RESEARCH ARTICLE

Age, Growth, and Population Structure of *Conomurex luhunuas*

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─ A B S T R A C T ─

Age and growth dynamics of *Conomurex luhuanus* were investigated to determine the population structure. Age-specific change in shell shape determined with geometric morphometrics revealed discrimination of shape between 0-3 years old at 99–100% while 3–4 years old can be separated with 81% certainty. Using the age discrimination data, K and L∞ were estimated at 1.00 year⁻¹ and 7.28 cm, respectively. Recruitment is bimodal with natural mortality (M) of 0.71 and fishing mortality (F) approximated at 3.92 year⁻¹. The exploitation rate (E) is 0.85 year⁻¹, indicating probable overharvesting of the population under study. The presence of a deep-water population, age-specific burying behavior, and bimodal recruitment pattern are possible resilience factors.

1. INTRODUCTION

*C*onomurex luhuanus (Linne 1578) is a widely exploited species within the Indo-West Pacific area and in some Pacific Islands (Thomas 2007; Hermosilia and Narido 2007). In the Philippines, *C. luhuanus* is one of the 12 commercially exploited mollusks harvested from the wild (Hermosilia and Narido 2007) as an alternative source of cash from fishing and even farming (Parducho and Palomares 2014). The exotic taste of its meat makes it one of the sought-after delicacies in coastal communities. The orange to red aperture makes the shell an important jewelry material and is part of the 2,100 metric ton decorative shells exported from the Philippines (Floren 2003).

Observation of declining harvest, however, seems to lend credence to anecdotal accounts that the species is already overharvested. In the Philippines, invertebrate fish catch is associated with gleaning and small-scale fishers that employ an estimated 1.3 million people (Garces 2011). However, empirical support for this claim is wanting with the absence of landing sites for commercially harvested mollusk species and the virtual absence of a monitoring program. Generally, there is a big gap in reporting on the commercial value of gleaned species, particularly mollusks (Jimenez et al. 2015; Jimenez et al. 2011). Thus, the population status of commercially important species is generally unknown.

The biology and ecology of *C. luhuanus* have mainly been studied in sub-tropical sites (Poiner and Catterall 1988; Catterall and Poiner 1983; Wada et al. 1983; Weidemeyer 1988). However, studies on the rate of exploitation of the species in tropical areas like the Philippines, along with other gleaned species, are mostly qualitative, describing catch per unit effort rather than biomass (Cabanban et al. 2014). Its fishery and population dynamics thus are mainly unknown, specifically in the Philippines, where it is widely exploited.

The effort to establish the population dynamics of most gastropods is limited by age-specific length data. In *C. luhuanus*, lengths of individuals are poor predictors of their age given environmental plasticity (Absalão et al. 2005; Roopnarine et al. 2008; Minton et al. 2008; Marquez et al. 2011; Minton et al. 2011) as well as habitat specificity of shell sizes (Catterall et al. 2001). On the one hand, length may poorly capture the age structure of the species since growth is determined to reach the maximum length at around two years old (Catterall and Poiner 1983).

After the asymptotic length is achieved, accretion of shell only happens on the outer margin of the lip resulting in age-specific lip thickness. The regression slope of length and lip thickness had been determined by Catterall et al. (2001), but the habitat factor in length is hard to determine. On the other hand, there is always a corresponding change in shape with growth (Goldman et al. 1990) and thus may be used to determine age. Recent developments in geometric morphometrics (GM) that use point geometry analysis retain information on landmarks (Slice 2007) that may be used to statistically differentiate taxon (Costa et al. 2008), age groups (Chatziginni and Halazonetis 2009), and intra-sexual shapes of different organisms (Sanchez-Escalona et al. 2017)

This paper aims to elucidate the exploitation rates, growth parameters, mortality rates, and recruitment patterns of *C. luhuanus.*

2. MATERIALS AND METHODS

The study was conducted in the general area of Tablas Strait, in Mansalay Bay, on the island of Mindoro, central Philippines (Figure 1). The study site has a multispecies seagrass area starting at the intertidal zone to a depth of 1 meter. Between 1.5 to 2 meters in depth, coral bommies occur. Sand and rubble area with sporadic *Halophila* patches are found at 2–10-meter depths.

