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RESEARCH ARTICLE

Stock Assessment of the Mackerel Scad, *Decapterus macarellus* (Cuvier, 1833) in Fisheries Management Area 6, Philippines

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ABSTRACT

This study presents a detailed length-based stock assessment of the mackerel scad (*Decapterus macarellus*) in Fisheries Management Area (FMA) 6, covering January 2014 to December 2022, to evaluate the stock's sustainability and guide future fisheries management strategies. Using length-frequency data collected from dominant fishing gears, including purse seines, ring nets, and drive-in nets, we assessed key indicators such as fishing mortality (F), exploitation rate (E), the percentage of mature fish in the population, and the biomass index ($B_{current}/B_0$). The results revealed high fishing mortality (F = 4.2M), significantly exceeding the sustainable threshold. Furthermore, only 15.7% of the catch comprised mature individuals, indicating a high risk of recruitment and growth overfishing. The exploitation rate (E = 0.80) substantially exceeds the ideal level of 0.50, indicating overexploitation of the population. The computed current biomass ($B_{current}$) was 0.18, far below the limit reference point at the MSY level of 0.32. The findings highlight the dire need for improved management measures, such as reducing fishing effort, right-sizing, gear restrictions, and seasonal closures, to ensure the long-term sustainability of *D. macarellus* stocks in FMA 6.

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1. INTRODUCTION

The Fisheries Management Areas (FMA) system in the Philippines was established through Fisheries Administrative Order No. 263, s. 2019. This policy separates the marine waters of the Philippines into 12 particular FMAs based on oceanographic characteristics, fish stock distribution, fisheries structure, and administrative divisions. The spatial delineation of areas was primarily derived from data provided by the National Stock Assessment Program (NSAP), supplemented by information obtained through public consultations. FMA 6 is the country's fourth-largest fishery management area, spanning approximately 293,930 km² and regarded as one of the Philippines' most significant and productive areas (DA-BFAR 2020). FMA 6 consists of six (6) administrative regions: 1, 3, 4A, 4B, National Capital Region (NCR), and Cordillera Administrative Region (CAR), with BFAR Region 3 serving as the FMA lead (Figure 1).

Management implementation in FMAs follows the Ecosystem-Based Approach to Fisheries Management (EAFM) framework, which strives to balance ecological and economic objectives and needs through good governance. In the FMA setting, policies are based on scientific information generated by NSAP, involving analysis of the current fish stock status and comparison to a predetermined set of reference points to produce recommended harvest control rules and measures to manage fish stocks sustainably (DA-BFAR 2020).

One of the target fishery resources to be managed is small pelagics, as they play crucial roles in

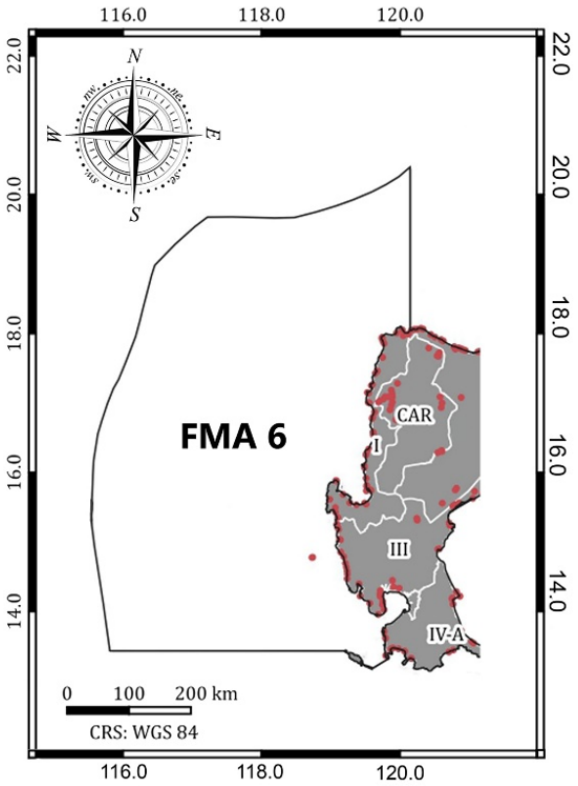

Figure 1. Administrative regions under Fisheries Management Area 6 (FMA 6).

maintaining diverse and healthy marine environments and boosting the economies of countries where they are harvested. Based on the 2022 fisheries profile report of the Bureau of Fisheries and Aquatic Resources (BFAR), the catch volume of small pelagic species reached an estimated total of 880,000 metric tons, which made up 44.2% of the total capture fisheries production in the country in that specific year (Bureau of Fisheries and Aquatic Resources 2023).

Decapterus spp. (roundscads) are considered economically significant small pelagic species in the tropical and subtropical waters of the world, where they are mostly found abundant (Shiraishi et al. 2010). Among the roundscad species commonly caught in FMA 6, the mackerel scad (*Decapterus macarellus*) is the most abundant roundscad species in production volume. At a larger scale, it is also the most dominant small pelagic species, having a share of more than half (52%) of the estimated total small pelagic production in FMA 6. *D. macarellus* is a small pelagic species within the Carangidae family and is primarily caught by ring or purse seine nets, both in commercial and artisanal fisheries (Ohshimo et al. 2006; Silooy et al. 2019; Shiraishi et al. 2010). The species can attain a maximum size of 46 cm, with a common size of 30 cm (Prado and Bearez 2004). These fishes are found in large, fast-moving schools (Ramlochan 2016), with large shoals of adult individuals inhabiting clear oceanic waters at depths of 40–200 m (Silooy et al. 2019; Ramlochan 2016; Widiyastuti et al. 2020), where tiny fishes such as anchovies are rarely or never found. Small schools of juveniles of *D. macarellus* have sometimes been reported in near-deep waters (McNaughton 2008).

D. macarellus plays a crucial role in both the national and local economy. It significantly contributes to the livelihood of small-scale fishers and commercial fishing operators in FMA 6. Often referred to as the "poor man's fish," it has been a staple in the Filipino diet, acting as an affordable source of protein (Dey et al. 2008). However, recent declines in productivity and market price increases have affected its accessibility and the socio-economic stability of fishing communities, leading to food insecurity, particularly for low-income families that depend on low-cost fish as a primary source of protein (Jimenez et al. 2020).

In recent years, major fishing areas in the Philippines have seen a decline in productivity. For instance, the volume of roundscad catch relative to 2020 production decreased by 14.6% in 2024 (Philippine Statistics Authority 2025). The Philippine Statistics Authority (PSA) reported that the total roundscad production was 172,420 MT in 2024, 191,070 MT in 2023, 172,270 MT in 2022, 181,520 MT in 2021, and 202,000 MT in 2020, showing a significant decreasing trend in catch every year (Philippine Statistics Authority 2025).

