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Fractal analysis of seahorses in Mindanao, Philippines: A tale of their own

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Abstract. *Tabugo SR, Claver PSS. 2022. Fractal analysis of seahorses in Mindanao, Philippines: A tale of their own. Biodiversitas 23: 5233-5238.* Monitoring populations of species is essential for science-driven policymaking. However, monitoring can be a daunting task for threatened and vulnerable species like seahorses. They are often threatened by overfishing and habitat destruction in the marine environment. Since they are considered a flagship species, monitoring populations in Panguil and Murcielagos Bay, which served as the home of the two common seahorses in Mindanao, Philippines, is vital. Fractals naturally occur in nature and hence can be used as possible predictors. Morphometric complexity patterns were investigated in the *Hippocampus kuda* and *Hippocampus comes* via fractal geometry to delineate irregular non-euclidean objects. The difference between fractal dimension and lacunarity values was tested between species. The hypothesis states that high fractal dimensions are deviations from the equilibrium state/chaos and, thereby, can be linked to vulnerability. High mean fractal dimension (Da) based on box-counting and coefficient of variation (CV) of the lacunarity method were found in *H. kuda* (F) and *H. comes* (F). The observed variations can be attributed to morphological complexity as they have adapted to varied microhabitats. Herewith, fractals can be a fast, easy, convenient, and non-invasive way of monitoring species. The results of the study can support conservation protection measures for the two species.

Keywords: Fractals, *Hippocampus comes*, *Hippocampus kuda*, microhabitat, monitoring

INTRODUCTION

Monitoring is fundamental to promoting good policy and efficient conservation management programs. In some countries, they rely on volunteers to monitor valuable vulnerable species. However, monitoring posed a major ecological and social challenge. The challenges may vary among individual threatened species and communities, which means that monitoring designs need to be tailored-fit carefully to each circumstance. The incessant search for cost-efficient, effective, and non-invasive methods becomes pertinent thus, the idea of 'shape' comes to mind. Shape information may tell a lot about the organism at hand. Studies showed that the shape of the object could be used to measure its complexity and like any other hierarchical construct, biological entities were thought to adapt undefined possibilities of configurations ('forms') inside the realm of a common general framework. Shape descriptors can be reliably used as overall indicators of the macro state (Neha et al. 2013). A proposed method for irregular non-euclidean objects is better described by fractal geometry and the measurable value is called the fractal dimension. In nature, there are myriads of phenomena of fractals such as the complex geometries of many types of biological cells, complex patterns such as river paths, tumor growth, tree growth, heart rates, diabetic retinopathy, gene expression, and cellular differentiation in space and time. This paved the way for the importance of fractals in biological forms and analysis. Spatial fractals are repeats of self-similarity on different scales having no loss of details at the same time, revealing self-similar forms (Huikuri and Stein 2012; Bai et al. 2020). The manifestation of repeats in the segments of trunk and tail rings impose fractal properties on seahorses.

Seahorses are of interest because they are unique in shape, and it was believed that the S-curved body shape is an evolutionary response to habitat and function, making it a recent bodily innovation. Body shape variation/ complexity can be affected by the environment and evolutionary adaptation with respect to function (Van Wassenbergh et al. 2011). Studies show that different species are said to be associated with different microhabitats and seahorses, often referred to as flagship species of the marine environment (Pajaro and Vincent 2015; Tabugo-Rico et al. 2017). At present, seven species of seahorses are listed as 'vulnerable' on the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species. While others remained 'data efficient,' hence, monitoring is vital. They are of interest to many researchers because of low mobility, relatively limited home ranges, parental status, and fidelity. Their value in Traditional Chinese Medicine (TCM), curios and aquarium trade led to increasing demand. Among the two (2) important species in Panguil and Murcielagos bay, Mindanao, the Philippines, that gained popularity in trading were *Hippocampus comes* (tiger-tail seahorse) and *Hippocampus kuda* (yellow seahorse) (Loh et al. 2014). Both bays experienced high sedimentation rates and are in fair to poor condition. It was recorded before that these bays were once rich fishing grounds but suffered from decades of overfishing, destructive fishing practices, pollution by poisonous chemicals, and mining activities (Israel et al. 2004; Cortes-Maramba et al. 2006). Hence, become appropriate areas for biomonitoring.