The population survey was done for eight consecutive quarters starting in September 2011. A systematic search of aggregations was done by deploying an imaginary transect belt with a 20-meter

width. A paddle boat was rowed, and made a survey stop every 50-meter distance. Aggregations were searched within a 20-meters radius of the boat. The search was aided by local fishermen who are used to looking for visual signs of aggregations from water surface down to 10-meters depth.

As a preliminary to establishing the species' age frequency data, an investigation of whether shape changes with age was conducted. A total of 256 individuals were collected by hand randomly from the observed aggregations to serve as test organisms. Animals were boiled to facilitate the cleaning of the shells. An a-priori aging was done based on the length and lip thickness (Poiner and Catterall 1988; Catterall et al. 2001): < 10 mm length are early recruits; 20–30 mm length with < 2 mm lip thickness are yearlings; 30–40 mm length with < 2 mm lip thickness are young adults; 30–45 mm length with 2.1-3.9 mm lip thickness as adults; and 30–45 mm length with > 4 mm lip thickness as mature adults. The shells were later photographed laying on their adaxial side using a Canon S95 digital camera with grid settings to assist in focusing on the image. Positioning was made constant by making the suture between the lip and the body whorl constantly visible on the image and the central portion of the shell filling the center quadrat of the camera grid. This was facilitated by setting the shell on clay dough to prevent toppling. Acquired images were edited using Microsoft® Office Picture Manager retaining 1-centimeter space around each image.

Ten (10) landmarks and 29 semi-landmarks were digitized along the surface of the captured images using tpsDig by Rohlf (2005) (Figure 2). Landmarks
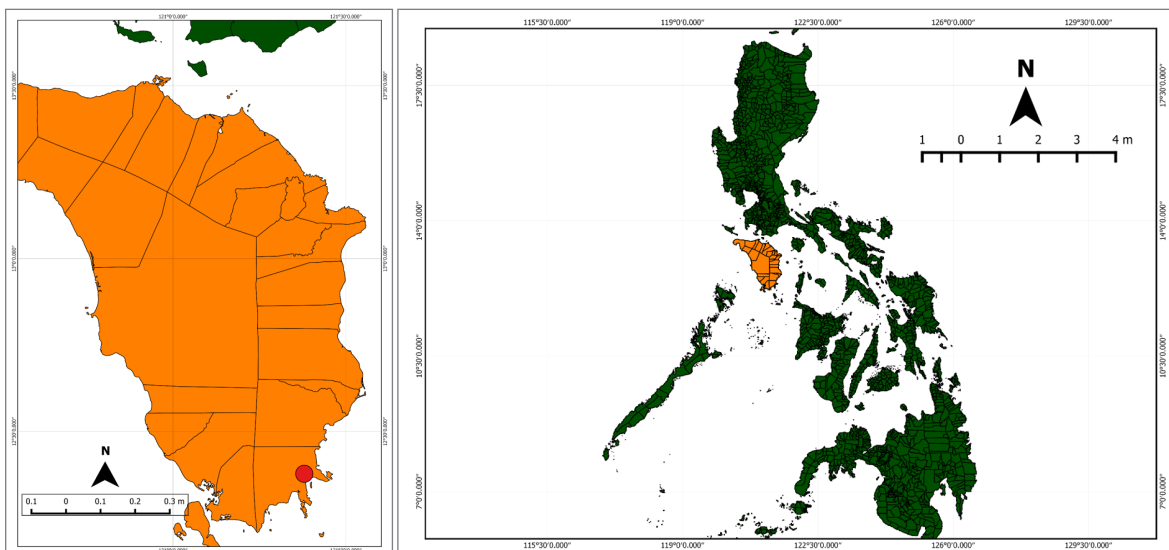

Figure 1. Map of the study sites.

Figure 2. Positions of landmarks (●) and semilandmarks (●) superimposed on the shell of *Conomurex luhuanus.*

are specific features that can easily be located, such as tips, maximum curvatures, and sutures, while semi-landmarks are points with relative positions from a landmark or along a surface (Zelditch et al. 2004). The acquired spatial points were converted into coordinates by tpsRelW (Rohlf 2003), which allowed data processing as shape variables. Principal Component Analysis (PCA) was done in MorphoJ (Klininger 2011) to determine possible age differences. Finally, the maximization of group separation was done with Canonical Variate Analysis (CVA).

