Classification of Marine Seagrasses by Leaf Fractal Dimensions Analysis

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Abstract

This particular study used the fractal dimensions of leaves of sea-grasses that were found near the Marine Protected Area (MPA) of Punta, Panaon, Misamis Occidental to determine if the same can be used for classification purposes. The species of sea-grasses used were: Thalassia hemprichii, Syringodium isoetifolium*, and* Cymodocea rotundata. *Findings revealed that the fractal dimensions can be used to differentiate one seagrass species from another sea-grass species to another species. (f= 6.12, p= 0.015). However, leaf fractal dimensions alone cannot differentiate between (*Thalassia hemprichii and Syringodium isoetifolium*) while it can differentiate between (*Thalassia hemprichii *and* Cymodocea rotundata*) and (*Cymodocea rotundata *and* Syringodium isoetifolium*). The results may be due to few samples for each species of sea-grass. The empirical probability of misclassification using the technique is approximately 10.89%.*

Keywords: leaf fractal dimensions, taxonomy, sea-grass, marine protected area

1.0 Introduction

Sea-grasses are marine flowering plants and belong to various plant families (see Section 2) all in the order Alismatales. The term sea-grass may have come from the observation in many species of these marine flowering plants, the leaves are long and narrow and they usually grow in large meadows looking much like a grassland, that is, they resemble terrestrial grasses of the family Poaceae. Seagrass beds form highly diverse and productive ecosystems harboring hundreds of associated species from almost all phyla. For instance, juvenile and adult fish, epiphytic and free-moving macro and microalgae, molluscs, bristle worms and nematodes can be seen in beds of sea-grasses. Originally, it was thought that very few species feed directly on seagrass leaves (because of their low nutritional values), recent scientific studies, however, have demonstrated that hundreds of species feed directly on sea-grasses including green turtles, dugongs, manatees, fish, geese, swan, sea urchins and crabs (Duarte et al.,1999). Furthermore, some fish species feed on the seagrass and feed their young in adjacent mangroves or coral reefs. Seagrasses are likewise important mechanisms for trapping sediments and slowing water movement causing suspended sediments to fall out thereby reducing sediment loads in the water and ultimately benefitting the coral reefs nearby. The ecological functions of seagrasses are therefore quite important in sustaining a healthy marine environment.

As an important aspect of ecological research, accurate identification of the species of sea-grasses are necessary if estimation of their impact on the marine environment is to be ascertained. The use of fractal dimensions for classification purposes is a relatively new area of study. Traditional geometric

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morphometric techniques such as the Elliptic Fourier Analysis (EFA) and others have certain inherent shortcomings that may be satisfactorily addressed by fractal analysis. For instance, the EFA used ellipses to estimate the outline of geometric figures and so, it cannot be used in cases where there are "pointed" or rough features of the geometric figure under consideration (Neto et al., 2005) and (Boudon, et.al., 2010). This study attempts to replicate the study of Almirol, Lapinig and Sabandal (2013) in using fractal dimensions as a tool for classifying and identifying sea-grass species.

2.0 Literature Review

Sea grasses have the following genera:

Family	**Genus**
Cymodoceaceae	Amphibolis Cymodocea Halodule Syringodium Thalassodendron
Hydrocharitaceae	Enhalus Halophila Thalassia
Posidoniaceae	Posidonia
Zosteraceae	Phyllospadix Zostera

Seagrasses are sometimes labeled ecosystem engineers, because they partly create their own habitat: the leaves slow down water-currents increasing sedimentation, and the seagrass roots and rhizomes stabilize the seabed. Their importance for associated species is mainly due to provision of shelter (through their three-dimensional structure in the water column), and for their extraordinarily high rate of primary production. As a result, seagrasses provide coastal zones with a number of ecosystem goods and ecosystem services, for instance fishing grounds, wave protection, oxygen production and protection against coastal erosion. Seagrass meadows account for 15% of the ocean's total carbon storage. Per hectare, it holds twice as much carbon dioxide as rain forests. Yearly, seagrasses sequester about 27.4 million tons of CO_2. Due to global warming, some seagrasses will go extinct –*Posidonia oceanica* is expected to go extinct, or nearly so, by 2050. This would result in CO_2 release (Green et al. ,2003).