This serves as an exploratory study to objectively describe the morphometric complexity of two common seahorses. Obtained fractal dimensions can be utilized as a quantitative predictor range and marker of morphological and biological shape complexity of species and associated microhabitats. It is hypothesized that fractals are triggered by conditions deviating from the equilibrium state and can be linked with chaos (Klein et al. 2013). The fractal dimension has been confirmed to measure the space-filling capacity of a pattern reflecting complexity which can be linked with vulnerability (Li et al. 2019). Thereby, vulnerability can be associated with high fractal dimensions. Seahorses exhibit natural fractal patterns in their body morphology. Is it hypothesized that high fractal dimensions can indicate a species' vulnerability. Since environmental perturbations may be manifested in an organism's morphological complexity (Jelinek et al. 2013), results may contribute to the knowledge of the nature of seahorse populations for conservation efforts.

MATERIALS AND METHODS

Field Sampling areas, specimen collection and identification

The sampling areas were in Panguil Bay and Murcielagos Bays, among the well-known and environmentally vulnerable bays in Mindanao. The sampling sites were in Tubod, Lanao del Norte, Lopez Jaena, Misamis Occidental and Rizal, Zamboanga del Norte. Panguil Bay is adjacent to Iligan bay in Mindanao, Philippines. The bay separates the Zamboanga Peninsula from the rest of the island in Mindanao. Meanwhile, Murcielagos Bay is on the northeastern side of Zamboanga del Norte. It has three major marine ecosystems, sea grass (2674.96 ha), mangroves (785.48 ha) and marine sanctuary (27 ha) (Israel et al. 2004) (Figure 1). For this study, opportunistic sampling was employed where adult seahorse specimens (bycatch samples) were courtesy of fishermen (under gratuitous permit, GP No. 0184-19) and live photos were taken from underwater surveys based on the standardized procedure. Samples were identified using a photographic guide to seahorses (Loh et al. 2014) along with consultation of experts. Pictures were taken for image processing and analyses. Underwater surveys verified the respective microhabitats associated with species of seahorses.

Image acquisition, processing, fractal analysis and statistical analysis

Images of seahorses from Tubod, Lanao del Norte; Lopez Jaena, Misamis Occidental, Panguil Bay and Rizal, Zamboanga del Norte, Murcielagos Bay were acquired using Canon DSLR 550D (for bycatch samples) and Canon SX260 HS (live underwater photography). Image processing was done in triplicates to reduce and avoid bias and error. Before the actual fractal analysis, full-colored images of seahorses were pre-processed using Adobe Photoshop. Fraclac v.2.5 software, available as a plugin to ImageJ, was used to process and analyze images per species. Thirty (30) images per sex/species in triplicates, then further subsampled by the software, were processed. Fraclac software has been designed to cater digital image analysis, which is suitable with binary digital images, especially biological forms or fractal contours. It is utilized in the measurement of difficult-to-describe morphological features. This study used box counting and lacunarity methods. Herewith, FracLac delivers a measure of complexity called fractal dimension (DB). This refers to the ratio of increasing detail with respect to scale (ε) and is expressed in fractals (Jelinek et al. 2013). The basic technique to generate the DB in Fraclac is via the box-counting method. Moreover, lacunarity refers to the gappiness or visual texture of the object. In any given image, it is a measure of heterogeneity (inhomogeneity) or translational and rotational variance. This value supplements DB in describing patterns of digital images.

