Classification of mangrove species based on leaf fractal dimensions*

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**Topic suggested by Dr. Roberto N. Padua, consultant, GADTC, MUST, UV and NMSC. Dr. Padua is currently developing the area of Fractal Statistics to support known results in Fractal Geometry.*

ABSTRACT

The study utilized the fractal dimensions of the leaves of mangrove species locally found in the City of Tangub to determine if the same can be used for classification purposes. The species used were: *Rhizophora mucronata*, *Avicennia marina*, *Pemphis acidula*, *Sonneratia alba* and *Acrostichum aureum*. Findings revealed that fractal dimensions can be used to differentiate one mangrove species from another through their leaf roughness ($f=14.400$, $p=0.000$). However, leaf fractal dimensions alone cannot differentiate the following mangrove species within groups: {*Rhizopora mucronata* and *Avicennia marina*}, {*Acrostichum aureum* and *Pemphis acidula*}, {*Sonneratia alba*}. In effect, leaf fractal dimensions identify only the following groupings: {*Rhizopora mucronata*, *Avicennia marina*}, {*Acrostichum aureum*, *Pemphis acidula*} and {*Sonneratia alba*}. The results may be due to the small sample sizes used for some of the mangrove species. In particular, the standard deviations of the fractal dimensions of the *Sonneratia alba* and *Avicennia marina* may have been over-estimated because of the small sample sizes. The empirical probability of misclassification using the technique is approximately 4.5%.

Keywords: *leaf fractal dimensions, taxonomy, mangrove species*

I. INTRODUCTION

Central to research ranging from physiology to conservation biology is the problem of sorting individuals into species categories. The importance of accurate species descriptions or accurate classification stems from their impact on estimations of species' habitat ranges, physiologic tolerance, and population sizes. Knowlton and Jackson (1994) noted, in fact, that these errors have consequences for our understanding of ecologic and evolutionary theory as well as the management and mitigation of the effects of global climate change. Establishing techniques that provide accurate characterization of species that minimize ambiguity in allocating individuals to species groups is important. Carlo, Barbeitos and Lasker (2011), however, averred that it is important to realize that traits used in discerning the evolutionary status of groups are not necessarily practical tools for

identification. Moreover, traits that can be used to identify specimens do not necessarily provide information about the evolutionary relatedness of species (Carlo, Barbeitos & Lasker, 2011). This study proposes the use of fractal dimensions as bases for taxonomic classification of mangrove species because of the sensitivity of fractal measures in detecting very small changes in the morphological features of plants and animals. Classification methods based on shape and morphological forms have been done in the past using Elliptic Fourier Analysis (EFA) and Geometric Morphologic Analysis (GMA) (Neto et al., 2006).

Rodriguez (2013), for instance, found that the fractal dimensions of fruit tree leaves endemic in the Philippines are significantly different across fruit trees but highly similar for the same fruit trees. These findings imply that the fractal dimensions of the leaves of fruits trees can be used for classification purposes. Palmer (1992) also found the same phenomenon for the fractal dimensions of leaves of trees endemic in the United States. In general, fractal dimensions have been used successfully for classification and identification purposes in various other fields. Barrera and Relatorres (2013) used fractal dimensions for handwriting analysis; Krummel (1986) applied fractal on soil fertility analysis; Selvam (2007, 2009) described the fractal dimensions of puffer fish; Telesca, Lapenna and Macchiato (2004) used fractal analysis for the seismic activities in Italy.

The use of fractals in classification and identification of mangrove species in the Philippines has not been tried out. This study is a pioneering investigation in this direction.

