Population Dynamics of Sulphur Goatfish, *Upeneus sulphureus* (Cuvier, 1829) in the Visayan Sea, Philippines

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ABSTRACT

Population dynamics of *Upeneus sulphureus* in the Visayan Sea was assessed using the FiSAT II program from a sample collected by trawl fishing from November 2018 to October 2019. A total of 1,129 individuals with lengths ranging from 8.0 to 18.5 cm were included in this study. The asymptotic total length (L_∞) was 20.63 cm, and the growth constant (K) was 1.4 year^{-1}, revealing that this is a fast-growing species. The mean length was 13.35 cm with a growth performance index (ϕ) of 2.78. The total mortality rate (Z) was computed as 5.34 year^{-1}, the natural mortality rate (M) was 2.47 year^{-1}, and the fishing mortality rate (F) was 2.87 year^{-1}. The quotient of F/Z values computed an exploitation ratio (E) of 0.54. The obtained E exceeded the 0.5 threshold, which indicates the presence of growth overfishing. The ideal management interventions for this species are to increase the mesh size of nets and decrease effort levels to allow sustainable exploitation of the stock. These measures should be implemented to ensure continuous food protein supply and income of the fisherfolk who rely on the Visayan Sea fishery.

Keywords: Growth parameters, Mortality rates, Sulphur goatfish, Visayan Sea

INTRODUCTION

Sulphur goatfish, *Upeneus sulphureus*, under the Mullidae family are fishes that feed on benthic prey that dwell in the sea and brackish waters above muddy or sandy substrates and coral reefs (Mohamed and Resen, 2010). Mullidae comprises six genera with 83 species worldwide (Bos, 2014). In the Western Pacific Ocean, the goatfish family is represented by the genera *Mulloidichthys*, *Parupeneus*, and *Upeneus*, with 41 recognized species (Froese and Pauly, 2019). The genus *Upeneus* consists of 30 species worldwide, of which 11 have been recorded in the Philippines (Froese and Pauly, 2019).

The sulphur goatfish, locally known as "salmonete," is demersal, migratory within the sea areas, and frequently found in schools at depths of 10-90 m. The species is extensively dispersed in coastal waters of various regions, from the Arabian Gulf to the Indo-West Pacific, in the east of African waters, the southern part of Japan, Southeast Asia countries, the eastern coast of China, and the coastal waters of Queensland and Fiji Islands (Kumaran and Randall, 1984; Kuronuma and Abe, 1986; Randall and Kulbicki, 2006).

The Visayan Sea is one of the major fishing areas in the Philippines, with high fish production of demersal and pelagic species (Aprieto and Villoso, 1979). The growing number of fishing trawlers in the Visayan Sea has created many suppositions concerning its impact on fishery resources. The majority of the marginal fisherfolk believe that the increasing number of trawlers operating in the Visayan Sea that catch small demersal fishes will deplete this species if not properly regulated and managed.

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Sulphur goatfish landed at Bancal Port in the Municipality of Carles, Province of Iloilo, Philippines, are caught in the Visayan Sea by commercial fishing vessels using trawl nets throughout the year. The status of the *U. sulphureus* fishery and of other commercial fish species in the Western and Central Visayan Sea was last studied by Guanco *et al*. (2009).

The estimated production of goatfishes from municipal and commercial fisheries in the Philippines in 2018 was 19,808.73 mt and 5,187 mt, respectively (PSA, 2019). In the Visayan Sea from 1998 to 2002, sulphur goatfish contributed 1.5 % of the total catch of the 15 dominant commercial fish species caught by trawls, ring nets, and purse seines (Guanco *et al*., 2009).

This study presents a summary of the data gathered from the *U. sulphureus* catch of the trawl fishery in the Visayan Sea from November 2018 to October 2019, and the growth parameters, mortality rates, and rate of exploitation of *U. sulphureus*. The results are then equated to the findings with the previous studies conducted in the Visayan Sea.

MATERIALS AND METHODS

Collection of data

The study concentrated on the *Upeneus sulphureus* caught by commercial trawlers who fished in the Visayan Sea and landed their catch at Bancal Fishing Port. The Visayan Sea is one of the significant fishing areas in the central Philippines, located between 11-12°N and between 123-124°E, and covering a total area of 5,184 km^2 (BFAR, 2002). Figure 1 shows the sampling area in the Visayan Sea, where trawlers engaged in fishing operations for *U. sulphureus*.