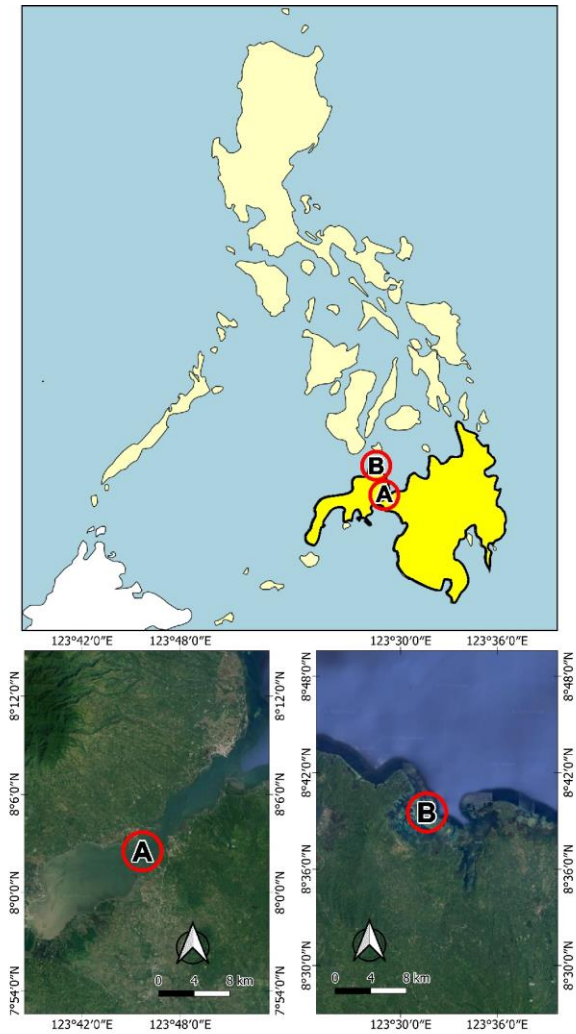

Figure 1. Study areas: A. Panguil Bay; B. Murcielagos Bay, Mindanao, Philippines (source:google maps)

Whereas lacunarity is calculated as the variation in pixel density at different box sizes and CV stands for coefficient of variation=∂/μ for pixel distribution. This value refers to the variation in the dataset and is thereby computed as the standard deviation over the mean of the data (∂/μ) (Karperien 2005). Values are automatically calculated by FracLac in a regular scan. To look at species differences, statistics were calculated using the PAST v.2.17, software. Measures of frequency, central tendency, dispersion, and test for normality (Shapiro-Wilk test) were performed. After this, the Kruskal-Wallis test and Mann-Whitney pairwise comparison were used to check for any significant difference between groups.

RESULTS AND DISCUSSION

In the Philippines, seahorses are often targeted by fisherfolk for trading, curios, medicinal, and aquarium use (Pajaro and Vincent 2015). Apparently, they are considered as vulnerable to bycatch fishing and habitat degradation. In Mindanao, there is still much to learn about the nature of seahorse populations. Panguil Bay and Murcielagos Bay once flourished in marine resources and became rich fishing grounds. Threats in the areas lead to habitat degradation and reduced fish catch. Data referring to morphological complexity in relation to vulnerability and resilience remain lacking. Thus, it is worthwhile to monitor populations in the area for programs on conservation and sustainability studies.

Previous studies on complex patterns of fractals show that fractals are deviations from the equilibrium state and are hence associated with chaos. High fractal dimension values indicate deviations from (relatively normal) equilibrium state (Klein et al. 2013). In like manner, seahorses exhibit natural fractal patterns in their body morphology. Is it hypothesized that high fractal dimensions may indicate species' vulnerability. Since environmental perturbations may be manifested in an organism's morphological complexity (Jelinek et al. 2013). Vulnerability refers to the inability of the system to successfully resist the effects of an undesirable environment (Giudicianni et al. 2021). Investigating these patterns may hold the key to the non-invasive biomonitoring of populations. Data in Table 1 shows the summary of mean fractal dimensions and coefficient of variation with corresponding minimum and maximum values, respectively. For *H. kuda* (M), predictor range values for D_B is from 1.5278-1.6102; *H. kuda* (F): D_B (1.5939-1.6645); *H. comes* (M): D_B (1.5325-1.6351); *H. comes* (F): D_B (1.5448-1.677) respectively.

The observed overlapped in the range of fractal dimension values may indicate similarity in morphological complexity and can be linked with common microhabitats (Klein et al. 2013; Pajaro and Vincent 2015; Tabugo-Rico et al. 2017). As such, *H. kuda* was found around 0.5 to 4m in depth in seagrass beds, rocky littoral zones, or clinging to hard corals. While *H. comes* were reportedly landed on shallow waters and 20m deep coral reefs, sponge gardens, and floating sargassum. Several studies show that different species can be associated with different microhabitats. Based on field observations and related studies among the two common seahorses, the *H. kuda* occupies different microhabitats such that they can be found in estuaries, coastal bays, lagoons, mangroves, harbors, coral reefs, seagrass beds, floating seaweeds, muddy, macroalgae, sandy bottoms, rocky littoral zones and lower reaches of rivers whereas *H. comes* typically found as juveniles on floating sargassum, moving to corals and sponges when older (Loh et al. 2014). The mean fractal dimension values were calculated based on the box-counting method and are shown in Figure 2. The lowest mean fractal dimension value (D_B) is *H. kuda* (M): 1.5612 and the highest is *H. kuda* (F): 1.6131. Meanwhile, the mean D_B for *H. comes* (M): 1.5682, and D_B for *H. comes* (F): 1.5721, respectively. In addition, lacunarity stands for gappiness or visual texture, it is a measure of heterogeneity (inhomogeneity) or translational and rotational variance in an image. This measure practically supplements fractal dimensions in describing patterns of digital images measuring the variation in the dataset and is expressed as the standard deviation over the mean of the data ($^{\partial}/_{\mu}$) (Karperien 2005). The mean coefficient of variation (CV) is shown in Figure 3. The lowest mean coefficient variation (CV) is of *H. kuda* (M): 0.2882 and the highest is *H. comes* (F): 0.3948 while *H. kuda* (F) has 0.3057 and *H. comes* (M): 0.3874. Herewith, the results of fractal dimensions (D_B) were not directly related with the coefficient of variation (CV) values. Showing that females have exhibited higher variability compared to the males for both species. These findings coincide with high D_B values for both females of *H. kuda* and *H. comes*. In biology, female seahorses occupy a wider range of movement and dispersal. As recorded for some species, females have a territory of about 100 m^2 and males have a territory of only about 0.5 square meters, but their territories overlap (Loh et al. 2014). Thus, the female is more exposed to varied microhabitats compared to the male species. Degradation of such microhabitats may increase their vulnerability. Females often become a subject also to bycatch by trawlers because of this.