They form extensive beds or meadows, which can be either mono-specific (made up of a single species) or in mixed beds where more than one species coexist. In temperate areas, usually one or a few species dominate (like the eelgrass *Zostera marina* in the North Atlantic), whereas tropical beds usually are more diverse, with up to thirteen species recorded in the Philippines

Syringodium isoetifolium, more commonly known as Noodle sea-grass, gets its name from the noodle-like shape of its leaves. This sea-grass is common and widely distributed throughout the Indo-Pacific region. Noodle seagrass typically occurs on muddy substrates in depths down to 6 meters, but has been observed on sandy bottoms in depths down to 15 meters. *Syringodium isoetifolium* can form monospecific meadows, however, it is usually associated with other seagrasses, including *Cymodocea rotundata*, *Cymodocea serrulata*, *Halodule uninervis* and T*halassia hemprichii*. Leaf blades are cylindrical approximately 7-30cm long and 1-22mm wide and narrow towards the base. There is a central vascular bundle within the leaf blade surrounded by a circle of 6-8 air channels and 7-15 pericentral vascular bundles. Both male and female flowers have been observed.

Thalassia hemprichii is typically found in the sublittoral zone in depths down to 5 meters. This *seagrass* forms dense, monospecific meadows and is the dominant seagrass species on dead reef platforms and in bottom sediments composed of coral sand and coral rubble. *Thalassia hemprichii* has also been observed growing on muddy sand and soft mud bottoms, as well as mud covered coral banks. *Thalassia hemprichii* is a fast growing seagrass species able to recolonize disturbed areas quickly. The seeds of this seagrass are buoyant which allow for wider dispersal facilitated by wind and currents. This seagrass is an important food source for dugongs and sea turtles and provides critical grazing habitat for fish. *Thalassia hemprichii* is a ribbon-like seagrass similar in nature to *Thalassia testudinum*. The rhizome of Sickle grass is very thick and well developed approximately 3-5mm in diameter. Every 5-33 internodes along the rhizome, a short, lateral branch occurs on which leaf blades are arranged distichously and measure 10-40cm long and 4-11mm wide. Leaf margins are entire, but will sometimes bear slight serrations towards an obtuse blade tip.

Cymodocea rotundata was described by Paul Friedrich, August Ascherson and Georg Schwweinfurth in 1870. The name is considered as validly published. It has simple leaves that are alternate. It is a species in the Genus *Cymodocea* which contains 4 species and belongs to the family of the Cymodoceacea or (Manatee grass). Leaves are linear and sessile, they have entire margins and parallel venation. The flowers are arranged solitary.

3.0 Concept of a Fractal and Fractal Dimensions

Classical geometry considers objects that have integral dimensions: points have zero dimension, lines have one dimension, planes have two dimensions and cubes have three dimensions. Within a plane, one can represent points and straight lines and other geometric objects as shown below:

Figure 1: A fractal object in a plane

It is possible to represent geometric objects within a plane that are neither points nor lines like the squiggly line above. This squiggly geometric object cannot have dimension equal to 1 because it fills up more space than a line; it cannot have dimension equal to 2 because it does not form an area. Hence, its dimension λ has to be between 1 and 2 like $\lambda = 1.63$. We will say that the squiggly line is a fractal (a geometric object having fractional dimension).

The fractal dimension of an object defines its roughness, ruggedness or fragmentation. The higher the fractal dimension, the more rugged and irregular-looking is the object. Thus, although fractals are rough and irregular objects, the pattern of irregularities are repeated over and over again. This is called the self-similarity property of fractal. Benoit Mandelbrot (1967) is acknowledged as the mathematician who opened roughness as a legitimate topic for investigation in modern science. He claimed that nature and natural processes are fractals, while uniform, smooth and continuous patterns are man-made concepts and pervade mathematical analysis. He also said that by introducing "randomness" into the situation, one gets more realistic fractal representations.

After the publication of Mandelbrot's book: Fractals: The Geometry of Nature, many scientists used fractals with great success (Cohen, 1987) on fractal antennae; (Krummel et al., 1987) on forest fractals and others). It has found applications in various disciplines as well as in many areas of practical technology.

In Padua (2012), fractal geometry was translated to statistical language. A probability distribution akin to Pareto's distribution for incomes was proposed as a model for fractal random variables X:

$$(1)\qquad f(x) = \frac{(\lambda-1)}{\theta}\left(\frac{x}{\theta}\right)^{-\lambda} \quad ,x \geq \theta, \lambda > 0$$

Where λ = fractal dimension of x, $\theta = \inf_x\{x\}$.