In East Java, Indonesia, the length-at-first-maturity of mackerel scad is computed at 23.93 cm TL for females and 24.03 cm TL for males, with an asymptotic length of 38.73 cm and a K value of 0.77. Moreover, total mortality (Z) was found to be 3.0, fishing mortality (F) was 2.741, and estimated exploitation value (E) was 0.905, all of which indicate overfishing (Bintoro et al. 2020). In West Java, Indonesia, a comparable study found that the length at first maturity for male mackerel scads is 23.8 cm, while for females, it is 24 cm. Most mature males and females were observed from July to December, which is indicative of the species' reproductive season (Munandar et al. 2024). Moreover, the growth parameters for mackerel scad collected from 2020 to 2021 were estimated in Southern Kyushu, Japan. Results showed that the asymptotic length of *D. macarellus* in southern Kyushu is 42.8 cm FL with a K value of 0.31 (Shiraishi et al. 2010).

In Cabo Verde, a reproductive biology study was performed to find possible connections behind the unexplained decline in mackerel scad fisheries, which revealed that the length-at-first-maturity is 24.1 cm FL for females and 26.6 cm FL for male individuals, both of which are higher than the minimum legal size of mackerel scads in Cabo Verde at 20 cm FL (Costa et al. 2020). The same study found two spawning peaks: one in March and another from July to October, suggesting that the reproductive season is from March to October. In another stock assessment study in Cabo Verde, the mackerel scad population had the following growth parameter estimates: length at first maturity = 20.3 cm, optimum length = 24.1cm, asymptotic length = 40.6 cm, K = 0.45, total mortality = 3.23, and fishing mortality = 2.31 (Vieira 2018).

Existing literature on mackerel scad offers minimal information regarding the production and stock status of the species in the country, let alone in fishing grounds inside FMA 6. Recent reports show a declining trend in roundscad and other small pelagic catches, highlighting the urgent need to comprehensively assess the status of *D. macarellus* as a representative small pelagic species to guide the sustainable management of small pelagic fisheries. One way to evaluate the condition of fish stock is through length-based stock assessment, a beneficial tool, particularly in data-limited fisheries like those found in the Philippines. Through analysis of the length-frequency distribution of *D. macarellus*, researchers can assess the subject species' growth, mortality, maturity, and exploitation levels. This study applied length-frequency analysis to determine key stock indicators such as fishing mortality, exploitation rates, the percentage of mature fish in the population, and the biomass index, which are used to assess population status and provide recommendations for sustainable fisheries management.

Effective resource management of mackerel scad stocks demands a robust framework of performance indicators and harvest control rules (HCRs), as well as harvest control measures (HCMs), to ensure sustainable exploitation and conservation of the species. HCRs are developed based on biological reference points (Mota 2020) to mitigate marine resource exhaustion and develop sustainable fishery management (Harlyan et al. 2019). These predefined rules are designed to prevent overfishing and ensure the long-term viability of the fishery (Apostolaki and Hillary 2009; Free et al. 2022). In recent decades, HCRs have become important tools in modern fisheries management because of their adaptability to uncertainty and ecosystem considerations. HCMs, on the other hand, are the specific tools and regulations used to implement HCRs. They include measures such as gear restrictions, minimum size limits, and catch quotas (Rosenberg et al. 2006). Effective HCMs for mackerel scad in FMA 6 must be customized to existing local fishing practices and ecological conditions. These measures are critical for achieving the objectives set out by the prescribed HCRs.

This study was conducted to assess the exploitation status of *D. macarellus* in FMA 6 using length-frequency data collected from commercial fisheries employing three major fishing gears: purse seine, ring net, and drive-in net. The study evaluated key stock indicators to determine whether the species is being overfished. The findings of this study will also serve as scientific bases for the formulation of specific and targeted fisheries management interventions (HCRs and HCMs) to advance the sustainability of *D. macarellus* in FMA 6 and safeguard the livelihoods of those who depend on this vital fishery resource.

2. MATERIALS AND METHODS

2.1 Research method and design

The study utilized the quantitative research design to determine the annual yield, distribution, seasonality, catch estimates per fishing gear, catch per unit effort (CPUE) of major gears, exploitation, percent mature, percent optimal-sized fish, and percent megaspawners; current biomass and virgin biomass ratio ($B_{current}/B_0$); and harvest control rules (HCRs) and harvest control measures (HCMs) appropriate for the mackerel scad population in FMA 6 based on 2014 to 2022 NSAP data. The research method consisted of data collection through fisherfolk interviews, actual weighing of catches, and measuring sample sizes of landed *D. macarellus* catch.

2.2 Location of the study

From 2014 to 2022, a total of 52 landing sites in FMA 6 monitored by NSAP have records of *D. macarellus* landings. There were ten (10) commercial landing sites (more than 3 GT fishing boats), 37 municipal landing sites (3 GT and below fishing boats), and five (5) sites with both municipal and commercial landings. Landed catch volumes and fishing gear utilized by boats per landing site were surveyed and monitored by NSAP enumerators (Figure 2).

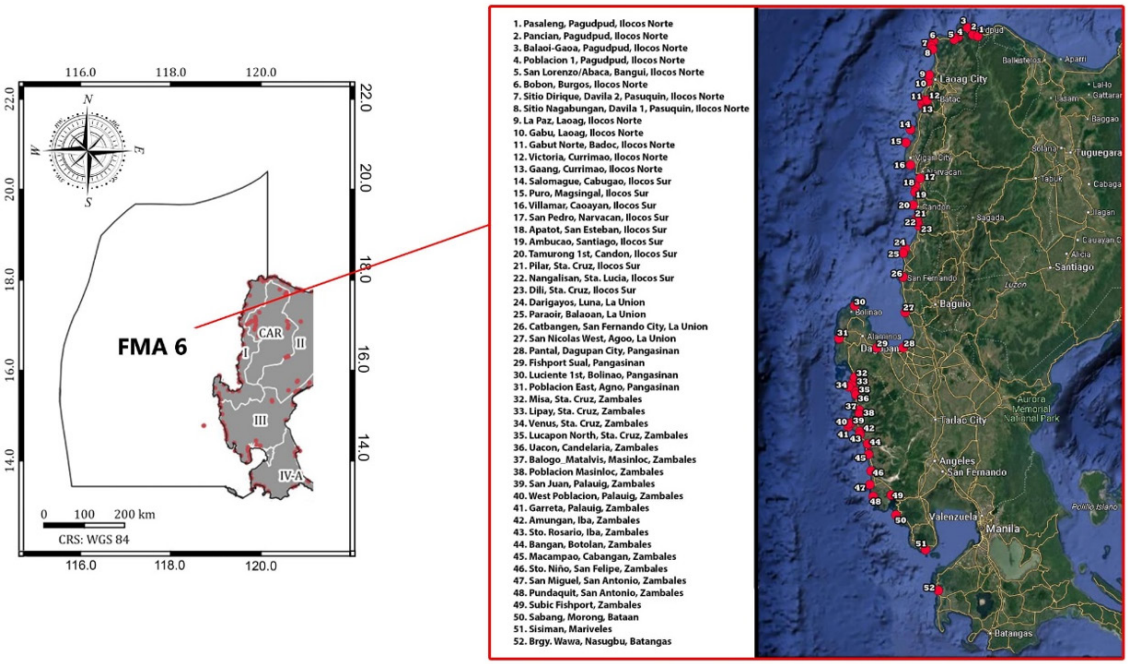

Figure 2. Map of NSAP-monitored landing sites in FMA 6 with mackerel scad (*D. macarellus*) landings from 2014 to 2022.