Data were collected twice a week from November 2018 to October 2019. The weight of the *Upeneus sulphureus* specimen was recorded to the nearest 0.01 g using a 5,000 g Cascade digital weighing scale. A 30-cm measuring board was used to measure the total fish length to the nearest 0.1 cm. The goatfish species was identified using identification keys by Carpenter and Niem (2001). A total of 1,129 *U. sulphureus* individuals were assessed during the one-year study period.

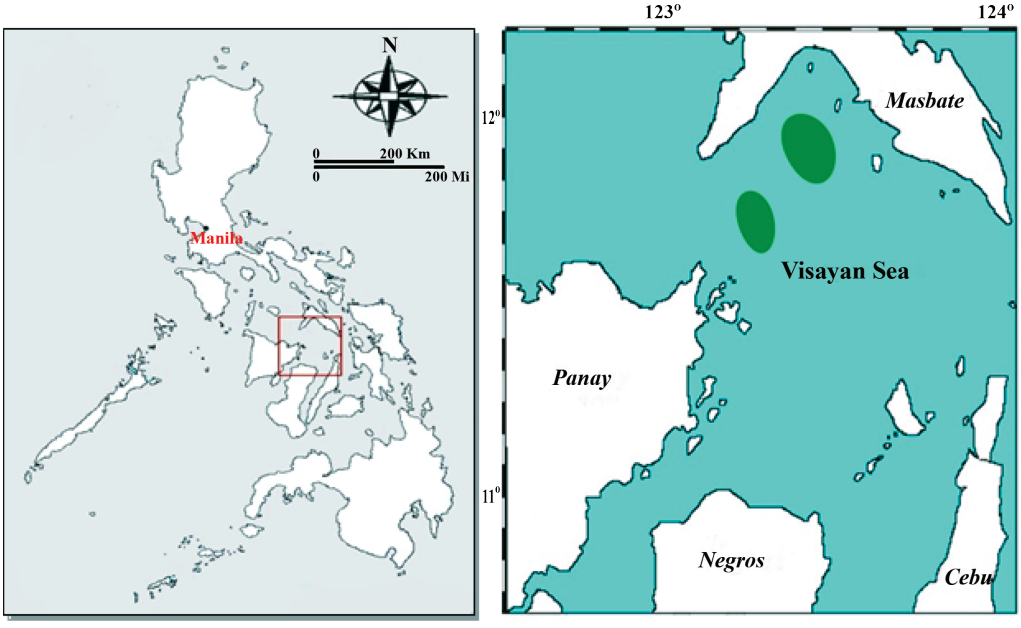

Figure 1. Map of the Visayan Sea showing the study area where *Upeneus sulphureus* were caught by commercial trawlers (circle).

Length-weight relationship (LWR)

The mathematical expression of Le Cren (1951) was used to compute the length-weight relationship:

$$W = aL^b$$

Where W is the total fish weight (g), and L is the total fish length (cm). The parameters *a* and *b* describe the length-weight relationship, where *a* is a coefficient related to the body form, and *b* is an exponent demonstrating isometric growth when its value is 3 (Pauly, 1984). Its mathematical expression was computed using the formula:

$$\log W = \log a + b \log L$$

Where logW is the logarithm of weight (g), log *a* is a logarithm coefficient, *b* is the logarithm of the exponent, and log L is the logarithm of total fish length (cm). This logarithmic form was used to estimate the significance level of r^2 through linear regressions.

Stepwise procedures for growth parameters estimation

Length-frequency data of *Upeneus sulphureus* caught in trawls were studied using the ELEFANT I package included in the FiSAT II program (Gayanilo *et al*., 1996). The complete stepwise procedure of estimating growth parameters followed the steps established by Amarasinghe and De Silva (1992). The steps are:

1. estimating the preliminary value of the asymptotic length (L_∞) and then the $\frac{Z}{K}$ (Z is the total mortality per year and K is the growth constant per year) via the Wetherall method (Pauly, 1986a; Wetherall, 1986);

2. obtaining preliminary estimates of growth parameters by ELEFANT I, estimating the value of L_∞ using the Wetherall method;

3. estimating probabilities of capture through scrutinizing the catch curve's ascending line and building a selection curve with the mortality rates (Z and natural mortality M) from the initial approximations of K and L_∞;

4. correcting the original length-frequency distributions via probabilities of capture (Pauly, 1986b); and

5. obtaining improved estimates of K and L_∞ from the corrected length-frequency distributions.