A maximum – likelihood estimator for λ based on a random sample of size n was provided as:

$$(2)\qquad \hat{\lambda} = 1 + n\left(\sum_{i=1}^{n} log\left(\frac{x_i}{\theta}\right)\right)^{-1}.$$

He then proceeded to show that for n=1:

$$(3)\qquad z = \hat{\lambda}\log\left(\frac{x}{\theta}\right) - 1 \underset{\sim}{d} Exp(\lambda - 1) \text{ or:}$$

$$(4)\qquad q(z) = (\lambda - 1)\, exp(-(\lambda - 1)z)$$

For a random sample of size n, the random variable:

$$(5)\qquad q = \hat{\lambda}\sum_{i=1}^{n} log\left(\frac{x_i}{\theta}\right) - n$$

Has the same distribution as

$$q^* = \sum_{i=1}^{n} log\left(\frac{x_i}{\theta}\right) = \sum_{i=1}^{n} Z_i.$$

The distribution of (5) is therefore

$Gamma\left(n, \beta = \frac{1}{\lambda-1}\right)$ where $\lambda > 1$:

$$(6)\qquad h(q) = \frac{(\lambda-1)^n}{\Gamma(n)}\, q^{n-1}\, e^{-q(\lambda-1)} \qquad ,q > 0, \lambda > 1.$$

$$h(q) = \frac{(\lambda-1)^n}{\Gamma(n)!}\, q^{n-1}\, e^{-q(\lambda-1)}$$

Thus, if we have one sample of a species and if we are able to estimate its (geometric) fractal (see for example some available freeware like FRAK.OUT), then we are able to compare the fractal dimension for species (say, λ_1) with the specimen (λ_2):

$$(7)\qquad u = |\lambda_1 - \lambda_2|.$$

We approximate the distribution of u by an exponential distribution and obtain:

$$(8)\qquad \delta_s = P(u \geq \varepsilon) = \frac{1}{2}\left(1 + exp\left(-\varepsilon^{(\lambda_2 - 1)}\right)\right)$$

a similarity index

where λ_2 = fractal dimension q specimen species. We refer to (8) as a similarity index. As the difference $\varepsilon = |\lambda_1 - \lambda_2|$ increases, the similarity index decreases. If $\lambda_1 = \lambda_2$ (hence, $\varepsilon = 0$), the fractal dimensions are identical and the two documents are 100% similar. This means that the two species contains exactly the same fractal characteristics: straight lines, curves, strokes, spacings, slants and so on, and, must therefore belong to the same species.

It is also possible to determine what values of ε will yield high similarity index thus:

$$(9)\qquad \delta_s \geq 1 - \alpha \Leftrightarrow \varepsilon \leq \left[\log\frac{1}{1-2\alpha}\right]\left[\frac{1}{\lambda_2 - 1}\right] \qquad ,0 \leq \alpha \leq 1$$

For instance, if $\alpha = 0.05$, then the values of ε above will indicate 95% similarity index or greater.

4.0 Research Design and Methods

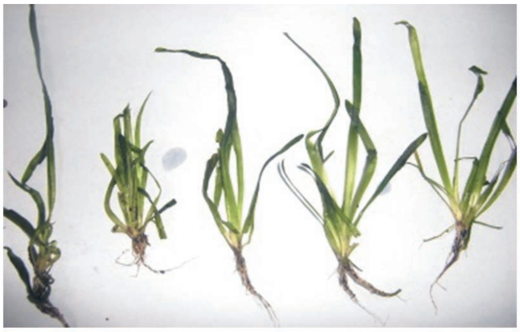
This particular study is designed to assess the viability of using fractal analysis in classifying and identifying leaves of seagrasses based on its fractal dimensions. The researchers randomly collected species of sea-grasses near the Marine Protected Area (MPA) in Panaon, Misamis Occidental. A total of three(3) seagrass species of five samples per species were collected. After the collection, the leaves were then washed with clean water then air dry for few hours. The cleaned specimens were then mounted on a white cardboard background prior to the actual photography.

Their fractal dimensions were calculated using FRAKOUT software. A digital camera was used and was mounted on a piece of white cardboard. Room lighting and dust contamination were controlled in order that the specimen's features are only caught on camera.