2.3 Data gathering procedures

Monitoring of catch and effort data on NSAP landing sites was conducted every other two days regardless of Saturdays, Sundays, and holidays following the NSAP standard methodology. The first day of sampling is intended to monitor major landing sites, while the second day is for conducting sampling surveys on minor landing sites. Sampling is continuous for the whole month, totaling 10 or 11 sampling days (for those months with 31 days). All pertinent data on the landed catch were recorded using the NSAP standard monitoring form.

2.4 Data treatment and analysis

Gathered data were encoded in and culled from the NSAP database. Further, the researchers used MS Excel to transform the data into graphs and tables using the Pivot function to obtain all necessary indicators.

2.4.1 Catch estimates

The estimated monthly catch per gear per site was derived from the monthly total catch of boats per gear per site multiplied by a raising factor based on fishery sector and fishing days. Commercial sites multiply their monthly catch by 1, while municipal sites multiply their monthly catch by either 2.8, 3.0, or 3.1, depending on the number of days in a particular month. This is done to have better monthly catch estimates that are as close as possible to the actual values of monthly catch.

2.4.2 Seasonality

The seasonality pattern of *D. macarellus* was based on the monthly catch or total yield from all gears and sectors from 2014 to 2022.

2.4.3 Growth and mortality parameters

To estimate the asymptotic length (L_∞), the Powell-Wetherall method (Gayanilo and Pauly 1997) based on the Beverton and Holt (1956) equation was utilized.

$$Z = k ((L_\infty - L)/ (L - L'))$$

Where: Z = total instantaneous mortality,
K = growth coefficient,
L = mean length,
L_∞ = asymptotic length, and
L' = the initial length of the sample.

ELEFAN I (Electronic Length Frequency Analysis) was used to estimate the values for L_∞ and K. The von Bertalanffy (1934) growth equation below was used for analysis of fish growth.

$$Lt = L_\infty (1-e^{-k(t-t0)})$$

Where: Lt = length of the fish at age t,

e = the base of the Naperian logarithm, and

t0 = the hypothetical age the fish would attain at length 0.

The values of mortality rate were computed using the equation:

$$Z = M+F$$

Where: Z = the instantaneous total mortality,

M = the instantaneous natural mortality due to predation, aging, and other environmental causes, and

F = the instantaneous fishing mortality.

Furthermore, M was estimated using Pauly's (1984) empirical formula:

$$\text{Log } M = 0.654 \text{ Log } k - 0.28 \text{ Log } L_{\infty} + 0.463 \text{ Log } T$$

Where: L_{∞} and k = von Bertalanffy Growth Function (VBGF) growth parameters, and

T = the annual mean water temperature (°C) of the habitat.

The length-converted catch curve (LCC) method was utilized to get the estimate of total mortality, Z (Gayanilo et al. 2005).

The exploitation rate is computed using this formula (Gulland 1971):

$$E = F/Z$$

Where: E = exploitation rate, and F and Z are as previously defined.

2.4.4 Life history tool in FishBase

To estimate length-at-first maturity (L_m), natural mortality (M), approximate life span, and length-weight relationships (a and b), the life history tool in FishBase was used.

The length at first maturity (L_{m50}) was estimated using this formula (Hoggarth et al. 2006):

$$L_{m50} = \frac{2L\infty}{3}$$

Where: L_{m50} = the length at first maturity (cm), and

L_{∞} = the asymptotic length.

In this equation, L_{m50} represents the length at which 50% of the fish population reaches sexual maturity (in cm), while L_{∞} is the asymptotic length.

2.4.5 The Froese Sustainable Indicator Tool

To assess the status and trends of *D. macarellus*, three easily understood indicators are estimated using the length-frequency of the catch. The percentage of mature fish, optimal-sized fish, and megaspawners are calculated using life history parameters, maximum length (L_{∞}), and length-frequency catch data (Froese, 2004).

The optimum length of the fish caught (L_{opt}) and recruitment pattern were analyzed in this study. L_{opt} was calculated using the formula by Froese and Binohlan (2000):

$$L_{opt} = 3 \times L_{\infty} / (3 + M/K)$$

Where: L_{opt} = the optimum length of the fish caught,

L_{∞} = the asymptotic length, and

M = the natural mortality rate, and

K = the growth coefficient.

The recruitment pattern was analyzed using the FiSAT II software.

2.4.6 The Mean Length Assessment (L_{bar})

The L_{bar} employs either fishery-dependent or fishery-independent length frequency information to assess fishing pressure. The estimate of fishing mortality is derived from the minimum (L_c), maximum (L_{∞}), and average length found in the catch, in addition to the estimates of the von Bertalanffy growth parameter K and natural mortality. Moreover, the initial length at full selectivity was used to estimate fishing mortality. By assuming that F_{msy} is equal to natural mortality, this approach enabled the researchers to compute F/F_{msy}. The L_{bar} control rule subsequently adjusts fishing pressure based on how far the current F/F_{msy} is from the desired F/F_{msy}.

2.4.7 The Stock Assessment Continuum Tool (previously Stock Synthesis Data-Limited Tool)

To estimate the biological parameters like Maximum Sustainable Yield (MSY), biomass ratio associated with MSY, carrying capacity, current biomass, and natural recruitment variation, the researchers used the Stock Assessment Continuum Tool / SSDL developed by Dr. Jason Cope (NWFSC - NOAA), which uses Stock Synthesis (SS3) (Methot and Wetzel 2012). The tool builds Stock Synthesis input files for provided data and life history information. It produces full plots and tables for each model run via the {r4ss} package and additional screen output for straightforward interpretation. The full walkthrough on how to run and conduct assessments using the Stock Assessment Continuum Tool is accessible through this link: https://github.com/shcaba/SS-DL-tool. GrabSPR was used to cull out the biomass indices based on the SAC Tool results.

