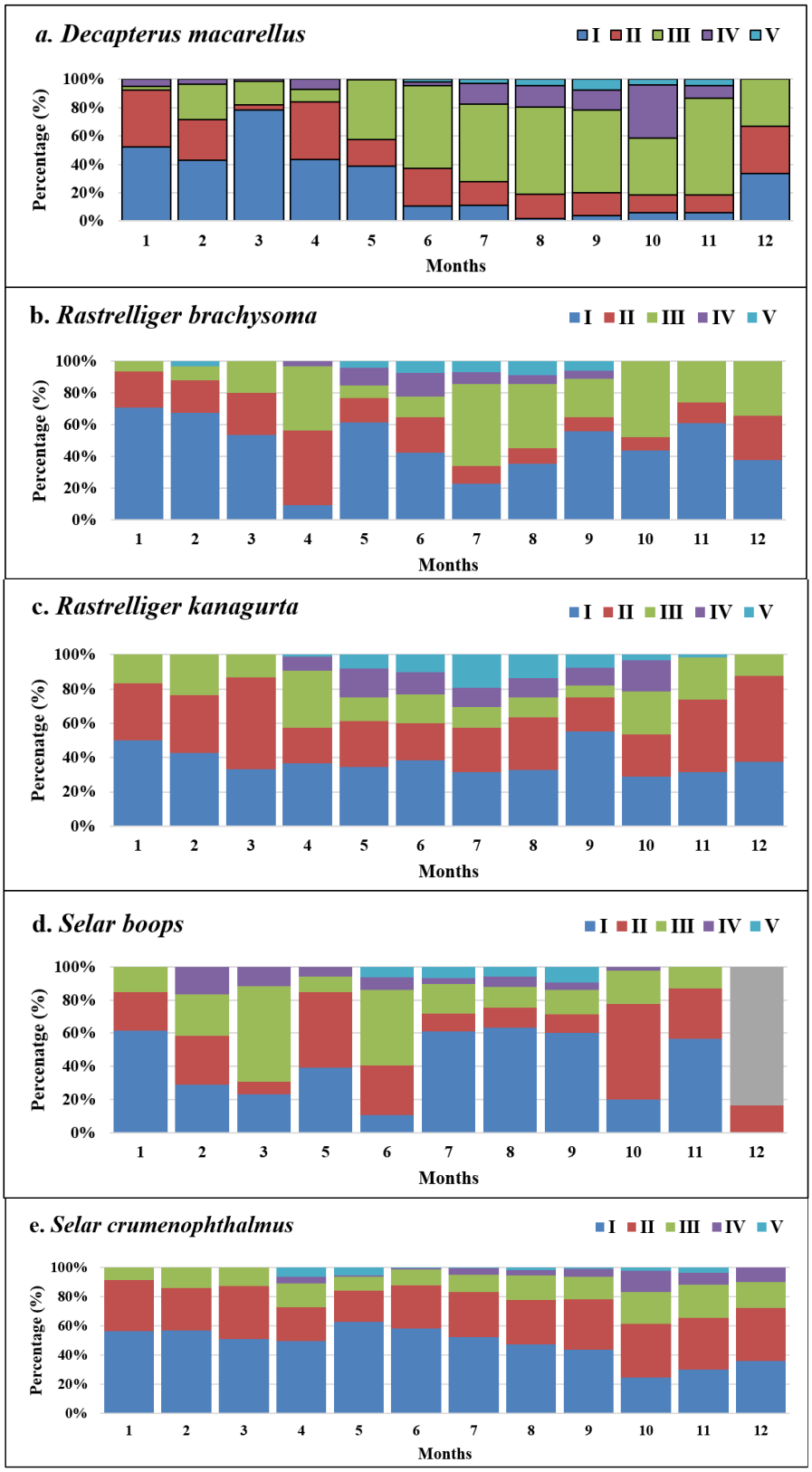

Figure 3. Monthly gonadal frequency distribution of a) *Decapterus macarellus*, b) *Rastrelliger brachysoma*, c) *Rastrelliger kanagurta*, d) *Selar boops*, e) *Selar crumenophthalmus*.

frequency. The resting stage occurs from July to September. For *S. crumenophthalmus*, stage IV occurs from April to December, coinciding with stage V (spent/resting).

3.3 Gonado-Somatic Index (GSI)

Figure 4a–4e shows the monthly mean GSI of selected small pelagics in the region. The mean GSI of *D. macarellus* ranged from 0.8 in February to 3.6 in November. R. brachysoma had the lowest mean GSI in January (0.2) and the highest in July (1.6). For *R. kanagurta,* the lowest mean GSI was recorded in December, while October had the highest mean. *S. boops* recorded the lowest mean of 0.3 in January and the highest mean in February with 2.6. *S. crumenophthalmus* recorded its lowest mean in May, while January had the highest mean.

3.4 Length at first maturity

The length at first maturity (L_m) is the average length of fish in a given population that is sexually mature for the first time (Villanueva 2018). The length at first maturity (L_m) values obtained using the logistic curve equation (Sparre and Venema 1992) for a) *D. macarellus*, b) *R. brachysoma*, c) *R. kanagurta*, d) *S. boops*, and e) S. *crumenophthalmus* were shown in Figure 5a- e.