II. REVIEW OF LITERATURE

On the river banks, *Rhizophora mucronata* is a small to medium size evergreen tree growing to a height of about 20 to 25 meters (66 to 82 ft). The more typical height on the fringes of the sea are within 10 or 15 meters (33 or 49 ft). Buttressing the trunk of the tree is a large number of aerial stilt roots. The shape of the leaves resembles ellipses with major axis about 12 centimeters (4.7 in) long and minor axis within 6 centimeters (2.4 in) wide. They have elongated tips but these often break off. There are corky warts on the pale undersides of the leaves. The seeds are viviparous and start to develop while still attached to the tree. The root begins to elongate and may reach a length of a meter (yard) or more. When sufficiently well-developed, the propagules become detached from the branch and these begin to take roots in the mud below. The natural habitat of *Rhizophora mucronata* consists of estuaries, tidal creeks and flat coastal areas subject to daily tidal flooding. This mangrove species appears to be more tolerant of flooding than other mangrove species and they often form an evergreen covering to mangrove areas. The mangrove species can occur as a single pure stand or they may grow with a mangrove species of the same genus *Rhizophora apiculata*.

On the intertidal zones of estuarine areas, *Avicennia marina*, commonly known as grey mangrove or white mangrove, grow in profusion in tropical regions. They grow as a shrub or tree reaching heights ranging from three to ten meters, or up to 14 meters when conditions are right. The overall feature of the shrub resembles a gnarled arrangement of multiple branches with smooth light-grey bark made up of thin, stiff, brittle flakes. The five to eight-centimeter long leaves are thick, with an upper surface of bright and glossy green on appearance, and grey or silvery-white surface below, with minute matted hairs. As with other Avicennia species, it has aerial roots (pneumatophores) which grow to a about 20 centimeters in height, and a diameter of one centimeter. These allow the plant to absorb oxygen, which is deficient in its habitat. These roots also anchor the plant during the frequent inundation of seawater in the soft substrate of tidal systems. The fruit contains large cotyledons that surround the new stem of a seedling. The grey mangrove can experience stunting of growth in the conditions of water which are too saline,

but thrive to their full height in waters where both salt and fresh water are abundantly found. High salinity can be tolerated by the species within the process of excretion of salts through its leaves. Grey mangrove is a highly variable tree, with a number of ecotypes, and forms closely resembling other species Extreme weather conditions, high winds, and invasion of various pests and diseases are highly tolerable within its system, according to reports. It is a pioneer in muddy soil conditions with a PH value of 6.5 to 8, but is intolerant of shade.

Described in 1775, *Pemphis acidula* is a genus of maritime plants in family *Lythraceae*. While it was originally believed to have only one species, scientists now believed that there are at least two species of the genus. *Pemphis* are highly adaptive to their environment and depending on environmental factors; they can be densely branched, or low and spreading bushes or short trees. There are also variations in the leaves of this mangrove species. Thus, leaves may be small, fleshy and succulent, or they may be larger, flat and not fleshy at all. However, all surfaces are generally covered in silky, colorless trichomes. Their main stems can be furcated and can lie nearly prone, or can develop into one erect trunk. Most Pemphis live either at the fringes of mangrove forests, staying away from the forest-ocean interface; or they sometimes colonize beaches behind the intertidal zone, taking hold on rocks, gravel or sand, laterite or limestone, and frequently on promontories or crags.

The Sonneratia are called 'berembang' in Malaya, 'mangrove apple' in English, and 'Mangrovenapfel', "Pagatpat" in the Philippines, particularly in the Bataan and Pampanga region or 'Holzapfelmangrove' in German. Sonneratia is a genus of plants in the family *Lythraceae*. The leaves of the Sonneratia resemble the leaves of apple trees, hence, the monicker "mangrove apple". They survive in brackish water with relatively low tolerance for high salinity. Likewise, they thrive in tandem with the Pemphis genus in most mangrove forests.

In mangrove swamps and other wet locations, *Acrostichum aureum*, the golden leather fern, grows in large numbers. Large fronds often growing to a length of 1.8 meters (six feet), the golden leather ferns have leaves that are glossy, broad and pinnate. The pinnae are dark green in color, leathery, alternate and widely spaced. The overall feature of the fern can be described with the outer fronds arching over sideways and the central ones being nearly straight. Some of the larger fronds bear sporangium (or reproductive organs) on the upper five to eight pairs of pinnae. These are brick red and give the pinnae a felted appearance. The golden leather fern is found in tropical and sub-tropical areas around the world. Tolerant of raised salinity levels, it grows in swamps and mangrove forests, salt marshes and on river banks. However spores germinate better in fresh water. It tends to grow on slight elevations in the mangrove swamp in areas which are inundated by the sea occasionally. It can also grow in freshwater locations. In Malaysia there are two plant forms. The larger ones occur on the periphery of the swamp where they may reach 4 meters (13 ft) while much more stunted plants grow in the areas which are frequently inundated. This mangrove species blend well and can grow in full sun or in deep shade with the mangrove *Rhizophora mucronata.*