3. RESULTS

3.1 Species description

The following descriptions of *D. macarellus* was based on Carpenter and Niem (1999) (see Box 1).

3.2 Catch Trend

The total annual landings of mackerel scad (*D. macarellus*) monitored across 52 landing sites in FMA 6 from 2014 to 2022 are shown in Figure 3. Based on metric ton (MT) values, the landings trend increased within the 9-year data collection period. The peak years were observed in 2019 (2396.92 MT) and 2022 (2303.82 MT). On the other hand, the lowest annual landings were in 2014, with 920.73 MT, which is about 38.4% of peak 2019 landings.

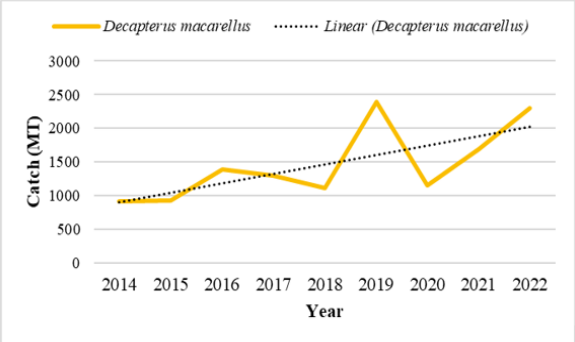

Figure 3. Catch trend of *D. macarellus* in 52 landing sites in FMA 6 (2014–2022).

Box 1. Species (*D. macarellus)* description.

Scientific Name: *Decapterus macarellus* (Cuvier, 1833)
Taxonomic Classification:
Kingdom: Animalia
Phylum: Chordata
Class: Actinopterygii
Order: Perciformes
Family: Carangidae
Genus: *Decapterus*
Species: *Decapterus macarellus*
English Name: Mackerel scad
Common name: Galunggong, GG, Palapal, Baraniti

Diagnostic features

- Has an elongated body, with a cross-section revealing a slender and near-round shape;
- Developed adipose eyelid that covers most of the eye;
- Scales on the top of the head that extend forward to the anterior margin of the pupil;
- Oral valve located at the symphysis of the upper jaw (visibly white in adults);
- Posterior end of upper jaw straight above, moderately rounded, and noticeably slanted anteroventrally, with both jaws having no teeth;
- 10 to 13 gill rakers on the upper limb and 34 to 41 gill rakers on the lower limb of the first gill arch;
- Cleithrum margin with two small papillae;
- Dorsal fins that are separated, the first fin having VII spines while the second fin has I spine with 31 to 37 soft rays;
- Anal fin with II detached spines followed by I spine and 27 to 31 soft rays;
- Anal and terminal dorsal fins consisting of detached finlets;
- Short pectoral fins;
- Tip of appressed fins falling considerably short of a vertical line from second dorsal-fin origin;
- Lateral line anteriorly with a low regular arch, with junction of curved and straight parts below vertical from eleventh to thirteenth soft rays of second dorsal fin;
- 58 to 75 scales in the curved part of the lateral line;
- Absence of scutes in the curved part; the straight part with 18 to 39 scales, followed by 24 to 40 scutes, with 110 to 138 total scales and scutes in the lateral line; and
- Vertebrae 10+14.

Color

D. macarellus is bluish green in color above while silvery below, with a small black blotch on the margin of the opercle near the upper edge; the caudal fin is yellow-green and the dorsal fin lobe is sometimes dark distally; and the anal and pelvic fins are pale to whitish.

Size

The size of *D. macarellus* is commonly 26 cm FL; the largest measured specimen was 30 cm FL and 32 cm TL.

Habitat, Biology, and Fisheries

- Schooling species are found in open waters and are common in insular habitats.
- Sometimes found near the surface but caught between 40 and 200 m in depth.
- Main diet consists of small planktonic invertebrates.
- Commonly caught using trawl and purse seines.

Distribution

- Circumtropical species, widespread throughout the tropical Indian Ocean, including the Red Sea but not the Persian Gulf; in the Indo-West Pacific to the Marquesas Islands, north to southern Japan, and south to Australia.

3.3 Distribution

D. macarellus in FMA 6 was landed, measured, and sampled from these following NSAP sites (Table 1).

3.4 Catch estimates per fishing gear

There were 20 kinds of fishing gear recorded catching mackerel scad in FMA 6, and using the fishing gear classification by Dickson et al. (2003), the

Table 1. Occurrence distribution of mackerel scad (*D. macarellus*) in 52 landing sites in FMA 6 (2014-2022). The (/) mark indicates a positive occurrence.

Region	Fishing Ground	Landing Site	Sector	
			Commercial	Municipal
Region 1	Lingayen Gulf	Fishport Sual, Pang.	/	
		San Nicolas West, Agoo, LU		/
		Pantal, Dagupan City, Pang.	/	
	Zambales Coast (Dasol Bay + WPS)	Luciente 1st, Bolinao, Pang.	/	
		Poblacion East, Agno, Pang.	/	/
	Ilocos Coast (NWPS)	Darigayos, Luna, LU		/
		Paraoir, Balaoan, LU		/
		Catbangen, San Fernando City, LU		/
		Ambucao, Santiago, IS		/
		Apatot, San Esteban, IS		/
		Dili, Sta. Cruz, IS		/
		Nangalisan, Sta. Lucia, IS		/
		Pilar, Sta. Cruz, IS		/
		Puro, Magsingal, IS	/	
		Salomague, Cabugao, IS	/	
		San Pedro, Narvacan, IS		/
		Tamurong 1st, Candon, IS		/
		Villamar, Caoayan, IS		/
		Gaang, Currimao, IN		/
		Gabu, Laoag, IN		/
		Gabut Norte, Badoc, IN		/
		La Paz, Laoag, IN		/
		Sitio Dirique, Davila 2, Pasuquin, IN		/
		Sitio Nagabungan, Davila 1, Pasuquin, IN		/
		Victoria, Currimao, IN		/
	Pasaleng Bay	Balaoi-Gaoa, Pagudpud, IN		/
		Pancian, Pagudpud, IN		/
		Pasaleng, Pagudpud, IN		/
	Bangui Bay	San Lorenzo/Abaca, Bangui, IN		/
		Poblacion 1, Pagudpud, IN		/
		Bobon, Burgos, IN		/
Region 3	West Philippine Sea	Balogo-Matalvis, Masinloc, Zambales	/	
		Misa, Sta. Cruz, Zambales	/	/
		Sabang, Morong, Bataan		/
		Sisiman, Mariveles	/	/
		Subic Fishport, Zambales	/	/
		Venus, Sta. Cruz, Zambales	/	/
	Zambales Coast	Amungan, Iba, Zambales		/
		Bangan, Botolan, Zambales		/
		Garreta, Palauig, Zambales		/
		Lipay, Sta. Cruz, Zambales		/
		Lucapon North, Sta. Cruz, Zambales		/
		Macampao, Cabangan, Zambales		/
		Poblacion Masinloc, Zambales		/
		Pundaquit, San Antonio, Zambales		/
		San Juan, Palauig, Zambales		/
		San Miguel, San Antonio, Zambales		/
		Sto. Niño, San Felipe, Zambales		/
		Sto. Rosario, Iba, Zambales		/
		Uacon, Candelaria, Zambales		/
		West Poblacion, Palauig, Zambales		/
Region 4A		Brgy. Wawa, Nasugbu, Batangas		/