Growth parameters

The empirical formula of Pauly (1979) was used to estimate the theoretical age at birth (t_0) with the formula:

$$\log_{10}(-t_0) = -0.3922 - 0.275 \times \log_{10} L_\infty - 1.038 \times \log_{10} K$$

Where t_0 is the theoretical age at length zero (year), L_∞ is the asymptotic length (cm), and K is the growth constant ($year^{-1}$).

Longevity (tmax) was calculated using the mathematical statement below by Pauly (1983):

$$t_{max} = \frac{3}{K} + t_0$$

Where t_{max} is the maximum fish age (year), K is the growth constant, and t_0 is the theoretical age at length zero.

In determining the growth performance index, the formula of Munro and Pauly (1983) is given below:

$$\phi = 2 \log_{10} L_\infty + \log_{10} K$$

Where ϕ is the growth performance index, L_∞ denotes the asymptotic length, and K is the VBGF curvature parameter (growth constant).

The values for L_∞ and K from the corrected length-frequency data were fitted to the classical

von Bertalanffy Growth Function (VBGF). Applying the VBGF fitted in ELEFANT I routine of FiSAT II (version 1.2.2), the growth constant (K) and asymptotic length (L_∞) were computed (Gayanilo *et al*., 2005) using the formula of Pauly (1984) as:

$$L_t = L_\infty (1\text{-}e^{-K(t\text{-}to)})$$

Where L_t is the length at time t, L_∞ represents the asymptotic length, e is the exponential constant with an approximate value of 2.718, K is the growth constant, and t_0, the theoretical age at length zero of fish.

Mortality rates

The Z was assessed from the length-converted catch curve result. The empirical formula of Pauly (1980) was used to determine the value of M or the natural mortality rate:

$$\log_{10} M = -0.0066\text{-}0.279 \log_{10} L_\infty + 0.6543 \log_{10} K + 0.4634 \log_{10} T$$

Where M = natural mortality (year^{-1}), and T = mean yearly sea surface temperature (taken at 28 °C). F or the fishing mortality rate was computed using the formula (Gulland, 1971):

$$F = Z\text{-}M$$

Where Z = total mortality (year^{-1}), F = fishing mortality (year^{-1}), and M = natural mortality (year^{-1}). The level of exploitation (E) was estimated by Gulland (1971):

$$E = \frac{F}{Z}$$

Probability of capture and recruitment pattern

Probabilities of capture of L25, L50, and L75 which represent lengths at 25 %, 50 %, and 75 %, respectively, of *Upeneus sulphureus* that are susceptible to gears) were estimated from an extended routine of catch curve analysis. A recruitment pulse reconstructed from the length-frequency data in time succession was used to identify yearly pulses and each pulse's strength (Nurul–Amin *et al*., 2009). The length at first ecruitment (L_r) value was calculated by determining the midpoint of the lowest length class interval (Murty *et al*., 1992, Gheshlaghi *et al*., 2012). The equation is:

$$L_r = \frac{LL+UL}{2}$$

Where L_r is the length at first recruitment (cm), LL is the lower limit (cm), and UL is the upper limit (cm).

Length at first maturity

The L_{m50} or length at first maturity was calculated using the mathematical expression of Hoggarth *et al*. (2006):

$$L_{m50} = \frac{2(L_\infty)}{3}$$

Where L_{m50} is the length at first maturity (cm), and L_∞ is the asymptotic length. It is the length (L_{m50}) of the fish that can increase the stocks.

Relative yield per recruit (Y'/R), relative biomass per recruit (B'/R), and yield isopleth

Relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) were approximated in FiSAT software applying the Beverton and Holt model (1966) as revised by Pauly and Soriano (1986). The E_{max} or maximum allowable limit of exploitation, which provides a maximum Y'/R, was approximated from the analysis. $E_{0.1}$ is the value of E with 10 % of its value at the slope of Y/R. $E_{0.5}$ is the E value related to a 1/2 cutback of the biomass of recruits in the untouched population

RESULTS

The length (TL) frequencies of 1,129 *Upeneus sulphureus* individuals in trawl catches in the Visayan Sea, ranging from 8.0 to 18.5 cm were determined. The computed mean length was 13.4±2.1 cm. The total weights obtained ranged from 6.0 to 86.0 g, and the mean weight was 31.7± 13.1 g.