All individuals from observed aggregations were photographed on their adaxial side *in situ*. Shells heavily encrusted with algae were lightly cleaned to expose the shell outline. Photos were processed using the same methodologies done on test organisms. A total of 3,624 individuals were used for this study.

Using the values from the CVA of the test organisms, Discriminant Function Analysis (DFA) in R (R Core Team 2016) was applied to age sample individuals to derive the age frequency distribution. Then, the derived age frequency data were used to compute growth parameters, mortality rates, recruitment patterns, exploitation rate, and yield per

recruit using FiSAT (FAO-ICLAM Assessment Tool) package (Gayanilo et al. 2005). Growth was assumed to be described by von Bertalanffy equation which had been proven to apply to bivalves and other gastropods (Dolorosa and Dangan-Galon 2014; del Norte-Campos and Villarta 2010; Al-Barwani et al. 2007; Cob et al. 2009; Tumanda et al. 1997).

The estimated maximum size when species is not caught (L∞), as well as the constant growth rate (*K*), was initially estimated by scanning for possible values given the age-frequency distribution using Elefan I in FISAT (Tumanda et al. 1997; Cob et al. 2008; Dolorosa and Dangan-Galon 2014). The values were confirmed with the subsequent fitting of derived age-frequency values where the Rn-value is the highest. Subsequently, the best combination of L∞ and K was taken using the Powell-Wetherall plot to take the proportion of total mortality (*Z*) and the growth rate (*K*). The K-value was taken as an approximation of the natural mortality (*M*) value which applies to exploited stocks that make a collection of natural mortality data impossible (Tumanda et al. 1997). For this approximation, the second point representing the yearling group (Age 1) was assumed to be fully recruited to the fishery.

Total mortality (*Z*) was estimated with Ault and Ehrhardt method in the FiSAT II package. The model was chosen with its relaxed assumption on the lifespan of the species being analyzed. Mortality from fishing (*F*) was computed using the relationship *F = Z-M*. The exploitation rate (*E*) was computed as the quotient of *F* and *Z* or *F/Z*.

Further assessment of the level of exploitation was done with Beverton-Holt Yield per Recruit analysis in FiSAT II, comparing maximum allowable exploitation (E_max) and the computed exploitation rate (*E*).

3. RESULTS

3.1 Use of shape variables to estimate age of samples

CVA showed that the first two eigenvalues accounted for 93.10% of the group variability (Figure 3). Three clusters are apparent. At age 0, the tiny juveniles or recruits are clearly separated from ages 1–4; ages 1–2 are clustered together; and ages 3–4 are lumped together. Discriminant Function Analysis cross-validation results showed that ages 0–3 are discriminated 99–100% while ages 3–4 can be separated with 81% certainty.
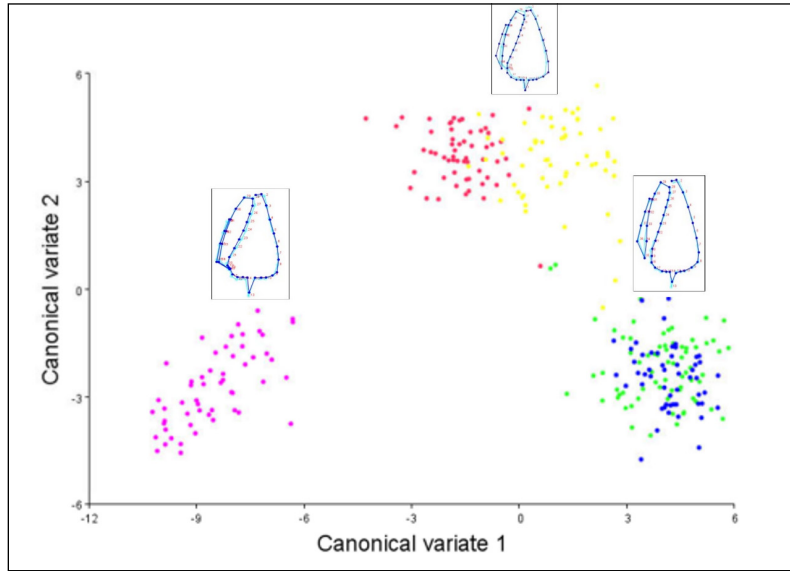
Change in shape is attained with outward