gear types identified were surrounding nets (purse seine, ring net, and baby ring net), gillnets (gillnet, bottom set gillnet, and drift gillnet), scoop net, drive-in-net, hook & lines (handline, multiple hook & line, multiple troll line, and troll line, bottom set longline), trawls (trawl, otter trawl), seine nets (beach seine, Danish seine), lift net (fish lift net, bagnet), and traps (fish corral).

Based on raised landings values, purse seine dominated the total mackerel scad production of FMA 6, contributing 5,097.41 MT (39%). Drive-in-net followed in catch volume share with 4,592.99 MT (35%), then ring net with 3,291.14 MT (25%), while other gears contributed a total catch of 204.46 MT (1%) (Figure 4).

3.5 Seasonality

In FMA 6, peak catch volumes for mackerel scad (*D. macarellus*) were observed from April to July of each year, while the lean months were seen from November to March, although the fish species is caught all year round (Figure 5). The observation in this study is comparable to the reported seasonality pattern of *D. macarellus* in the Malacca Strait, where good fishing seasons were noted in January, March to May, June to August, and November (Fadhilah et al. 2021).

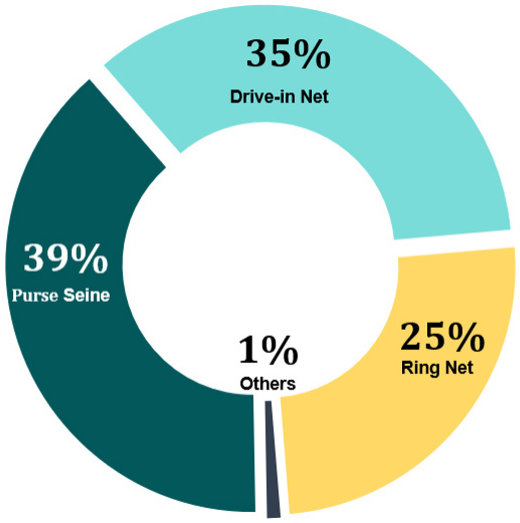

Figure 4. Relative catch percentage of fishing gears used in catching *D. macarellus* in FMA 6.

3.6 Population parameters

3.6.1 Growth

Growth parameters are the estimates of the physical and biological characteristics of fish species being subjected to analysis. The graphs below present the length frequency distribution superimposed with the von Bentalanffy Growth Function (VBGF) curve of *D. macarellus* in a restructured and unrestructured output (Figures 6a & 6b).

There were 91,507 mackerel scad individuals measured for this study, with a minimum midlength of 5.50 cm and a maximum midlength of 45.5 cm. Following FISAT analysis, the determined L_∞ for *D. macarellus* in FMA 6 was 42.6 cm, which is the maximum theoretical length that *D. macarellus* can reach. This asymptotic length is larger than most of the values reported in FishBase: Philippines (Guimaras Strait): 19.8 cm (FL), 24.3 cm (TL); Taiwan/Ch Taipei (Taiwan Strait and adjacent waters): 31.4 cm (TL); and Sri Lanka (Southwest coast): 41.2 cm (FL). The calculated L_∞ of 42.6 cm is only slightly larger than the value from Sri Lanka, which is 41.2 cm. This suggests that *D. macarellus* has the potential for larger growth than the fish populations in the regions listed. This may indicate favorable conditions in the West Philippine Sea (e.g., habitat, food availability) compared to the other areas.

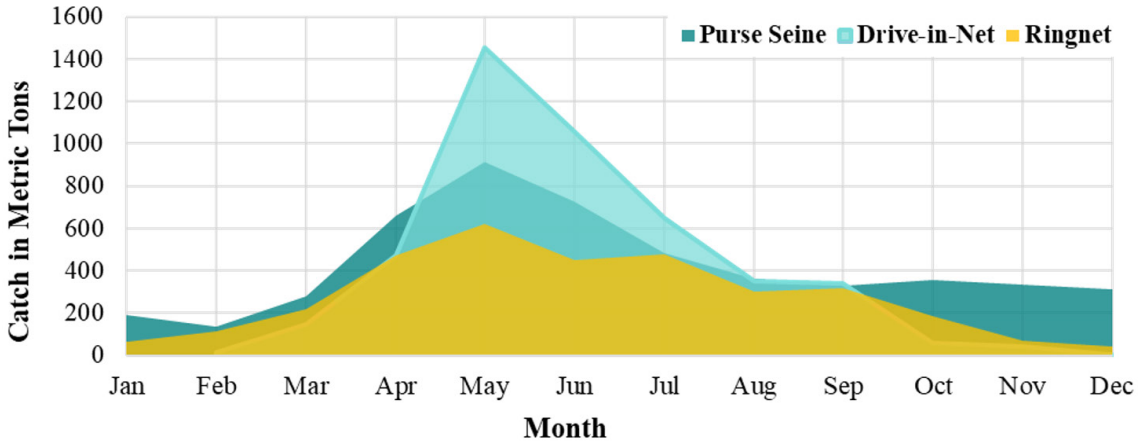

Figure 5. *D. macarellus* seasonality from 2014 to 2022.

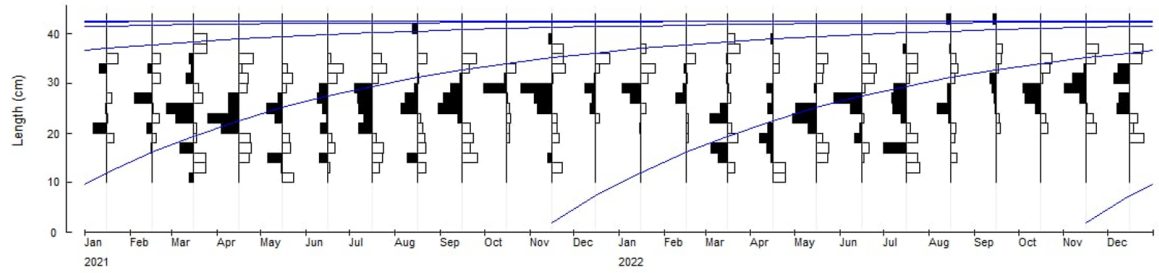

Figure 6a. Restructured VBGF and length frequency plot of *D. macarellus* (2021–2022).