While the present study uses the fractal dimensions of the leaves of mangrove species, other authors have used elliptic fourier shape analysis (EFA). Neto et al (2006) used elliptic Fourier (EF) and discriminant analyses to identify young soybean (*Glycine max (L.) merrill*), sunflower (*Helianthus pumilus*), redroot pigweed (*Amaranthus retroflexus*) and velvetleaf (*Abutilon theophrasti Medicus*) plants, based on leaf shape. Chain encoded, Elliptic Fourier harmonic functions were generated based on leaf boundary. A complexity index of the leaf shape was computed using the variation between consecutive EF functions. Principal component analysis was used to select the Fourier coefficients with the best discriminatory power. Canonical

discriminant analysis was used to develop species identification models based on leaf shapes extracted from plant color images during the second and third weeks after germination. The classification results showed that plant species during the third week were successfully identified with an average of correct classification rate of 89.4%. The discriminant model correctly classified on average: 77.9% of redroot pigweed, 93.8% of sunflower, 89.4% of velvet leaf and 96.5% of soybean. Using all of the leaves extracted from the second and the third weeks, the overall classification accuracy was 89.2%. The discriminant model correctly classified 76.4% of redroot pigweed, 93.6% of sunflower, 81.6% of velvetleaf, 91.5% of soybean leaf extracted from trifoliolate and 90.9% of soybean unifoliolate leaves. The Elliptic Fourier shape feature analysis could be an important and accurate tool for weed species identification and mapping (Neto et al. (2006).

III. CONCEPT OF FRACTAL AND FRACTAL DIMENSIONS

Classical geometry considers objects that have integral dimensions: points have zero dimensions, 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 λ = 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 the object is. 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 and colleagues (2012, 2013), 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:

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

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

He then proceeded to show that for n=1:

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

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

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

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

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

$,q > 0, \lambda > 1.$

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

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) $u = |\lambda_1 - \lambda_2|$.

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

(8) $\delta_s = P(u \geq \varepsilon) = \frac{1}{2}\left(1 + exp\left(-\varepsilon^{(\lambda_2 - 1)}\right)\right)$, 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) $\delta_s \geq 1 - \alpha \Leftrightarrow \varepsilon \leq \left[\log\frac{1}{1-2\alpha}\right]\left[\frac{1}{\lambda_2 - 1}\right], 0 \leq \alpha \leq 1$

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

IV. DESIGN AND METHOD

The study is designed to assess the viability of using fractal analysis in classifying and identifying the taxonomic classification of mangrove species based on the fractal dimensions of their leaves. For each species of mangrove, we randomly collected at least five (5) leaves. The leaves were carefully washed to ensure that only the leaf shape, form and structures are photographed. Their fractal dimensions were calculated using the available FRAKOUT software. A digital camera was mounted and fixed approximately one ft. (12 inches) from a platform where the specimen is mounted on a piece of white , 11" x 8", cardboard. Room lighting and dust contamination were controlled in order to ensure that only the specimen's features are caught on camera.

The percent correct identification is then calculated as:

(10) $\underset{Per\ Species}{Percent\ Correct\ Identification\ (PCI)} = \frac{No.\ of\ \delta_s\ greater\ or\ equal\ to\ 99\%}{q} x100\%$

The PCI's are then compared across species to determine if the proposed methodology is sensitive to species differences through an analysis of variance methodology.

To augment the metric (10), we also computed for average similarity index (δ_s) per species:

(11) $\underset{Per\ Species}{Average\ Similarity\ Index} = \frac{\sum_{i=1}^{q} \delta_{s_i}}{q}$.

V. RESULTS AND DISCUSSION

Plates 1 to 5 show the mangrove leaves used.