Table 1. Summary of fractal dimension (D_B) and coeffiecient of variation (CV) values for lacunarity of seahorses found in Panguil and Murcielagos Bay, Philippines

	Mean D_B	**Min D_B**	**Max D_B**	**Mean CV**	**Min CV**	**Max CV**
Hippocampus kuda (M)	1.5612	1.5278	1.6102	0.2882	0.2414	0.3434
Hippocampus kuda (F)	1.6131	1.5939	1.6645	0.3057	0.2754	0.3454
Hippocampus comes (M)	1.5682	1.5325	1.6351	0.3875	0.3242	0.5346
Hippocampus comes (F)	1.5721	1.5448	1.6277	0.3948	0.3405	0.5392

M: male; F: female

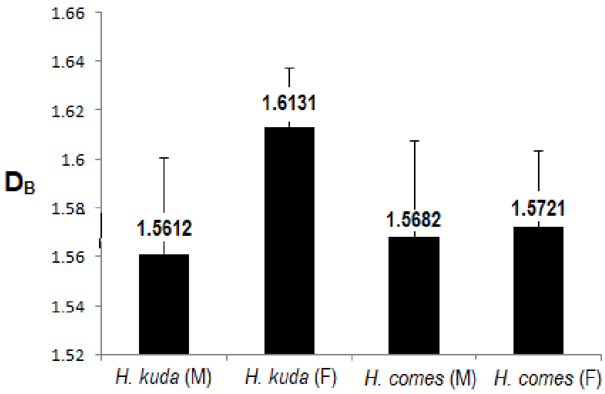

Figure 2. Mean fractal dimension values (DB) of seahorse species from Panguil Bay and Murcielagos Bay, Philippines (M: male; F: female)

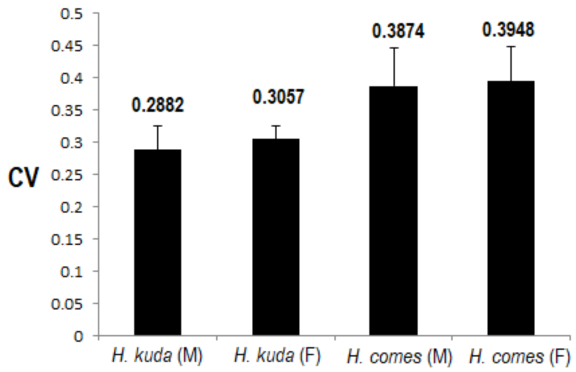

Figure 3. Mean coefficient of variation (CV) values for lacunarity of seahorse from Panguil Bay and Murceilagos Bay, Philippines (M: male; F: female)