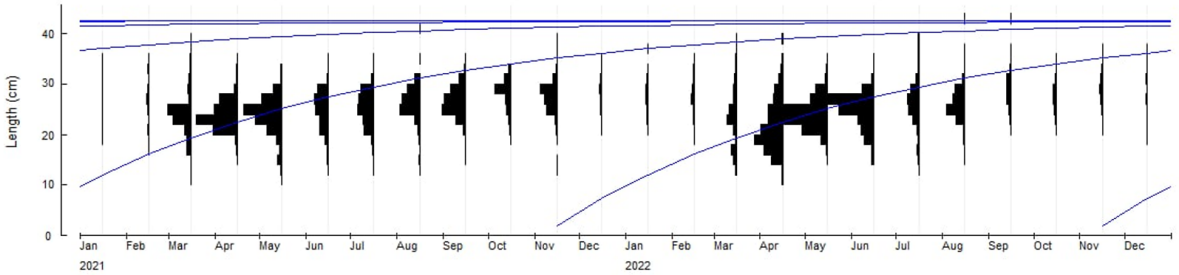

Figure 6b. Unrestructured VBGF and length frequency plot of *D. macarellus* (2021–2022)

The K value was estimated to be 1.71. K value refers to the relative index of growth of species, with species having a K value of more than 1.0 (K > 1.0) considered as fast-growing species, while a value of less than 1.0 (K < 1.0) means that the species is slow-growing (Ramos et al. 2018). The computed K value for mackerel scad denotes that it is a relatively fast-growing species.

The calculated K value (which represents the rate of growth) is 1.71, which is higher than the values listed in FishBase: Philippines (Guimaras Strait): 1.0; Philippines (Pujada Bay): 1.8; Taiwan/Ch Taipei: 0.28; and Sri Lanka (Southwest coast): 0.8. The K-value of 1.71 indicates that *D. macarellus* has a relatively faster growth rate compared to the populations in some regions in the Philippines and Sri Lanka. However, the computed K value for mackerel scad in FMA 6 for this study is still slightly lower than the K value of 1.8 reported for Pujada Bay, Philippines. Faster growth rates or higher K values could suggest better growth conditions or a younger population structure in the West Philippine Sea. Conversely, lower K values (as observed in Taiwan and Sri Lanka) may indicate slower growth, potentially due to environmental constraints such as temperature, habitat quality, or food availability.

Moreover, the calculated Φ' value is 3.49, which is an indicator of overall body condition and the growth performance of the species. The values listed in FishBase are Philippines (Guimaras Strait): 2.59; Philippines (Pujada Bay): 3.03; Taiwan/Ch Taipei: 2.44; and Sri Lanka (Southwest coast): 3.13.

The Phi-prime (Φ') of 3.49 is the highest value among the reported results, suggesting that the *D. macarellus* in the West Philippine Sea may have better overall growth conditions. A higher Φ' generally correlates with better body condition and a more favorable growth environment. This implies that the fish in a study area are likely benefiting from superior habitat conditions or less fishing pressure than those in the other regions, especially considering the Φ' values from Taiwan (2.44) and the Philippines (2.59).

The fish population in the West Philippine Sea appears to have favorable growth conditions, as indicated by the relatively high L_{∞}, K value, and Φ'. However, further studies are recommended to evaluate other factors influencing growth, such as food availability, habitat quality, and anthropogenic impacts.

Using Length-based Models (L_{bar}), the length-at-full-selectivity (L_c) or the length with the most catch by frequency (mode) and L_{bar} or average lengths (L_{ave}) per year are given in Table 2. The annual average lengths of caught mackerel scad were higher than the computed length-at-first-maturity (L_m), which was 24.3 cm TL (Table 2). L_m refers to the average length at which a fish of a given population matures for the first time (Froese et al. 2005) or the average length at which 50% of a fish population has reached reproductive maturity (Pérez-Palafox et al. 2022). In this case, the L_{bar} being higher than L_m indicates that, on average, the fish landings are larger than the size required for maturity — implying good for sustainability.

Table 2. Values of growth parameters of *D. macarellus* (2014-2022).

Growth Parameters	Length (cm)									Assessment Method
	2014	2015	2016	2017	2018	2019	2020	2021	2022	
L_c	24.5	23.5	25.5	23.5	25.5	26.5	25.5	24.5	25.5	L_{bar}/LF Data
L_{ave} (L_{bar})	26.84	26.16	27.51	26.31	27.39	28.13	27.54	27.1	27.83	
L_∞					42.64					FiSAT
L_m					24.3					FishBase Life History Tool
L_{opt}					29.5					FROESE
K					1.71					FiSAT
Phi-prime (Φ')					3.49					FiSAT

The optimum length (L_{opt}) was computed using the nine-year data of *D. macarellus* is 29.50 cm TL (Figure 7). The L_{opt} for a fish stock is the intermediate length class at which the product of individuals and average weight reaches the maximum (El-Ganainy and Riad 2008). The fishery would reach the maximum possible yield and economic value if it were to catch only fish within the optimum size range (Froese 2004). Selectively capturing optimally sized fish directly allows juveniles to reach maturity and for megaspawners to live longer and produce offspring.

3.6.2 Mortality

In fish stock assessment, total mortality is divided into fishing mortality (F) and natural mortality (M). Optimal exploitation is commonly defined where F = M (F/M = 1) (Gulland 1971). Fishing mortalities derived for *D. macarellus* were higher than its natural mortality from 2014 to 2022. The target reference point for F/M should be ≤ 1, but the results for all the years revealed that F/M > 1, which falls within the limit reference point. This signifies that the fish stock has experienced intense fishing pressure. The value of total mortality (Z) was estimated to be quite high also during the period (see Table 3). The values of Z were derived from the sum of F and M (Z=F+M).

Optimal exploitation for a fish stock occurs when F is proportional to M (F=M or F/M=1), and this proportionality results in a fixed optimal rate of exploitation (E_{opt}), which is 0.5. *D. macarellus* in FMA 6 reached exploitation rates quite higher than the optimal rate (Figure 8).

An E-value that is too high indicates that the fish population is being harvested at an unsustainable rate, leading to overfishing in fishing grounds inside FMA 6. The fact that *D. macarellus* is found to be overexploited based on E-values; despite having a positive L_∞, K-value, growth index (Φ'), and a L_{bar} > L_m, it is a cause for concern.

Although L_{bar} > L_m suggests that a significant portion of the fish are reaching maturity, excessive fishing pressure could result in poor recruitment (the entry of young fish into the population). This means fewer younger fish are entering the population, which ultimately affects the long-term sustainability of the stock.