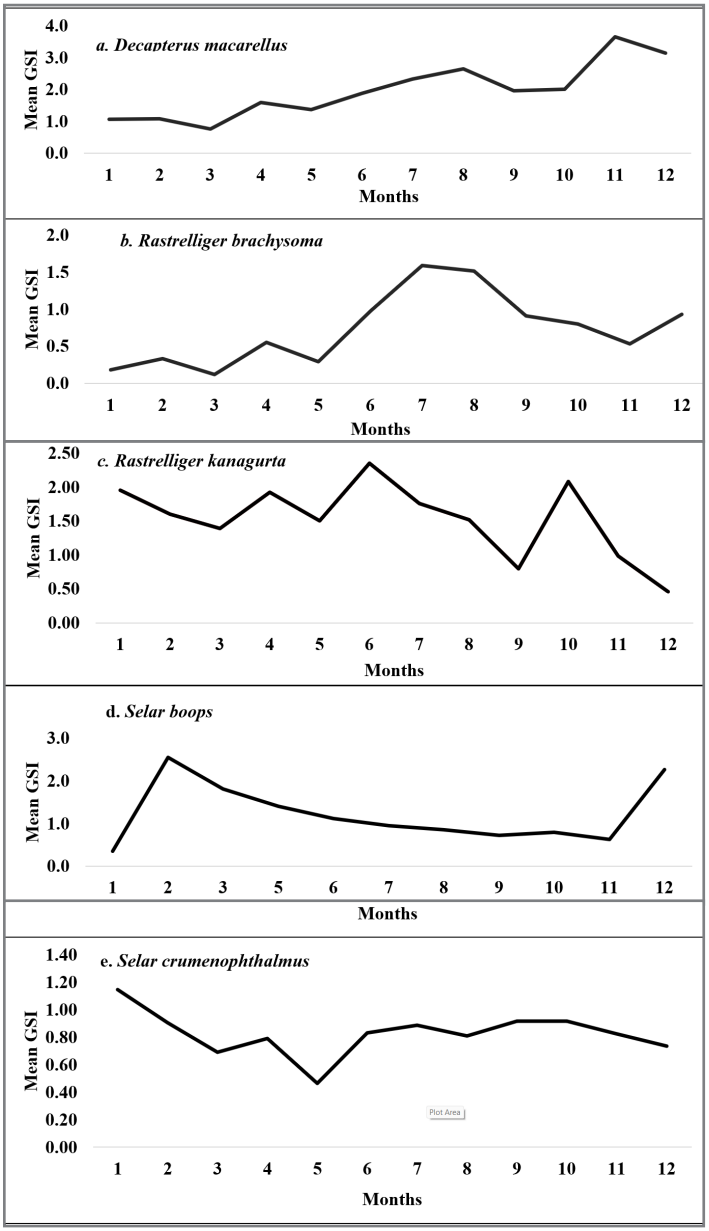

Figure 4a-4e. Monthly gonadosomatic index of female a) *Decapterus macarellus*, b) *Rastrelliger brachysoma,* c) *Rastrelliger kanagurta,* d) *Selar boops,* e) *Selar crumenophthalmus.*

D. macarellus L_m value was 19.92 cm, with the estimated starting length (SL) corresponding to the fraction retained of 20.75 cm to 25.75 cm. For *R. brachysoma*, L_m was 17.84 cm. The SL corresponding to the fraction retained was 15.25–19.25 cm. The estimated SL corresponding to the fraction retained for *R. kanagurta* was 16.25–20.25 cm. Using the logistic curve equation, the computed L_m was 18.14 cm.

For *S. boops,* the computed L_m is 18.14 cm, with SL corresponding to the fraction retained of 15.25 cm to 19.75 cm. Following the logistic curve equation, the computed value of L_m for *S. crumenophthalmus* is 19.96 cm. The estimated SL corresponding to the fraction retained was 13.25 cm to 19.25 cm.

3.5 Probabilities of capture

As shown in Table 4, the computed L_m for *D. macrellus* is 19.92 cm, which is smaller than the length at full captivity (L_{50}) of 27.55 cm and the mean length of 24.24 cm. However, the computed L_m for *R. brachysoma*, *R. kanagurta*, *S. boops,* and *S. crumenophthalmus* is almost equal to the value computed for their L_{50}.