High fractal dimension (DB) values were associated with females of *H. kuda* and *H. comes*, respectively. A study on fractals shows that fractals are deviations from the equilibrium state and are thus associated with chaos (Klein et al. 2013). Some studies show that the fractal dimension is considered a key factor associated with vulnerability, where the quantitative power function relationship between vulnerability and fractal dimension generated an unambiguous mathematical formula. The fractal dimension has been confirmed to measure the space-filling capacity of a pattern reflecting complexity which can be linked with vulnerability (Li et al. 2019). Hence, high fractal dimensions can be associated with vulnerability. The greater the fractal dimension (DB) value, the more complex the species are and perhaps vulnerable. Results show that the females for *H. kuda* and *H. comes* from both Bays have high mean fractal dimension values and coefficient of variation. It is morphologically complex and may have implications for its vulnerability. Noteworthy, between the two, *H. kuda* is among the highly valued seahorse species in the Philippines because of its smooth appearance and usually exhibiting pale yellow color that is much preferred by overseas markets of both traditional medicine and curious trade (Celino et al. 2012). They are often seen in shallow waters in coastal bays and lagoons, sea grass beds, floating seaweeds, sandy sediments in the rocky littoral zone, muddy bottoms, mangroves, estuaries, and lower reaches of rivers. *Hippocampus kuda* has a smooth, deep body, thick snout, and head. Color variation exists for these species. But generally, females have more narrow bodies than males (Tabugo-Rico et al. 2017). Since they are quite versatile in relation to the varied microhabitats they occupy, they can also be vulnerable. Meanwhile, *H. comes* were found in shallow waters to 20m depth waters. They are commonly spotted in sponge gardens, coral reefs, and some floating sargassum beds. The species has an average to narrow body, a small head relative to the body with rugged spines on the body, double cheek, striped tail, prominent nose spine and a low coronet. The males exhibit a deep ventrolateral medial portion having conspicuous bellies. Reports support *H. comes* and list it as vulnerable (VU A2bd+4bd) based on suspected declines of 30%-50% due to incidental catch, targeted catch, and habitat degradation. Studies revealed evidence of a decline in the availability of this species, also given its popularity for dried TCM trade and for live aquariums. The population decline related to this species in other areas apart from the Philippines remains unknown, but, the abundance of *H. comes* surveyed in several islands of the Philippines shows evidence of a decline in availability. The presence of anthropogenic activities, habitat deterioration and minor success in conservation indicate threats in the future for this species (Nellas and Vincent 2012; Loh et al. 2014; Woodall et al. 2015; Woodall et al. 2018). Moreover, Panguil Bay has suffered for decades from overfishing and destructive fishing practices. One of the biggest contributors to over-exploitation was the excessive use of filter nets, locally called *'sanggab'*. These nets were designed to trap all marine organisms, even macro-plankton, depleting the food chain in the bay. Further degradation is a consequence of habitat destruction (such as mangrove areas converted to fishing ponds), pollution caused by poisonous chemicals, and increasing human development along the bay's shore. The inevitable decline in fish catch prompted rehabilitation efforts that included the removal of illegal fishing structures such as filter nets. While in Murceilagos Bay, marine resources are facing an alarming condition, according to scientific studies, due to small- and large-scale mining in Sibutad, Zamboanga del Norte, which remains a threat in the area (Cortes-Maramba et al. 2006).

Test for normality (Shapiro-Wilk test) was performed where $p<0.05$ indicating that the populations examined were not normally distributed. Any significant difference among species in terms of morphological complexity based on fractal dimensions was then analyzed via Kruskal-Wallis test where p: 0.007169 ($p<0.05$).

Mann-Whitney pairwise comparison was performed to check which groups significantly differ (Table 2). This was visualized through a box plot (Figure 4). Results show a significant difference between species and are highly evident between *H. kuda* (M) and *H. kuda* (F); *H. kuda* (F) and *H. comes* (M); *H. kuda* (F) and *H. comes* (F) respectively showing significant difference in females between species.

Table 2. Mann-Whitney pairwise comparison between fractal dimensions (D_B) of species of seahorses found in Panguil and Murceilagos Bay, Philippines

	***Hippocampus kuda* (M)**	***Hippocampus kuda* (F)**	***Hippocampus comes* (M)**	***Hippocampus comes* (F)**
Hippocampus kuda (M)	-			
Hippocampus kuda (F)	0.001652*	-		
Hippocampus comes (M)	0.7728	0.0404*	-	
Hippocampus comes (F)	0.1659	0.01019*	0.2366	-

*p<0.05 is significant; M: male; F: female

Table 3. Mann-Whitney pairwise comparison between coefficient of variation (CV) values for lacunarity of species of seahorses found in Panguil and Murceilagos Bay, Philippines

	***Hippocampus kuda* (M)**	***Hippocampus kuda* (F)**	***Hippocampus comes* (M)**	***Hippocampus comes* (F)**
Hippocampus kuda (M)	-			
Hippocampus kuda (F)	0.2855	-		
Hippocampus comes (M)	9.735E-05*	0.0001233*	-	
Hippocampus comes (F)	4.695E-05*	6.006E-05*	0.5834	-