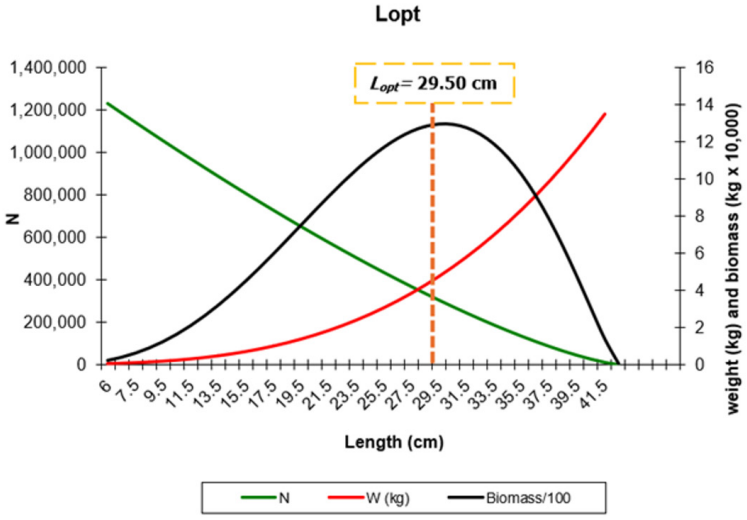

Figure 7. Length optimum of *D. macarellus* (2014–2022).

3.6.3 Maturity indicators

Figure 9 shows the length frequency data of *D. macarellus* landings from 2014 to 2022 in FMA 6. Results imply that a large portion of the catch were juveniles or immature. Approximately 56% of the fish individuals of the total landed catch from the top three fishing gears have not yet reached maturity and are considered below the length-at-first-maturity, indicating growth overfishing.

Table 3. Values of mortality parameters of *D. macarellus* (2014-2022).

Mortality Parameters	Years									Assessment Method
	2014	2015	2016	2017	2018	2019	2020	2021	2022	
F	9.26	8.3	10.54	7.64	11.47	12.89	10.37	7.91	8.58	L_{bar}/LF Data
Z	11.56	10.6	12.84	9.94	13.77	15.19	12.67	10.21	10.88	
F/M	4.03	3.61	4.58	3.32	4.99	5.6	4.51	3.44	3.73	
M					2.3					FishBase Life History Tool

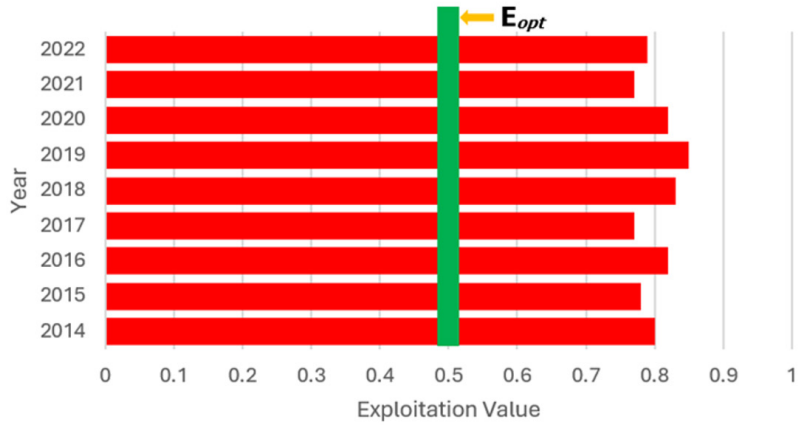

Figure 8. Exploitation rates of *D. macarellus* (2014–2022).

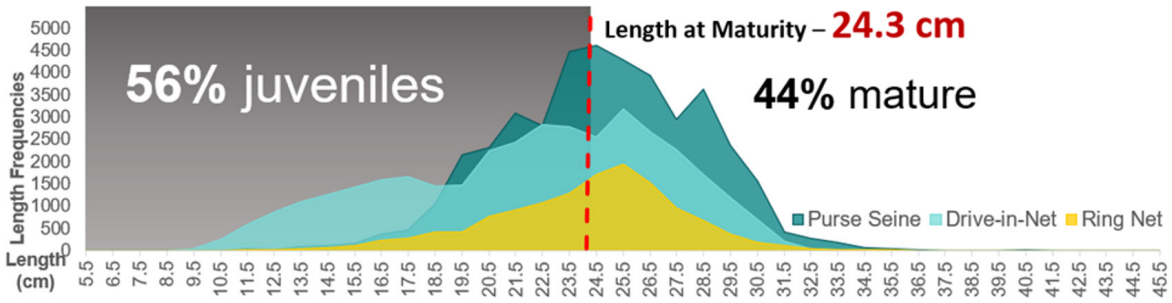

Figure 9. Length frequency of *D. macarellus* (2014–2022).

3.6.3.1 Indicator 1: Let them spawn!

Percent mature is measured as a percentage of mature *D. macarellus* in terms of length size from the total number of individuals caught. Using the Froese Sustainable Indicator Spreadsheet, the percentage mature per year were estimated (see Table 4). These values signify that most of the landed *D. macarellus* are juveniles or immature, and only a small percentage of this species were left for reproduction, indicating that the stock is at the trigger point and nearing the limit reference point.

3.6.3.2 Indicator 2: Let them grow!

The optimal size fish percentage is measured as the percentage of fish caught at optimum length. This length is where the number of fish in a given unfished year class multiplied by their mean individual weight is maximum; thus, the maximum yield and revenue are obtained. Optimal sized percentage of landed *D. macarellus* per year were estimated in Table 4.

As mentioned earlier, the L_{opt} is 29.50 cm TL. The Lopt range is ±10% of L_{opt}; therefore, the optimum harvest range based on length is from 26.55 cm TL to 32.45 cm TL. This length range contains the suggested sizes of *D. macarellus* to be caught by fisherfolk in FMA 6. As for this study, *D. macarellus* caught and landed in FMA 6 within the optimum harvest range is at 32.12% and lesser in other years. This percentage within ±10% of L_{opt} is way below the limit reference point and denotes an immediate action and necessity to let the fish grow first until they reach the desired sizes before catching them. This would greatly help reach the sustainable and desirable fishery level in FMA 6.

Table 4. Summary of performance indicators for *D. macarellus* generated using FROESE, the L_{bar} method, and SSDL.