Figure 3. CVA discriminated the 5 age groups of *C. luhuanus* test organisms, which forms the basis for the aging of the samples. Inset figures are discriminant shape differences between ages 0 (●) and 1 (●) , ages 2 (●) and 3 (●), between and ages 3, and 4 and 5(●).

movement points on the shoulder of individual *C. luhuanus*. As an effect, the protoconch is pushed outward, elongating the shell. In older individuals, the thickening of the lip affects a differential narrowing of the aperture as individuals age. This narrowing effect may be minimal for group ages 3–4, as shown in overlapped points in CVA. Constraining separation through DFA, however, still recognizes age groups 3 and 4 as statistically separated.

Results showed a significant change in shape with growth that can be mathematically quantified. This demonstrates the utility of GM in aging commercially harvested gastropod species to minimize sampling artifacts.

3.2 Growth dynamics

The estimated K and L∞ values for *C. luhuanus* are 1.00 year^{-1} and 7.28 cm, respectively. The trajectory of growth of the species is visually presented in Figure 4, showing a very rapid growth within one year, after which the growth rate plateaus until the third year. The determinate growth rate (Poiner and Catterall 1988) is apparent, with growth almost indiscernible in length between the second and third year.
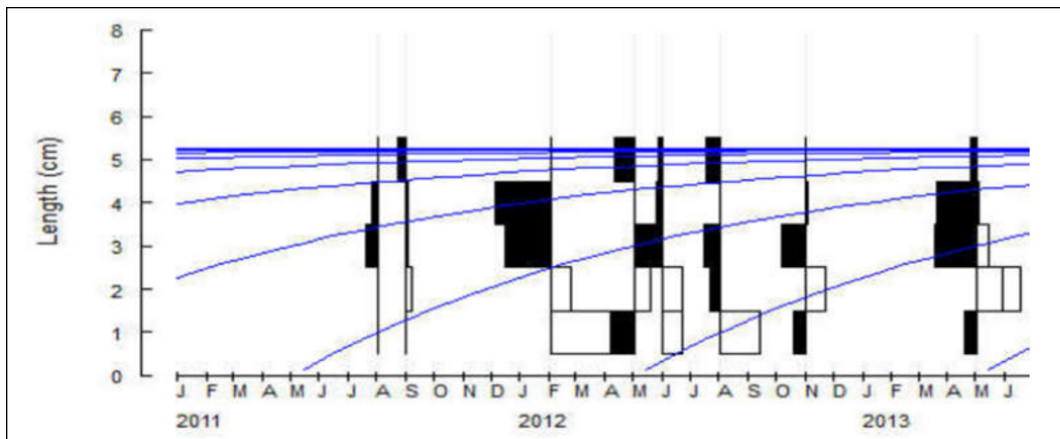
Recruitment appears to be year-round for

Figure 4. Growth curve of *C. luhuanus* derived from age frequency data (N=3,624). Drawn lines are the estimated growth trajectory superimposed on the age frequency data. Black and white bars are negative and positive deviations, respectively, from the computed average of age-classes presenting pseudo-cohorts.

the population under study, with bimodal peaks approximately in May and November (Figure 5). The spawning peaks seem to coincide with thermal landmarks. May is considered the warmest month in Mansalay, but it is also the outset of the rainy season (Climate-Data.Org 2019). On the other hand, November is the outset of warm-wet months in the area.