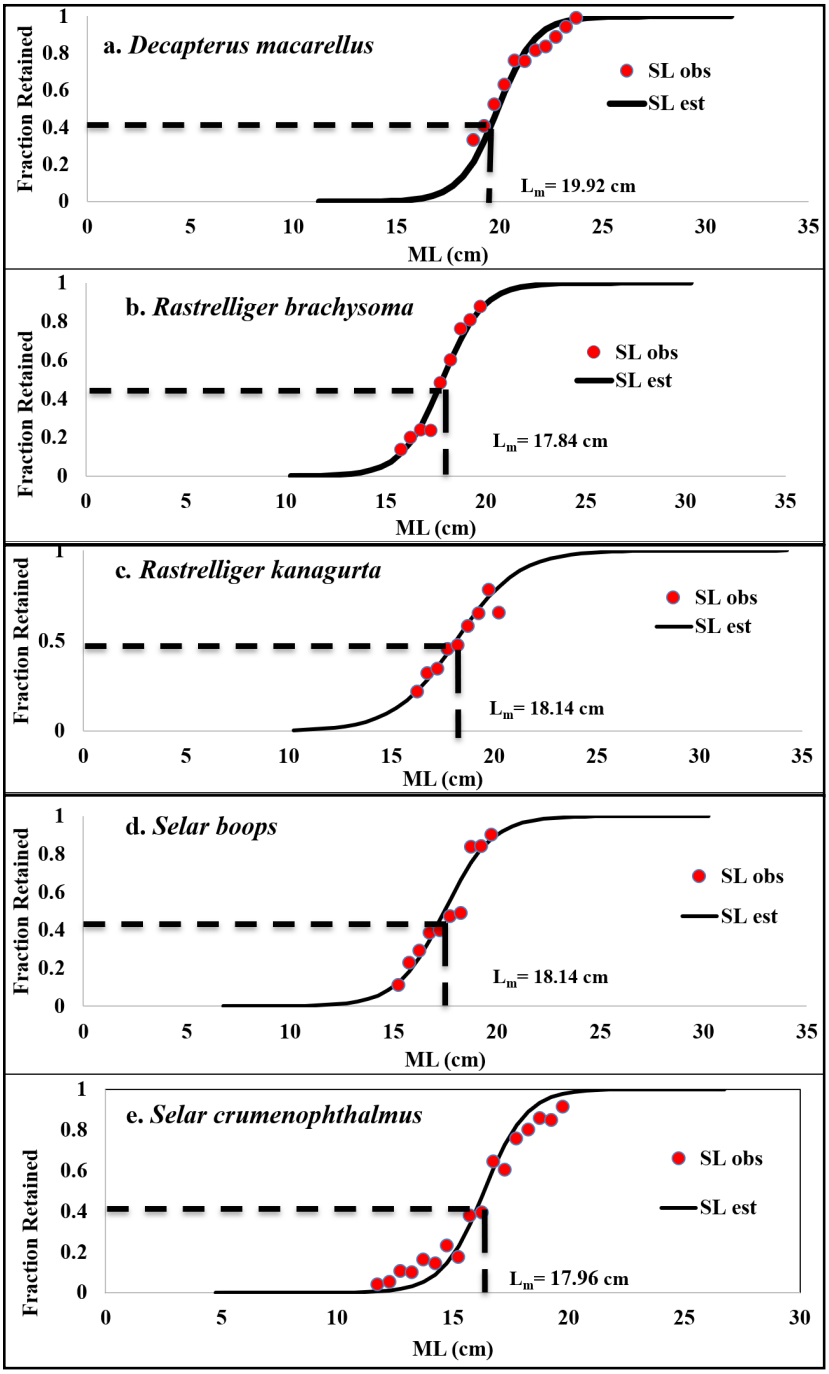

Figure 5a-5e. Computed length at first maturity of a) *Decapterus macarellus*, b) *Rastrelliger brachysoma*, c) *Rastrelliger kanagurta*, d) *Selar boops*, e) *Selar crumenophthalmus*.

The table also shows that, for *D. macarellus* and *S. boops*, the length at full selectivity is smaller than the computed L_{50} value, while for the other species, the length at full selectivity is larger than the L_{50}.

3.6 Spawning Potential Ratio (SPR)

SPR indicates the capacity to replenish the outstanding biomass in an unfished population, with a limit reference point (LRP) of 20% and a target reference point of 30–40%, as shown in Table 5.

In this study, *D. macarellus* has an SPR ratio of 33%, which falls within the target reference point (30-40%). *R. kanagurta* has an SPR of 23%, which is within the threshold of the limit reference points. However, *S. crumenophthalmus* has a very low SPR (13%), placing it at the lower limit reference point.

3.7 Length at first maturity fitted to length frequency of various fishing gears

Figure 6 shows five (5) fishing gears catching *D. macarellus*: Beach seine (BS), Gillnet (GN), Drive-in Net (DIN), purse seine (PS), ring net (RN), and hook and line (H&L). Most of the catch from the three-year data was recorded by drive-in net, purse seine, ring net and tuck seine. Using these gears, 98% of the catch was mature. The highest length frequency for DIN and RN is 24.5 cm, while for GN, PS, and H&L it is between 19.5–21.5 cm.

R. brachysoma caught using GN and T has a high length frequency approaching the Lm (17.96 cm); additionally, this species was captured by BS, T, and GN as immature individuals, as shown in Figure 7. The highest length frequencies are greater than the computed L_m, except for BS. Meanwhile, gears used to catch *R. kanagurta* extract sizes near Lm, and the highest length frequencies are also near Lm (Figure 8).

Table 4. Comparative values of length at first maturity (L_m), length at full captivity (L_{50}), mean length (L), and the mode length (L_c) f selected commercially important small pelagics.

Species Name	Length at Full Captivity (cm)	Length at First Maturity (cm)	L_{mean} (cm)	Length at full selectivity (cm)
Decapterus macarellus	27.55	19.92	24.24	25.25
Rastrelliger brachysoma	17.97	17.84	18.34	18.5
Rastrelliger kanagurta	17.54	18.14	19.37	19.5
Selar boops	18.26	18.14	17.54	16.5
Selar crumenophthalmus	17.52	17.96	18.21	18.5

Table 5. Spawning Potential Ratio of *Decapterus macarellus, Rastrelliger kanagurta,* and *Selar crumenophthalmus.*

Performance Indicators	Species	Target Reference Point	Limit Reference Point	Results	Inter-pretation	Assessment Method
SPR	*Decapterus macarellus*	30-40%	20% and below	33%	/	Barefoot Ecological Tool Box
	Rastrelliger kanagurta			23%	/	
	Selar crumenophthalmus			13%	x	