The length and weight measurements of all 1,129 sulphur goatfish specimens were used to describe the length-weight relationship. The constant (*a*) was 0.0104, while the growth pattern (*b*) was 3.07 (Figure 2). The computed *b* value (3.07) of the sample showed no significant difference from the isometric growth value of 3 (t-test, $p > 0.05$). The equation describing the length-weight relationship was: $W = 0.0104\ L^{3.0726}$, with the regression coefficient $r^2 = 0.90$.

The L_∞ of VBGF for *U. sulphureus* was 20.63 cm, and the K was 1.4 year^{-1}. The response surface (Rn) was computed as 0.232. The growth curve revealed four cohorts (Figure 3). The Von Bertalanffy Growth Equation was $L_t = 20.63\ (1\text{-}e^{-1.4\ (t\ -\ -0.04)})$ with a growth performance index (ϕ) of 2.78. The estimated Z/K ratio was 2.94.

The theoretical age at birth (t_0) was -0.04, and the maximum age (t_{max}) was 2.10 years. Thus, the estimated VBGF model of body length concerning the age predicted the sizes reached by *U. sulphureus* as 10.94, 15.72, 18.24, 20.61, and 20.63 cm at 0.5, 1.0, 1.5, 2.0, and 2.5 years.

The total (Z), natural (M), and fishing (F) mortality rates were estimated as 5.34 year^{-1}, 2.47 year^{-1}, and 2.87 year^{-1}, respectively. The rate of exploitation (E) was estimated as 0.54 (Figure 4).

The length-at-first capture L_{c50} (length at 50 % capture) and age at first capture (t_c) were 11.63 cm and 0.56 year, respectively. The estimate for L_{25} was 10.81 cm, and L_{75} was 12.52 cm (Figure 5).

Two peaks of recruitment for one year were generated for *U. sulphureus*. The recruitment happens in the midyear and going to the end of the year (Figure 6). The L_r was 8.5 cm, and the t_r was 0.34 year.

The length at first maturity (L_{m50}) and age at first maturity (t_m) obtained were 13.75 cm and 0.75 years, respectively.

The relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) of *U. sulphureus* were estimated using the knife-edge analysis method. The input requirements in the procedure were $L_{c50}/L_\infty = 0.56$ and $M/K = 1.76$. The maximum exploitation rate (E_{max}) that gives maximum yield-per-recruit was estimated as 0.63 (Figure 7). Relative yield-per-recruit decreases when the exploitation rate value increases beyond 0.63. The exploitation level that would reduce the unexploited biomass by 50 % (E0.5) was 0.34. However, the exploitation level value of 0.51 would increase Y'/R by 10 % (E0.1).

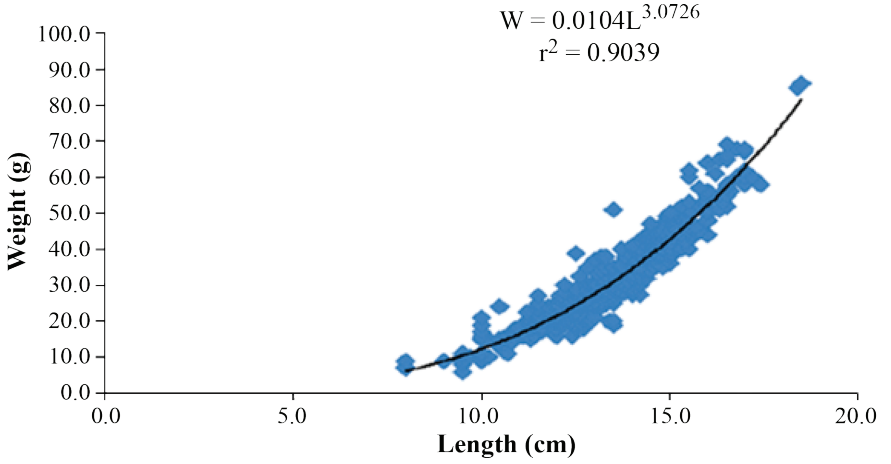

Figure 2. Length-weight relationship of *Upeneus sulphureus* in the Visayan Sea.