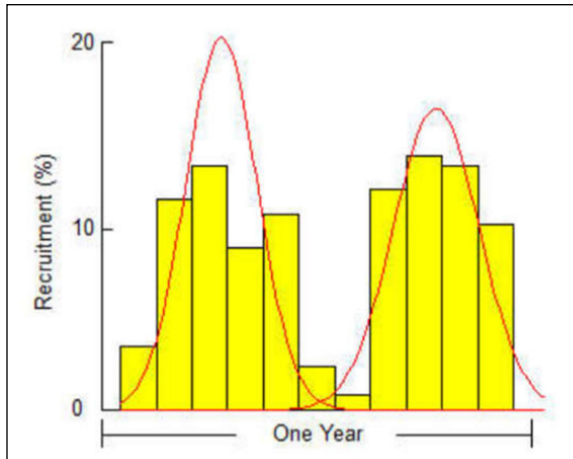Total mortality (*Z*) was approximately 4.63

Figure 5. Recruitment pattern of *C. luhuanus* showing two cohorts in a year derived using ELEFAN-I in FiSAT.

year⁻¹ from 2011 to 2013. Natural mortality (M) was considered equal to the derived *Z/K* value (*M*=0.71). Fishing mortality (*F*) for the two years covered by the study, taken to be equal to the difference between *Z* and *M*, was approximately 3.92 year⁻¹. The ratio of *F* and *Z* is 0.85, taken as the species' exploitation rate (*E*).

The maximum exploitation rate was computed at 0.42 (Figure 6), which is the level by which the population may be sustained given fishing pressure, a level that is below the computed *E*-value. Removal of 50% of the biomass has a variable exploitation rate of 0.30 to 0.50, which is probably dependent on the initial population.

4. DISCUSSIONS

Growth of *C. luhuanus* is deterministic, with maximum length attained by the second year, after which changes in the organism are observable in lip thickness. This limits the use of available analytical tools on the fishery of the species with disproportionate change in length with age. As this growth pattern is true for all Strombids, applying GM to age individuals is a significant tool for collecting age-frequency data for population studies. The approach also eliminates

sampling artifacts that may be significant for exploited populations. Over other methods used in generating age-frequency species distribution with deterministic growth, i.e., weight of shell (Cob et al. 2009; Sheldon 2011), GM data can be generated in situ without significant interference to the species under study. Field photos, however, need to be standardized for robust analysis.

The L∞ value generated for the species (7.28 cm) indicates that despite the high exploitation rate, mature individuals can contribute to the next generation. On the other hand, the *K*-value of 1.0 yr⁻¹ expresses a growth rate faster than the commercially valuable *C. gigas* with K at 0.27 yr⁻¹ to 0.4 yr⁻¹ (Cardenas and Aranda 2013; Appledorn 1988) but slower than the commercially exploited species *Conomurex canarium, Perna viridis,* and *Modiolus metcalfei* at *K* = 1.2 yr⁻¹, *K* = 1.5 yr⁻¹, and *K* = 2.04 yr⁻¹, respectively (Cob et al. 2009; Al-Barwani et al. 2007; Tumanda et al. 1997). Given its deterministic growth, a yearling may already be considered to have large meat and may be harvested. In addition, sea ranching the species may be a good option given other ecological considerations like seagrass protection.

The idea that the species may be considered for sea ranching becomes more relevant in light of the 85% exploitation rate for the species. Relative to E-values derived for other exploited Strombid species (Table 1), the higher value computed for *C. luhuanus* indicates possible overharvesting of the species. This high value may be attributed to the species' gregariousness allowing the gathering of the whole
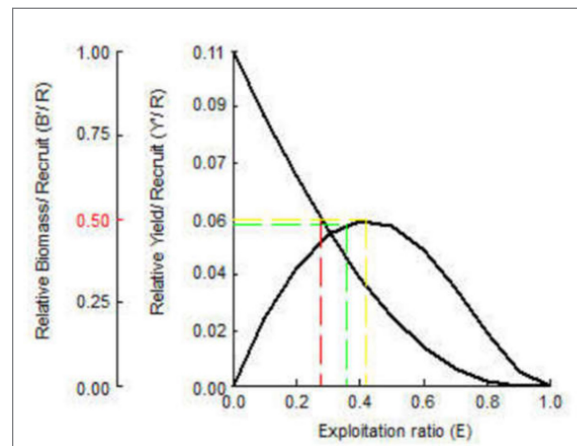

Figure 6. Yield pre-recruit (Y/R) and biomass per recruit (B/R) estimate of *C. luhuanus* (Lc/L∞ = 0.051; M/K = 1). The red dotted line indicates the exploitation rate by which 50% of the biomass is removed; the green dotted line is the 50% exploitatio n rate level by which more than 60% of the existing biomass is removed; the yellow dotted line is the maximum exploitation rate at which population can be sustained.