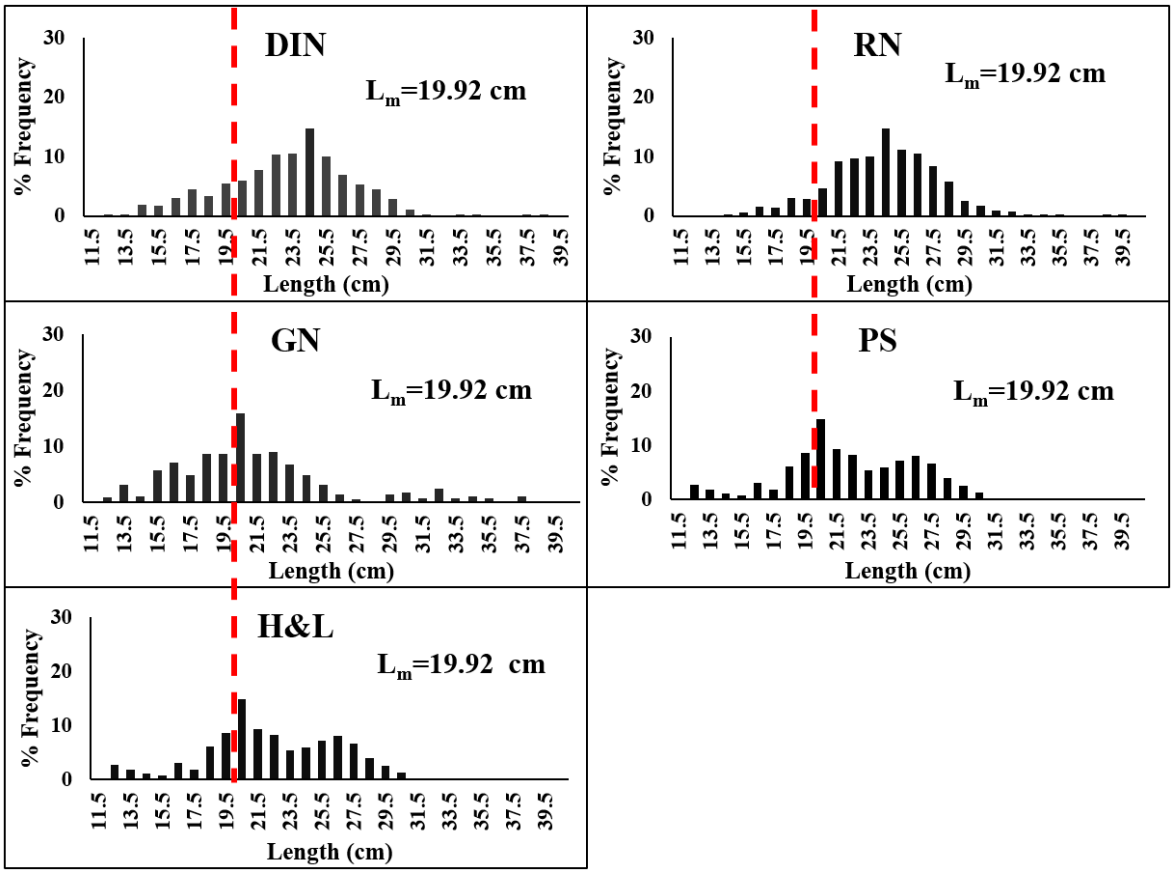

Figure 6. Length at first maturity fitted to length frequency of various fishing gears catching *Decapterus macarellus.*

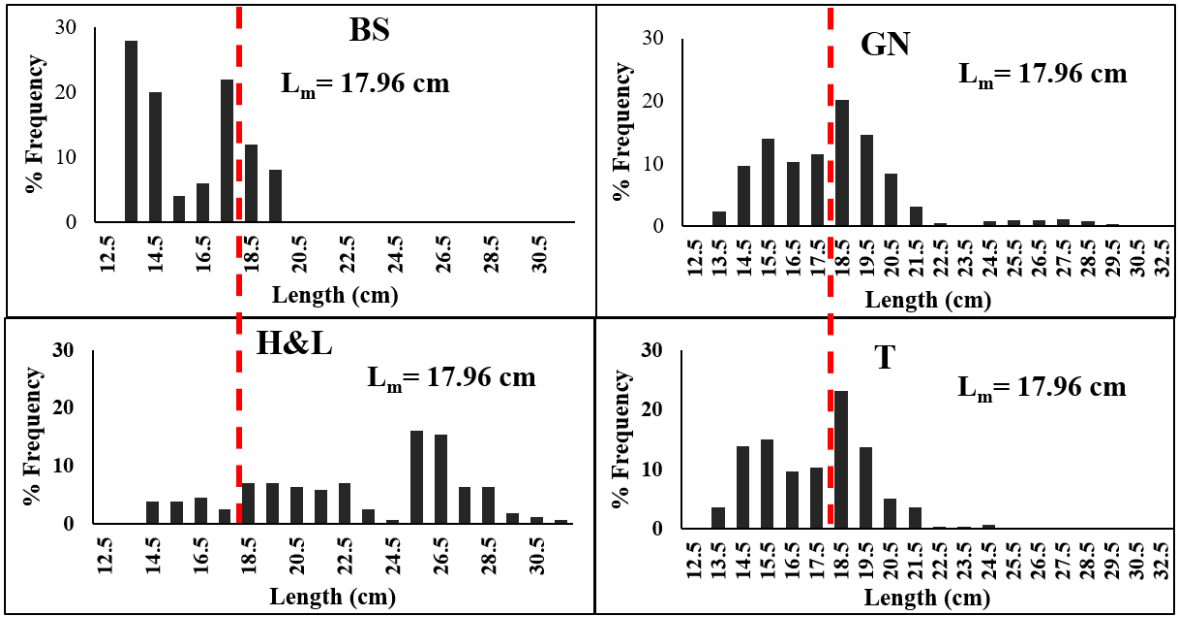

Figure 7. Length at first maturity fitted to length frequency of various fishing gears catching *Rastrelliger brachysoma.*