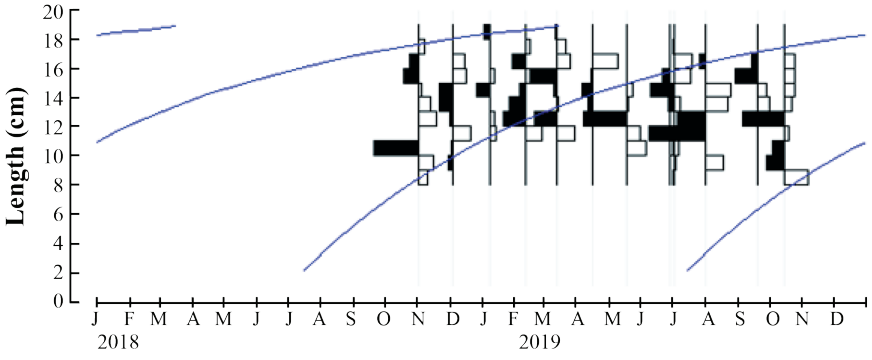

Figure 3. Restructured length-frequency distribution of samples of *Upeneus sulphureus* from trawl catches in the Visayan Sea superimposed with growth curves.

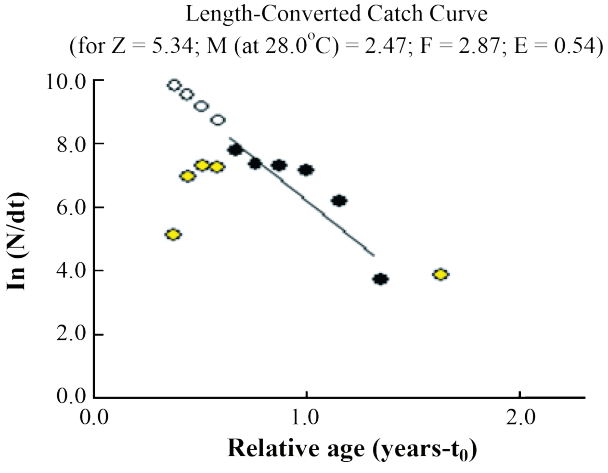

Figure 4. Length-converted catch curve plot based on length composition data of *Upeneus sulphureus* in the Visayan Sea.

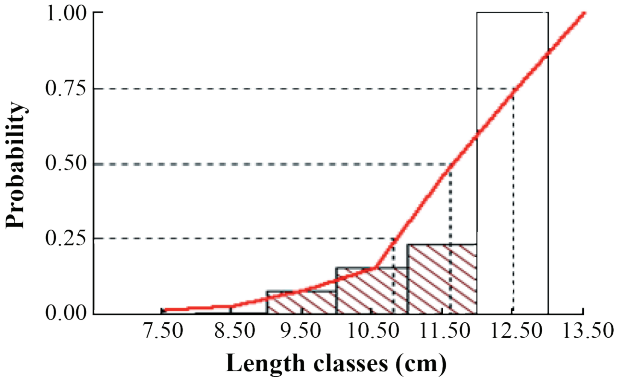

Figure 5. Probability of capture of *Upeneus sulphureus* in the Visayan Sea.

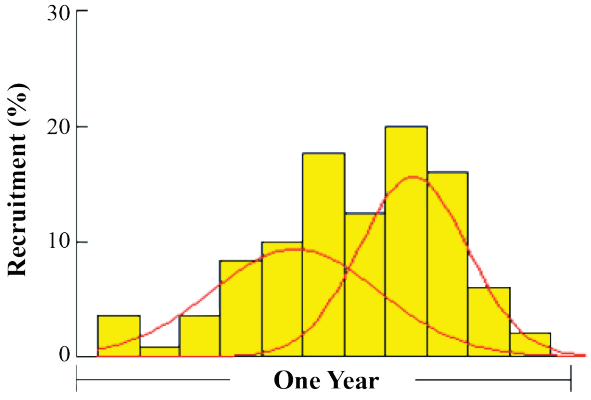

Figure 6. Recruitment pattern of *Upeneus sulphureus* in the Visayan Sea during one year (from January to December).