5.0 Results and Discussion

Figures 1- 3 show the seagrass leaves used

Thalassia hemprichii



Cymodocea rotundata

Syringodium isoetifolium

Table 1: Summary of Empirical Fractal Dimensions of Seagrasss Leaves

Trial	*Thalassia hemprichii*	*Syringodium isoetifolium*	*Cymodocea rotundata*
1	1.5295	1.5508	1.5828
2	1.5638	1.5500	1.5747
3	1.5499	1.5127	1.5888
4	1.5591	1.5408	1.5969
5	1.5032	1.5154	1.5456

Table 2: Means and Standard Deviations of the Fractal Dimensions

Variable	N	Mean	Median	TrMean	StDev	SE Mean
Thalassia hemprichii	5	1.5411	1.5499	1.5411	0.0249	0.0112
Syringodium isoetifolium	5	1.5339	1.5408	1.5339	0.0186	0.0083
Cymodocea rotundata	5	1.5778	1.5828	1.5778	0.0197	0.0088

Table 3. One-way ANOVA: Thalassia hemprichii, Syringodium isoetifolium, Cymodocea rotundata

Analysis of Variance

Source	DF	SS	MS	F	P
Factor	2	0.005536	0.002768	6.12	0.015
Error	12	0.005428	0.000452		
Total	14	0.010964			

Table 4: Summary of t-values for comparing fractal dimensions

Pair	Mean difference	t-value	p-value
Thalassia vs Syringodium	0.0072	0.51	0.623
Thalassia vs Cymodocea	-0.0367	-2.58	0.036
Syringodium vs. Cymodocea	-0.0439	-3.62	0.009
		Probability of Misclassification	0.1089

6.0 Discussions

All the seagrass leaves showed relatively high fractal dimensions. *Cymodocea rotundata* registered the highest fractal dimension among all segrasses considered. This means that of the three (3) species, *Cymodocea rotundata* has the most complex and rugged features *Thalassia hemprichii* and *Syringodium isoetifolium* recorded similar fractal dimension implying that these two species of sea-grasses have similar roughness features. Figure 4 below shows the fractal dimensions of the three (3) sea grass species:

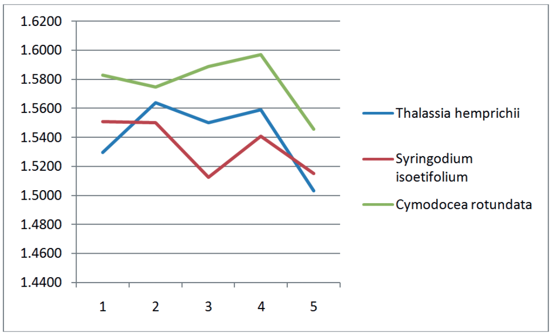


Figure 4: Fractal dimensions of the three seagrass species

The graph of the fractal dimensions of the three sea-grass species clearly illustrate that Cymodocea rotundata consistently registered the highest fractal dimension. It is therefore quite easy to distinguish this particular sea-grass species from the other two species.

Comparison of the fractal dimensions between seagrasses using ANOVA revealed that the fractal dimensions of the three (3) seagrasses leaves are significantly different (F=6.12, p= 0.015). The high computed value could be attributed to the small standard errors of the mean (fractal dimension) computed for each species. The significant difference noted for the fractal dimensions of the three (3) species imply that the use of fractal dimensions to differentiate across species is quite effective.

Further analysis, however revealed that both *Cymodecea rotundata* and *Syringodium isoetifolium* are unrecognizable while Thalassia hemprichii would easily be detected by the proposed methodology.

Some scientists like (Mancuso, 1997) and others (Ng et.2002)), used twenty (20) leaves as their samples. The larger sample size would reduce the standard error of the mean of the fractal dimensions. It is therefore very likely to have resulted to different findings. Due to the limited time and resources, however, we were constrained to use five samples (n=5) for each species. The researchers therefore, recommend using larger sample sizes for future studies and other factors can also should be considered like carbon absorption etc. (Boudon, 2004).

7.0 Conclusion

The use of fractal dimensions of leaves of seagrasses is a potential powerful technique in classifying and allocating sea-grasses according to their appropriate binomial nomenclature. Misclassification probability was recorded at (10.89%). However, leaves belonging to the same mangrove species have equally high similarity index exceeding to 90%.

ACKNOWLEDGEMENT

The authors are grateful to Dr. Roberto N. Padua for his technical assistance and guidance in the use of fractal statistics.

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