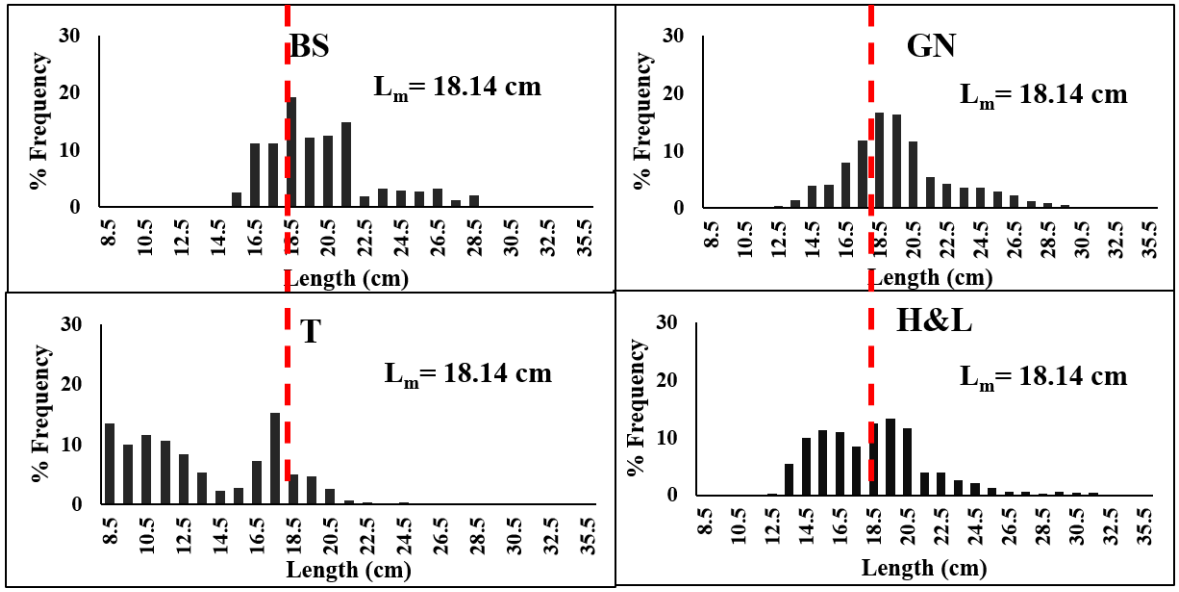

Figure 8. Length at first maturity fitted to length frequency of various fishing gears catching *Rastrelliger kanagurta.*

As shown in Figure 9, *S. boops* are caught using H&L, T, and GN. H&L show a wide range of catches for mature sizes, with the highest frequency recorded at 20.5 cm. Trawl, by contrast, recorded a high catch frequency for both immature and mature sizes, while GN captured smaller sizes relative to its Lm.

The lengths of *S. crumenophthalmus* caught by GN and T are smaller than the computed L_m of 17.96 cm, as shown in Figure 10, while H&L caught larger sizes. This indicates that these gears catch both mature and immature *S. crumenophthalmus*.

4. DISCUSSION

The results show a female-to-male ratio of 1:1, similar to the reproductive biology of common small pelagic fishes in Manila Bay, Philippines, as reported by Rivera et al. (2017).

Increasing GSI values indicate the mature or ripening stage, while decreasing GSI values indicate the gravid and spawning stages; therefore, GSI is used as a gauge in reproductive biology (Rizzo and Bazzoli 2020).

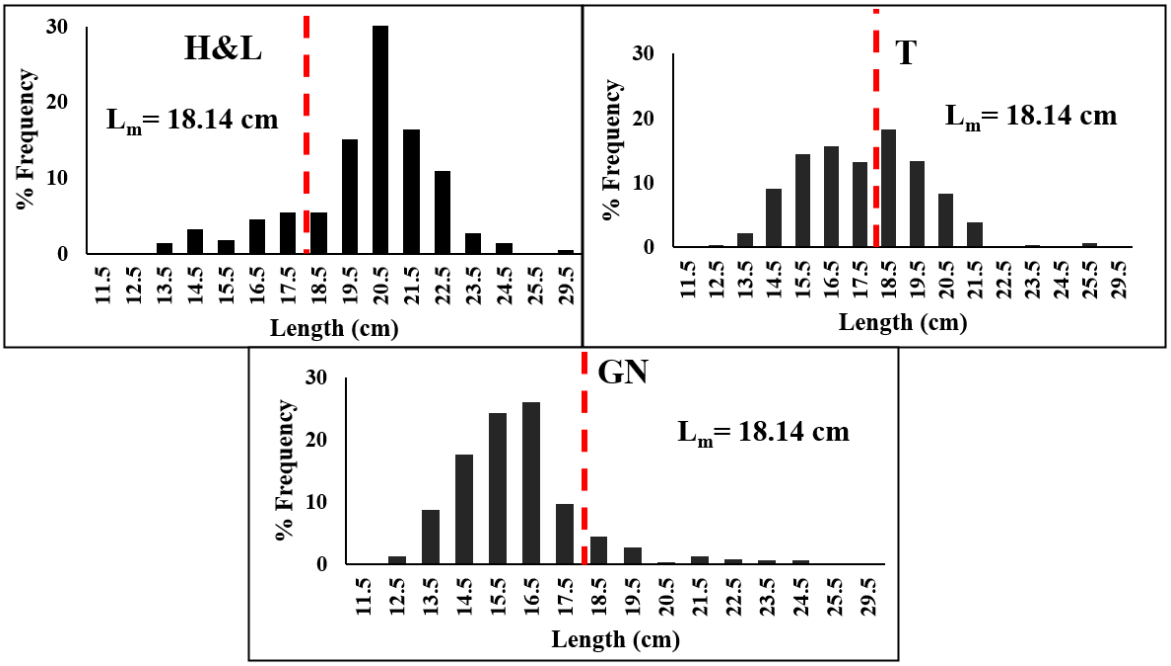

Figure 9. Length at first maturity fitted to length frequency of various fishing gears catching *Selar boops.*