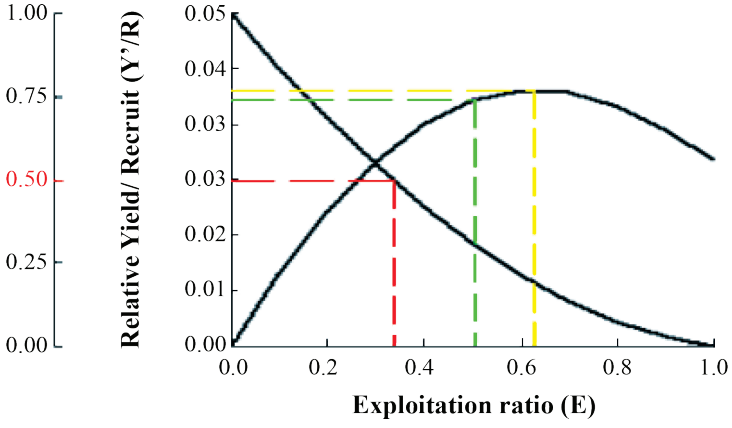

Figure 7. Beverton and Holt's relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) of *Upeneus sulphureus*.

DISCUSSION

According to Pauly (1984), growth coefficient *b* values equal or nearer to 3 show an isometric growth, while values different from 3 significantly signifies allometric growth. The growth coefficient *b* value (3.07) estimated in the present study does not differ significantly from the *b* value (3.0) of Federizon's (1993) study in Central Visayas. The values show that sulphur goatfish in the Visayan Sea and adjacent fishing grounds have isometric growth.

Considerable knowledge regarding population parameters is required to effectively manage and conserve any fishery resource in a particular fishing ground (Abohweyer and Falaye, 2008). Sulphur goatfish is one of the utilized fish commodities in the Philippines, and has been for years, but there is also a considerable dearth of information about the species. However, the population dynamics of *Upeneus sulphureus* can be correlated with the other studies in the Philippines and other parts of Asia (Table 1).

According to Sparre and Venema (1992), a value of K of 1.0 indicates that fish exhibit fast growth, whereas 0.5 is medium growth, and 0.2 is slow growth. The K estimate of 1.4 for *U. sulphureus* from this study is considered fast growth.

Table 1. Comparison of population parameters of *Upeneus sulphureus* from the Philippines and other Asian countries.

Location	L_{max} (cm, *TL)	L_∞ (cm, TL)	K (year^{-1})	ϕ	Z (year^{-1})	M (year^{-1})	F (year^{-1})	Source
Visayan Sea	20.37	21.24	1.38	2.77	-	-	-	Guanco *et al*., 2009
Samar Sea	-	19.5 (*FL)	1.20	2.66	-	-	-	Armada and Silvestre, 1981
Burias Pass	-	23.5 (FL)	1.30	2.86	-	-	-	Corpuz *et al*., 1985
Visayan Sea	18.50	20.63	1.40	2.78	5.34	2.47	2.87	Present Study
Other Asian countries								
Peninsular east coast, Malaysia	-	19.40	0.56	2.32	-	-	-	Ahmad *et al*., 2003
Sarawak, Malaysia	-	22.0	0.65	2.50	-	-	-	Ahmad *et al*., 2003
Java Sea, Indonesia	-	19.9	0.875	-	-	-	-	Budihardjo, 1988
Northwest Arabian Gulf, Iraq	18.6	19.60	0.725	-	-	-	-	Mohamed and Saleh, 2000
Northwest Arabian Gulf, Iraq	17.0	18.85	0.72	2.36	2.43	1.85	0.58	Mohamed *et al*., 2008

Note: TL = total length, FL = fork length

In the Indo-West Pacific, the sulphur goatfish is widely distributed with a maximum size of 23 cm TL (Froese and Pauly, 2019); in this study, the maximum size was only 18.5 cm TL. The lesser size obtained in the present study could be from the fishing gravity level or differences and resulting adaptations to abiotic conditions, e.g., water temperature and food availability (Welcomme, 1999 and 2001; Froese, 2006). However, comparing growth performance index (ϕ), the value obtained in this study (ϕ = 2.78) is nearly identical to Guanco *et al*. (2009), also in the Visayan Sea, and similar to values previously recorded in other areas of the Philippines such in Burias Pass and Samar Sea. Nevertheless, this study suggests that the sulphur goatfish grows faster in the Philippines than in other parts of Asia where it has been studied (Table 1).

The size of *Upeneus sulphureus* at its length with a 50 % probability to be captured (L_c) was 11.63 cm (Figure 5), demonstrating that it is being exploited in the first year of its life.