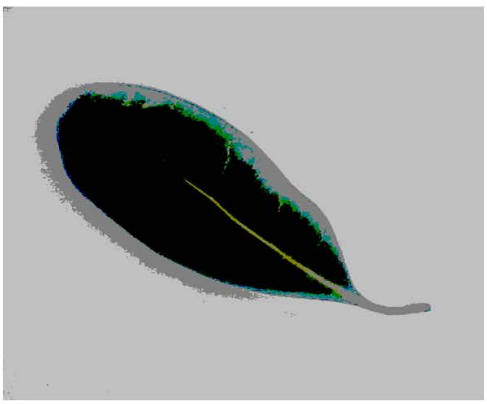


Plate 1. *Avicennia marina*

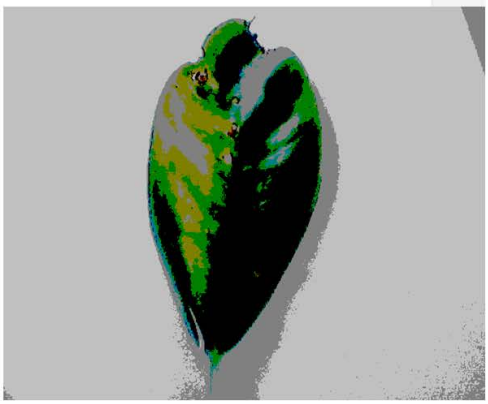


Plate 2. *Rhizopora mucronata*

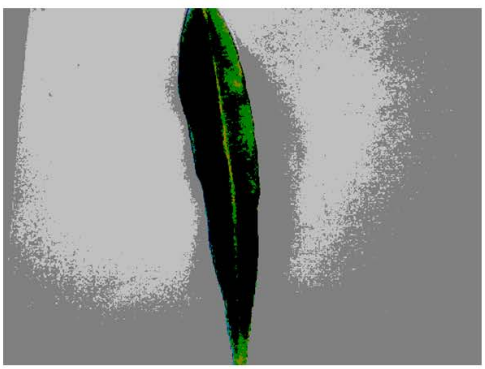


Plate 3. *Acrostichum aureum*



Plate 4. *Sonneratia alba*

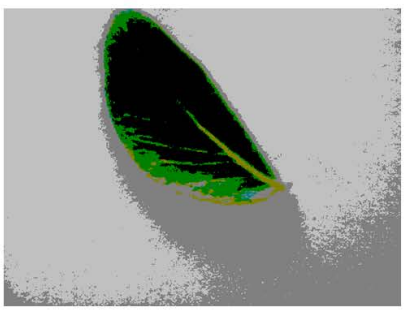


Plate 5. *Pemphis acidula*

Table 1. Summary of Empirical Fractal Dimensions of Mangrove Leaves.

Trial	*Rhizophora macrunata*	*Acrostichum aureum*	*Avicennia marina*	*Sonneratia alba*	*Pemphis acidula*
1	1.9523	1.9722	1.9582	1.9496	1.9686
2	1.9536	1.9610	1.9525	1.9601	1.9584
3	1.9458	1.9579	1.9471	1.9454	1.9570
4	1.9596	1.9711	1.9600	1.9360	1.9639
5	1.9484	1.9692	1.9564	1.9465	1.9603
6	1.9447	1.9686	1.9466	1.9414	1.9535
7	1.9453	1.9628	1.9458	1.9321	1.9582
8	1.9478	1.9528	1.9528	1.9408	
9		1.9610	1.9610	1.9409	
10		1.9591	1.9591		

Table 2. Means and Standard Deviations of the Fractal Dimensions.