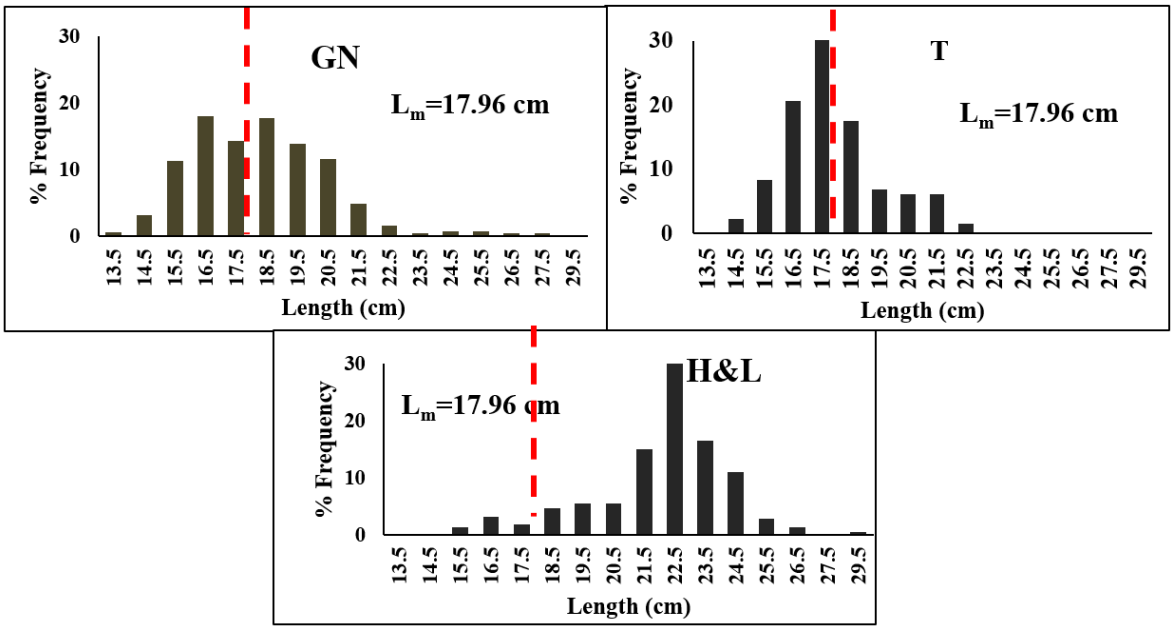

Figure 10. Length at first maturity fitted to length frequency of various fishing gears catching *Selar crumenophthalmus.*

In this study, the GSI corroborates the gonadal frequency distribution. The GSI trend increases abruptly in *D. macarellus* and *R. brachysoma*; however, in R. kanagurta, it decreases, while *S. boops* and *S. crumenophthalmus* show a nearly steady trend.

In this study, *D. macarellus* showed spawning frequency in June-November; however, Shiraishi et al. (2010) determined that the age of maturity of *D. macarellus* was 2 years, with a prolonged spawning period from April-July. Similarly, in July-November, this study found the gonads in the resting stage.

This study found that *R. brachysoma* spawns from April to September; however, Suyama et al. (2000) observed no distinct spawning season in South Sulawesi, Indonesia. For *R. kanagurta*, one spawning season occurs from April to October, with the highest

frequency in May and September. Kantun et al. (2018) reported that *R. kanagurta* gonads began developing in March, increased substantially in May, and peaked between July and August, with spawning occurring in September. On the contrary, two spawning seasons were recorded per year in the Mahout Coast, but at different periods in the span of the study conducted by Zaki et al. (2016); interestingly, a study in Indonesia by Arrafi et al. (2015) also suggested two spawning seasons that occurred in the months of January-March and August-October.

Regarding spawning seasons, *S. boops* spawns from February to October, with peaks in February-March; conversely, a study in the Moluccas Sea, Indonesia, reported spawning from October to January, with October as the peak season (Rudi et al. 2018). In *S. crumenophthalmus*, the spawning period runs from April to December; this result is comparable to Roos et al. (2007) in the southwest Indian Ocean, which found that *S. crumenophthalmus* spawns in November. However, records show it starts to reach sexual maturity in April.

Studies indicate that environmental factors might influence the biological characteristics of fish species. Delayed maturity, fewer spawns and eggs produced, and skipped spawning are consequences of a poor-quality environment that fails to provide the nutrients fish need for reproduction (McBride et al. 2015).

Length at first maturity (L_m) is the length at which 50% of the fish have reached maturity (Alba et al. 2016), while, length at full captivity (L_{50}) is the 50% probability of capture, whereas length at full selectivity (L_c) is the highest frequency of length in the catch. Compared with length at full selectivity, the computed L_{50} is larger, implying that *D. macarellus* can spawn before capture.

Results indicate a critical stage for *R. brachysoma, R. kanagurta, S. boops,* and *S. crumenophthalmus*, as their computed Lm is near their computed L_{50}. This indicates that fishing gear catching these species targets sizes at first spawning. Smaller sizes than L50 were also recorded, and L_m was also recorded at the length of full selectivity (L_c) for *S. boops*. This suggests that the method captured both mature and immature sizes.