Performance Indicators	Target Reference Point	Limit Reference Point	Results									Interpretation	Assessment Method
			2014	2015	2016	2017	2018	2019	2020	2021	2022		
Average Length (cm), ***where Lm=24.30 cm TL***	Above Lm and Increasing	Below Lm and Decreasing	24.50	23.50	25.50	23.50	25.50	26.50	25.50	24.50	25.50	x	**LBAR/LF Data**
Fishing Mortality	F=M or F/M ≤ 1	F=2M or F/M ≥ 1 or 2	4.03	3.61	4.58	3.32	4.99	5.60	4.51	3.44	3.73	x	
Percent Mature	90-100% mature;	50% mature and less;	11.83	9.33	14.30	15.13	14.92	13.99	19.79	18.49	23.28	x	**FROESE**
±10% of Length Optimum, ***where Lopt=29.50 cm TL***	100%	80% and less	16.59	13.14	18.72	20.39	20.44	20.72	27.96	25.43	32.12	x	
Percent Megaspawner	0-10% for (groupers, snappers, etc.) or 30-40% for fast growing species	20% megaspawner	1.14	0.15	0.20	1.20	1.09	1.06	1.19	1.18	2.18	x	
Exploitation Value	E = 0.5	E = 0.6	0.80	0.78	0.82	0.77	0.83	0.85	0.82	0.77	0.79	x	**LBAR/LF Data**
$B_{current}/B_0$	0.5	≤0.32 (MSY)	0.18										**SSDL**

3.6.3.3 Indicator 3: Let the megaspawners live!

Percent megaspawner is a percentage of old and large fish individuals in the catch. Long-term population sustainability depends on the survival of large, old fish. These individuals, especially females, produce exponentially more eggs and contribute higher-quality offspring, reflecting strong genetic fitness. Preserving megaspawners extends the reproductive phase and buffers against recruitment failure, making their proportion a key indicator of stock resilience.

The percentage of megaspawners in landings per year were estimated (see Table 4). Megaspawners are those whose lengths are 33.63 cm TL (1.14x of the L_{opt}=29.50 cm) and above. Results revealed that the percentages of *D. macarellus* megaspawners just ranged from 0.15% to 2.18% of the total stock. Given these values, there is a need for an approximately 10% increase or more to meet the ideal percentage of megaspawners in the fish stock.

3.7 Biomass indices

Fish current biomass over virgin biomass ($B_{current}/B_0$) is a ratio used in fisheries science to assess the status of a fish population relative to its historical abundance. $B_{current}$ is the estimated total weight of a fish population at present. This is often determined using stock assessments and includes fish of all ages and sizes currently present in the population. On the other hand, B_0 is the estimated total weight of the fish population before it was subject to fishing pressure. This represents the population size in its natural or unexploited state, often referred to as the "unfished" or "pre-fishing" biomass.

Using the Stock Assessment Continuum Tool (SACT)/SSDL, the $B_{current}/B_0$ computed was 0.18 (Table 4). The ratio is less than the limit reference point (LRP) ($B_{current}/B_0 \leq 0.32$) and differs largely from the target reference point (TRP) ($B_{current}/B_0 = 0.35$), suggesting that the population has been reduced in comparison to its historical levels. According to Silvar-Viladomiu et al. (2021), low stock spawning biomass ratios should prompt measures to reduce fishing pressure and mortality to promote population recovery.

The LRP was set at biomass at MSY where $B_{current}/B_0 = 0.32$. The biomass associated with MSY indicates the stock level necessary to achieve the maximum yield that can be sustained over time. According to Caddy et al. (1995), biomass at MSY is used to help set harvest limits and effectively manage fishing efforts. Moreover, managing fish stocks at or near biomass at MSY prevents potential stock depletion and ensures that productions are sustainable in the long term (Hilborn and Walters 1992).

All performance indicators are summarized in Table 4. These indicators were presented to and approved by the Scientific Advisory Group (SAG) as the basis for developing management strategies for D. macarellus in FMA 6. Furthermore, they were reviewed and endorsed by the Technical Working Group (TWG) and the Management Board (MB) for stakeholder consultation.

4. CONCLUSIONS

Based on the study's findings, *D. macarellus* exhibited a fluctuating catch trend from 2014 to 2022 and was recorded at 52 NSAP landing sites within Fisheries Management Area 6 (FMA 6). Seasonal peaks in catch were consistently observed from April to July throughout the study period, although the species was harvested year-round. A total of 20 types of fishing gear were utilized, with purse seine (39%), drive-in-net (35%), and ring net (25%) contributing the majority of the catch, while all other gear types accounted for less than 1%. The estimated asymptotic length (L_∞) was 42.6 cm total length (TL), with a growth coefficient (K) of 1.71. Both the length-at-full-selectivity (L_c) and the mean length (L_{ave}) exceeded the length-at-first-maturity (L_m = 24.3 cm TL) across all years. However, approximately 56% of the total landed catch from the dominant fishing gears consisted of immature individuals.

Furthermore, exploitation rates consistently exceeded the optimal E-value of 0.5, indicating unsustainable harvesting and overexploitation of the stock. The biomass ratio ($B_{current}/B_0$) was estimated at 0.18, which is substantially lower than the biomass at maximum sustainable yield (B_{MSY} = 0.32). Overall, most performance indicators, with the exception of Lave and Lc, exceeded established limit reference points, suggesting that the *D. macarellus* stock in FMA 6 is heavily fished and overexploited. These findings highlight the urgent need to implement policies and management measures aligned with the proposed harvest control rules to ensure stock recovery and long-term sustainability.

5. RECOMMENDATIONS

Fishing activities should be reduced, particularly for purse seine, drive-in-net, and ring net operations, which require proper management.

Law enforcement agencies must strictly implement Fisheries Administrative Order No. 201-2000 to prevent the use of active fishing gear, such as drive-in-nets, within municipal waters. To reinforce stronger law enforcement and encourage boat and gear registration, increasing the mesh size of nets used by dominant fishing gears is also recommended. In addition, a reproductive biology study should be conducted to accurately determine the spawning season and length at first maturity of *D. macarellus* in FMA 6, which may help inform the establishment of closed seasons. Finally, policies based on harvest control rules and measures for *D. macarellus* in FMA 6 should be developed and implemented.

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AUTHOR CONTRIBUTIONS

Noces ML: Conceptualization, Validation, Formal Analysis, Writing - Original Draft, Writing - Review & Editing, Visualization. **Gaerlan RSP:** Conceptualization, Supervision. **Cruz WM:** Conceptualization, Supervision. **Yutuc RV:** Conceptualization, Project Administration, Supervision, Writing - Review & Editing. **Mendoza RA:** Formal Analysis, Validation, Writing - Original Draft. **Parido LD:** Data Curation, Writing – Original Draft, Visualization. **Gualberto AJS:** Formal Analysis, Writing - Original Draft, Writing - Review & Editing, Visualization.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest in any way.

ETHICS STATEMENT

No animal or human studies were carried out by the authors.

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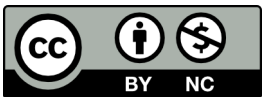

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