*p<0.05 is significant; M: male; F: female

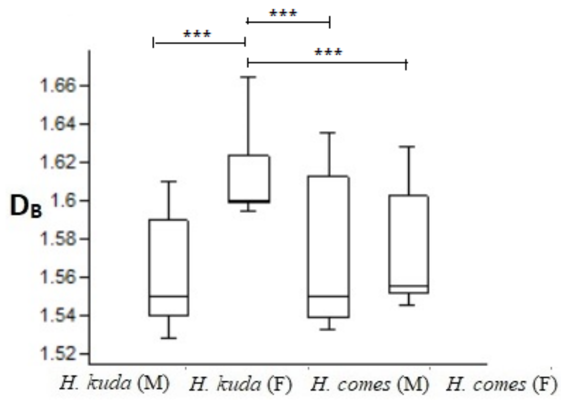

Figure 4. Mean fractal dimension values (D_B) and significant difference (*) between seahorse species from Panguil and Murceilagos Bay, Mindanao, Philippines (M: male; F: female)

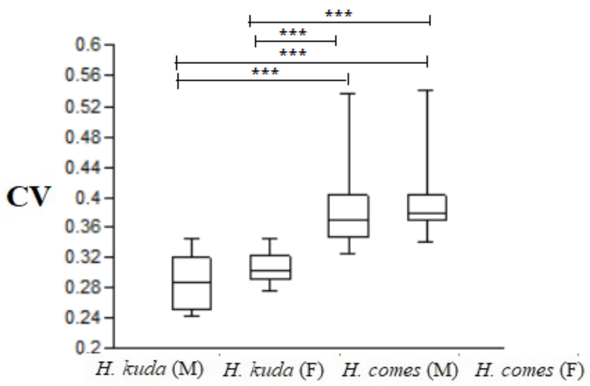

Figure 5. Mean coefficient of variation (CV) for lacunarity and significant difference (*) between seahorse species from Panguil and Murceilagos Bay, Mindanao, Philippines (M: male; F: female)

Moreover, results were further verified through coefficient variation (CV) for lacunarity via Kruskal-Wallis test where p: 3.428E-07 ($p<0.05$). Mann-Whitney pairwise comparison was further performed to check which groups significantly differ (Table 3) then results were visualized in a box plot (Figure 5). The results yield a significant difference between species and is highly evident between *H. kuda* (M) vs. *H. comes* (M); *H. kuda* (M) vs. *H. comes* (F); *H. kuda* (F) vs. *H. comes* (M); *H. kuda* (F) vs. *H. comes* (F) respectively. A significant difference could be attributed to morphological complexity and preferred microhabitat. Herewith, *H. kuda* and *H. comes* female species yield to be the most complex, variable and can be vulnerable. Noteworthy is that the observed significant difference among fractal dimensions and CV values for lacunarity show promising potential as an objective parameter in describing morphological complexity in seahorses.

In addition, findings suggest a positive correlation between fractal dimensions and lacunarity. It supports a direct relationship between fractal dimension, coefficient of variation, morphological complexity, and heterogeneity, which was found consistent for the females. In this respect, investigating fractals provides a fast, easy, convenient, inexpensive, and reliable method (Reishofer et al. 2012; Metze 2013; Di Ieva et al. 2014; Fabrizii et al. 2014). Results aide in the conservation of important microhabitats and most threatened ecosystems such as seagrass meadows (Sondak and Kaligis 2022), coral reefs (Wulandari et al. 2022), sargassum beds, mangroves (Alimbon and Manseguiao 2021), sponge gardens and estuaries.

In conclusion, the results of this study provide baseline data on the morphological complexity of seahorses based on fractals in cognizance of conservation efforts in Panguil and Murceilagos Bay. It is hypothesized that fractals are deviations from the equilibrium state and thus associated with chaos. Hence, high fractal dimensions may have implications for vulnerability. Results show that *H. kuda* and *H. comes* females have the highest mean fractal dimension values and coefficient of variation, thus the most morphologically complex and can be vulnerable. There is a significant difference between species based on fractal dimensions (D_B) and coefficient of variation (CV) values which could be attributed to differences in morphological complexity and preferred microhabitats. Also, females are more exposed to varied microhabitats compared to the male species and thus can be vulnerable. Moreover, fractal dimensions and CV values for lacunarity show promising potential as an objective parameter in describing morphological complexity in seahorses and hence can be employed for monitoring purposes. Herewith, significant findings contribute to understanding the nature of seahorses, especially from Panguil and Murceilagos Bay, for conservation efforts.

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