The SPR method is based on the idea that enough fish must live to an age where they can spawn to ensure stock sustainability. This suggests that *D. macarellus* can still sustain the stock because it falls within the target reference points. In addition, this supports the results that were computed in Table 4.

R. kanagurta falls within the threshold of limit reference points, which means that the capacity of this species to replenish new stock is low. Moreover, an exploitation value of 0.62 and fishing mortality of 2.76 were also determined, both of which fall within the limit reference points. These results align with Table 3.

The computed SPR of *S. crumenophthalmus* indicates that this species cannot sustain the current biomass, as the SPR falls within the limit reference points. The exploitation rate and fishing mortality were also high, at 0.73 and 4.28, respectively. Compared with the computed length parameters for this species in Table 5, *S. crumenophtalmus* needs management intervention.

To provide more detail and support a comprehensive discussion, we fitted the length at first maturity to the percent frequency of length for various fishing gears catching *D. macarellus*, *R. brachysoma, R. kanagurta, S. boops*, and *S. crumenophthalmus* (Figures 6, 7, 8, 9, 10).

Notably, all fishing gears are catching a wide range of mature sizes. Based on the computed L_m, the catch comprises 98% mature and 11% immature. However, Table 4 indicates that *D. macarellus* is still within the range of target reference points. However, Figure 6 suggests that fishing gear regulation is needed, as these gears (RN, GN, H&L, and TS) are extracting mature fish, while GN catches immature fish.

Moreover, the exploitation rate of this species is 0.70 (FiSAT II), which falls within the limit reference points. Comparing natural mortality (1.34) with computed fishing mortality (3.15) indicates that fishing drives exploitation and that fishing gear is catching immature sizes. Correlating these mortality values with virtual population analysis shows that high fishing mortality occurs in sizes ranging from 19 cm to 21 cm.

A high frequency of catch near the length at first maturity (Lm) was recorded for GN and T for *R. brachysoma* (Figure 7). The figure also shows that BS, T, and GN extract immature fish. This clearly shows that fishing gear catching these species exploits both immature and mature sizes. Based on the computed $L_{m,}$ mature sizes comprise 53% of the total catch, while 47% are immature. Table 3 provides further evidence. Using FiSAT II, we also computed the exploitation rate, which was high (0.83) and fell within the reference limits. Compared with natural mortality, fishing mortality is higher, suggesting that fishing drives exploitation.

All fishing gears catching *R. kanagurta* show a high probability of extracting sizes near Lm (Figure 8), which depicts the same analysis with the computed

Lm and L50 (Table 3). Evidently, this supports the notion in Table 3 that there is a high probability of capturing the stocks that are first to spawn. Moreover, for immature fish, GN, T, and H&L catch the highest frequency of sizes. Relative to the computed results, the exploitation value is 0.62, which falls within the limit reference point, and fishing mortality is higher than natural mortality, indicating that fishing drives exploitation of this species.

Notably, for *S. boops*, the Lm of 18.14 cm is close to the length at full selectivity (L_c) of 18.5 cm. This depicts a high probability of catching the first-time spawner of *S. boops.* The gillnet is catching smaller sizes than the Lm and 16.5 cm being the length at full selectivity of this fishing gear. The species shows a high exploitation rate (0.78), exceeding the 0.60 limit and indicating overexploitation. FiSAT results further show that fishing mortality surpasses natural mortality, confirming fishing as the primary driver.

For *S. crumenophthalmus*, T and GN catch smaller sizes beyond the L_m (Figure 10). H&L shows a wide range of catch, and the highest frequency is observed in sizes larger than the L_m. The length at full selectivity (L_c) of this gear is 22.5 cm. The computed immature proportion based on L_m is 54.53%, while mature individuals comprise 45.47% of the total length frequency. This indicates that both the mature and immature are extracted by the gears catching this species. This result further supports Tables 3 and 4, which show that the reference points for *S. crumenophtalmus* fall within the limit.

Section 89 of Republic Act 8550, as amended by Republic Act 10654, prohibits the use of nets below the prescribed mesh size, except for collecting naturally small but mature species such as fry, glass eels, elvers, tabios, and alamang, as defined in the implementing rules. Mesh sizes used for gillnets range from 3 cm to 4 cm. This shows that fishers using this gear comply with RA 8550 as amended by RA 10654, but the study suggests that GN extracts first-time spawners and immature sizes.

DIN uses a scaring device, such as dynamite, to move fish toward the gear. Mesh sizes range from 2.34 cm to 4 cm. The 2.34 cm mesh size is used by the fishers in Puro, Magsingal, Ilocos Sur and Gabut Norte, Badoc, Ilocos Norte.

The mesh size of purse seine ranges from 2.77 to 3.3. Purse seine is a commercial fishing gear used in Fishport Sual and Luciente Bolinao, Panagasinan, while beach seine is a municipal fishing gear used 15 km from the shoreline. Mesh size ranges from 0.5 cm at the bunt to 5.08 cm.

A ring net is a commercial fishing gear with a mesh size of 1.54 cm from its bag/bunt to 4.08 cm to its wings. The target species of this fishing gear are *Katsuwonus pelamis*, *Thunnus albacares, and D. macarellus.* Comparing their catch, *D. macarellus* recorded the highest catch from CY 2016-2018.