Table 1. Comparative published values of total mortality (Z), fishing mortality (F), and exploitation rate (E) of different exploited molluscan species.

Species	Country	Total Mortality/ year (Z)	Fishing Mortality/year (F)	Exploitation rate (E; %)	Source
Perna viridis	Malaysia	2.48	0.79	32.00	Berwani et al. 2007
Modiolusmetcalfei	Philippines	7.64	5.60	73.00	Tumanda et al. 1997
Polymesodaerosa	Philippines	3.74	2.33	62.00	Dolorosa and Dangan-Galon 2015
Paphia undulata	Philippines	6.18	4.61	79.00	del Norte-Campos and Villarta 2006
Strombus (Conomurex) canarium	Malaysia	2.56 (females); 2.72 (males)	1.61 (females); 1.86 (males)	63.00 (females); 68.00 (males)	Cob et al. 2009
Conomurex luhuanus	Indonesia	3.03 (females) 4.32 (males)	1.94 (females); 3.42 (males)	64 (females); 79 (males	Haumahu and Uneputty 2021
Conomurex luhuanus	Philippines	4.52	3.70	85.00	This study

patch by fishermen. Interviews with gleaners also indicate that improvement of fishing equipment also increases harvesting pressure on the species. Using compressors by some enterprising fishers allows the complete harvest of individuals within a patch and exploitation of aggregations beyond 8-meters depth.

Despite a very high exploitation rate, size frequency distribution shows the presence of reproductive individuals inconsistent with profiles of most exploited species. This suggests that the harvesting effort is not length specific. The crypsis attained by adults from algal growth on the shell and the burying behavior of younger individuals may be factors for this observation.

Given the behavioral factors that may be cushioning harvesting pressure, the computed E-value is still twice the computed E-max at which level the population may be sustained despite exploitation. Past the E-max value, the population may be considered extirpated, where reproduction may be compromised, and population recovery is nil (Cabral et al. 2014). However, age-frequency data indicate that recruitment may be actively happening twice a year. Interviews with fishers also indicate a "reappearance" of aggregations after periods of low density. Population refugia and dynamic spatial aggregation formation may be factors that need to be explored to explain apparent population resilience. The population studied was at snorkeling depth, where artisanal fishing is being done. Reports on the use of hooks for the species in deeper waters seem to support the occurrence of populations in deeper waters, which may serve as a refuge from harvesting pressure at shallow depths.

Deep water aggregations may also contribute to the recruitment of shallow water aggregations.

Aside from deep water aggregations, there may be a possibility of populations associated with habitats other than seagrass areas. For example, rubble and sand sites may be occupied by the species as observed during data gathering. In addition, periodic movement of individuals may constitute a spatial dynamic that may cushion harvesting pressure, but these need further exploration.

5. CONCLUSIONS

Conomurex luhuanus shows a bimodal recruitment pattern indicating high population turnover. The growth parameter (*K*-value) is 1.00 yr^{-1} which is relatively slower than other commercially exploited species. The computed exploitation rate (*E* = 0.84) of *C. luhuanus*, together with fishing mortality (*M*) rate of 0.71 and fishing mortality (*F*) at 3.92 year^{-1}, points to an overexploited population, possibly with the reproduction compromised. However, other biological data points out factors that may cushion overharvesting. These factors may include crypsis, burial behavior, the presence of refugia, and spatial dynamics of aggregation, and the bimodal reproduction cycle may balance out harvesting pressure. Exploration of these factors may elucidate effective intervention options that may be applied to other aggregating species exploited by the artisanal fishery.

ACKNOWLEDGEMENT

AUTHOR CONTRIBUTIONS

Sanchez-Escalona KP: Writing - Original draft preparation. **Aliño PM**: Idea input and editing

CONFLICTS OF INTEREST

We declare no conflict of interest in doing this work.

ETHICS STATEMENT

The researchers followed all institutional and national guidelines for the use of animals as subjects, such that only those used as training animals for GM were directly harvested from the identified aggregations.

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