The *Upeneus sulphureus*' mortality rateson total mortality (Z), natural mortality (M), and fishing mortality (F) were 5.34 year-1, 2.47 year^{-1}, and 2.87 year^{-1}, respectively. This is an indication of an unbalanced standing stock of *U. sulphureus* in the Visayan Sea, since the fishing mortality was higher than natural mortality. According to Gulland (1971), a stock is ideally exploited if fishing mortality is equal to natural mortality; *Fopt* = *M* or the exploitation rate (*E*) is equal to 0.5. This E value (0.54) exceeded the 0.50 threshold, indicating that the *U. sulphureus* stock is overfished and confirms the observations reported for the same species and study site by Guanco *et al*. (2009). Furthermore, some factors that contribute to overfishing in the Visayan Sea are a high number of fishers and high fishing pressure on several fish stocks, low-value species in the catch, destruction of habitat, and overcapitalization, as previously indicated in the studies of Hermes *et al*. (2004), Siason *et al*. (2005) and Vakily (2005).

When the Z/K ratio is < 1, it shows a growth-dominated population; Z/K ratio > 1 means the population is mortality-dominated; when it is equal to 1, the mortality and growth are in equilibrium (Barry and Tegner, 1989). The Z/K ratio of 3.8 for sulphur goatfish in the present study shows a mortality-dominated population due to the high fishing mortality rate (2.87 $year^{-1}$) in the Visayan Sea. Etim *et al*.'s (1999) study reported that a Z/K ratio ≈ 2 indicates over-exploitation. In this study, the natural mortality rate's value in the growth coefficient (M/K) of sulphur goatfish was 1.8. M/K values normally range from 1.5 to 2.5, and the ideal value is 2.0 (Beverton and Holt, 1957). Exceeding this ideal value (M/K = 2) makes the fish vulnerable to substantial natural mortality before reaching its old age (Mohamed and Resen, 2010).

This present investigation indicates that the pattern of recruitment of *Upeneus sulphureus* is constant with two recruitment events per year, which agrees with the previous work of Guanco *et al*. (2009). Pauly and Navaluna (1983) and Ingles and Pauly (1984) reported that most of the Philippines' fish stocks exhibit two pulses of recruitment each year. In the study of Akter *et al*. (2020), *U. sulphureus* was reported to spawn twice a year, during January-May and during August-October in the Northern Bay of Bengal, Bangladesh. In this study, it was observed that the major spawning of *U. sulphureus* occurred during May-June and August-September (Figure 7). The modal pattern implies the biological importance for this species to utilize the Visayan Sea as nursery and feeding grounds. Moreover, the high occurrence of recruits displayed that the recruitment cycle is efficient and functional (Amponsah *et al*., 2016).

Relative yield-per recruit and relative biomass-per-recruit are computed based on the input of the length at first capture. The E_{max} or the maximum allowable limit of exploitation rate estimated as 0.63 will give a maximum relative yield per recruit (Y'/R). With the exploitation rate (E) of 0.54 estimated for *U. sulphureus* in this study, the E_{max} of 0.63 is comparable to the E value computed. The fishery's E value is higher than the optimum exploitation rate of E_{opt} = 0.50. Furthermore, E is above the typical concept of yield ($E_{0.1}$ = 0.51), showing that the small rise in relative yield-per-recruit is 10% of its value at a shallow exploitation level (Amarasinghe *et al*., 2017). This reveals that the *U. sulphureus* stock in the Visayan Sea is probably being over-exploited in terms of Y'/R and B'/R. Thus, the fishing pressure on the sulphur goatfish stock is excessive, resulting in its overexploitation.

As the Visayan Sea has an open-access fishing condition, the potential interventions for *U. sulphureus* are to increase the mesh size of nets and decrease effort levels of the fisherfolk to attain sustainable exploitation of this stock.

CONCLUSION

Upeneus sulphureus is a fast-growing species and possesses a short lifespan, premature sexual maturity, and constant recruitment. Its status is overfished in the Visayan Sea and demands a decrease in fishing effort and the prohibition of nets with small mesh sizes used to catch this species. The continuous presence of recruits year-round reveals strong recruitment into the stock. Given the significant contribution of *U. sulphureus* to the fisherfolk's food protein supply and income, relevant and efficacious fisheries management actions are essential and immediately needed to prevent the potential downfall of the sulphur goatfish stock in the Visayan Sea.

Author contributions. Q.Y.C. designed the study, performed the fieldwork, analyzed the data, and wrote the paper; N.O.S. performed the fieldwork, was involved in the planning, and participated in writing the paper and data analysis. Both authors discussed the results and provided substantial contributions to the final manuscript.

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