Trawl is also a commercial fishing gear that targets demersal fishes. However, Figures 4b, 4d, and 4e suggest it also catches pelagic species. *Leiognathus spp.* are also recorded in the catch composition of this gear (CY 2016–2018), suggesting they may be operating in municipal waters. The trawl mesh size is 3.38 cm.

Link Between Growth Parameters and Reproductive Biology Results

The biological parameters of the small pelagic species analyzed provide general insights into their growth patterns, reproductive cycles, and stock status in the region. Differences in total length, mean size, and reproductive indices may reflect reproductive adaptations to existing environmental conditions and the degree of resource exploitation.

The range of sampled lengths of *D. macarellus* and *R. kanagurta* indicates that the sampled stock included both juvenile and adult cohorts, suggesting continuous year-round recruitment. These two species showed wide size distributions, which may imply multiple age groups and sustained growth consistent with extended spawning activity. This observation aligns with their gonadal frequency distributions and GSI trends, which show mature and spawning individuals occurring year-round, peaking from May to October. Results of this study support the idea and results of Longhurst and Pauly (1987), where prolonged spawning periods are typically observed in tropical pelagic species in stable environments with increased primary productivity.

On the other hand, *S. boops* and *S. crumenophthalmus* had narrower size ranges and more distinct peaks in GSI and spawning activity during particular months (*S. boops* in February and March while *S. crumenophthalmus* in January), which suggest coordinated and possibly reproductive events that are sensitive to ongoing environmental conditions.

The calculated length at first maturity (L_m) for all species further clarifies the link between growth parameters and reproductive biology. The LM value range of 17.80 cm to 20.00 cm indicates that fish individuals typically reach maturity early in their growth cycle. This early maturation may reflect the species' adaptation to intense fishing, allowing it to reproduce before being harvested (Pauly, 1980; Froese,

2004). This is the case for *D. macarellus*, where the L_m is smaller than L_{50}, suggesting the species reaches maturity early before capture. In contrast, the L_m for *S. crumenophthalmus* is roughly the same as the average size at capture, meaning current fishing practices target fish before or as they reach maturity. If this situation persists, recruitment overfishing is possible for this species.

Moreover, trends in GSI and Lm values across the five species closely correspond. Based on the results, *R. brachysoma*'s GSI values start to rise in April, then peak in June to July, indicating active spawning in fish that have reached and exceeded Lm. Similarly, *D. macarellus*' GSI values begin to increase midyear and reach their highest values from November to December, suggesting that larger mackerel scads are the major drivers of reproduction toward the end of the year. Further, *R. kanagurta*, *S. boops*, and *S. crumenophthalmus* also show increased GSI values in months when individuals exceed their respective L_m values, supporting a direct relationship between length and gonadal development, where larger body size meant higher energy allocation to reproductive processes (Murua and Saborido-Rey 2003).

Overall, the results show a clear trend: species with wider length ranges and lower Lm values, such as *D. macarellus* and *R. kanagurta*, likely have longer spawning seasons and greater resilience to overfishing and overexploitation. Conversely, species with narrower growth ranges and higher Lm values, such as *S. crumenophthalmus*, have limited reproductive windows, suggesting lower resilience to intense fishing pressure and exploitation.

5. CONCLUSION

The study revealed that the spawning seasons of the five small pelagic species: *D. macarellus, S. crumenophthalmus, S. boops, R. brachysoma,* and *R. kanagurta* fall in different quarters. In terms of SPR, only *D. macarellus* can replenish the cohort, and the other four species have a high frequency of being caught during their first spawning. This resulted in a low ability to replenish remaining biomass, which may lead to collapse. Moreover, the exploitation value of the five species exceeded the optimum value of 0.5, which signifies overfishing. This is primarily because of the rampant and unsustainable use of fishing gear such as gillnet, purse seine, hook and line, trawl, and beach seine, contributing to high catches of small pelagic species.

6. RECOMMENDATIONS

Based on the results of the study, it is hereby recommended to conduct information dissemination on the status of the selected small pelagics of Region 1 through NSAP scientific data results and findings. Gillnet, purse seine, hook and line, trawl, and beach seine catch immature sizes and first-time spawners; hence, the mesh sizes of gillnets must be regulated, and these fishing gears must be banned during the peak of spawning. Establishing a closed season is also necessary. Finally, further studies should be conducted to support the findings, e.g., genetic studies and others.

ACKNOWLEDGMENT

The authors gratefully acknowledge the Bureau of Fisheries and Aquatic Resources–Regional Fisheries Office 1 for its continued support. They also extend sincere thanks to the reviewers for their constructive comments and recommendations, and to the data analysts and enumerators for their invaluable assistance in conducting this study.

AUTHOR CONTRIBUTIONS

Reyes MA: Conceptualization, Validation, Methodology, Formal Analysis, Writing, Original Draft, Writing-Review and Editing. **Gaerlan RSP:** Supervision. **Buccat FGA:** Writing-Review and Editing, Supervision. **Noces ML**: Conceptualization, Validation, Methodology, Project Administration, Writing-Review and Editing. **Gualberto AJS**: Visualization, Investigation, Writing-Review and Editing. **Wayet FD:** Visualization, Investigation, Writing-Review and Editing.

CONFLICTS OF INTEREST

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

ETHICS STATEMENT

In this study, standards in handling and collection of data were strictly followed. Letters requesting permission to gather data were sent to the respective offices: the Office of the Governor down to the District Representatives, Municipal Mayors, and barangay captains of the villages where the selected NSAP landing sites are located in Region 1, and were granted.

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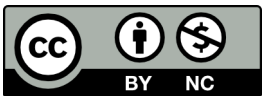

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