Variable	N	Mean	Median	TrMean	StDev	SE Mean
Rhizopho	8	1.9497	1.9481	1.9497	0.0051	0.0018
Acrostic	10	1.9636	1.9619	1.9638	0.0064	0.0020
Avicenni	10	1.9540	1.9546	1.9541	0.0058	0.0018
Sonnerat	9	1.9436	1.9409	1.9466	0.0814	0.0027
Pemphis	7	1.9600	1.9584	1.9600	0.0049	0.0019

Table 3. One-way ANOVA: *Rhizophora m, Acrostichum, Avicennia ma, Sonneratia a, Pemphis a.*

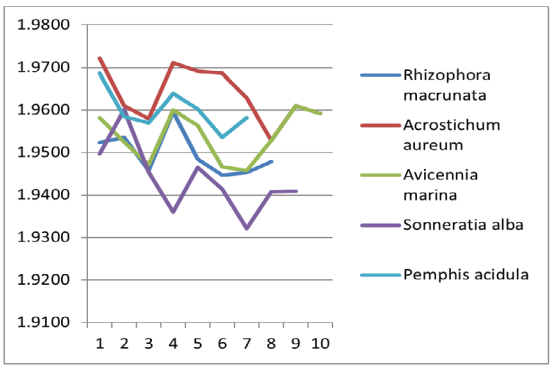
Analysis of Variance					
Source	**df**	**SS**	**MS**	**F**	**P**
Factor	4	0.0022786	0.0005696	14.44	0.000
Error	39	0.0015388	0.0000395		
Total	43	0.0038174			

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

Pair	Mean difference	t-value	p-value
Rhizopora vs. Acrostichum	0.01388	5.10	0.000*
Rhizopora vs. Avicenia	0.00426	1.64	0.121
Rhizopora vs. Sonneratia	0.00304	1.87	0.087
Rhizopora vs. Pemphis	0.01030	3.95	0.002*
Acrostichum vs. Avicenia	0.00962	3.51	0.002*
Acrostichum vs. Sonneratia	0.01993	5.85	0.000*
Acrostichum vs. Pemphis	0.00358	1.30	0.214
Avicenia vs. Sonneratia	0.01031	3.14	0.007*
Avicenia vs. Pemphis	0.00604	2.30	0.020*
Sonneratia vs. Pemphis	0.01634	4.96	0.000*
		Probability of Misclassification	**0.0451**

All the mangrove leaves display high fractal dimensions which demonstrate that mangrove leaves are indeed highly complex and rugged in shape and form. *Acrostichum aureum* and *Pemphis acidula* registered the highest fractal dimensions (beyond 1.96) while the most uniform in shape is *Sonneratia alba* (1.9436). The graph of the fractal dimensions below clearly illustrates the complexities of the mangrove leaves. Notice that the red curve (*Acrostrichum aureum*) is monotonically higher than the rest of the curves; the light blue curve (*Pemphis acidula*) follows closely. The violet curve (*Sonneratia alba*) is the lowest curve in the set of curves reflected on the graph.

Figure 6. Graph of the fractal dimensions of selected mangrove leaves.



Comparison of the fractal dimensions between mangrove species revealed that the fractal dimensions of the five (5) mangrove leaves are significantly different ($f = 14.400$, $p = 0.00$). The high computed f-value could be attributed to the small standard errors of the mean (fractal dimension) computed for each species. This means that leaves belonging to the same species of mangrove have relatively the same fractal dimension in comparison to leaves belonging to different species. The similarity index computed for the fractal dimensions of the leaves exceeded 95%.

Further analysis, however, revealed that *Rhizopora mucronata* and *Avicenia marina* have statistically similar fractal dimensions. This is true as well for *Acrostichum aureum* and *Pemphis acidula* . In other words, the proposed methodology using fractals in classifying the mangrove leaves across species would not be able to detect differences between the leaves of the aforementioned mangrove species. On the other hand, *Sonneratia alba* would be easily detected by the proposed methodology.

In the study of Mancuso (1997) and others (Ng et al., 2002), the number of leaves used for each species of plants was 20 or more. The larger sample size would have the effect of reducing the standard error of the mean of the fractal

dimensions. It is therefore very likely that the findings of the present study would be different had more observations been taken. Due to time and resource limitations, however, we were constrained to reduce the observations to 10 or less.

From the present study, it is possible to recommend studies that would respond to scientific questions such as: Do water salinity and PH impact on the fractal dimensions of the mangrove species? Can the carbon sequestration properties of mangrove species be deduced from knowledge of the fractal dimensions of their leaves? (see for example Boudon et al., 2006) who studied the carbon sequestration properties of other trees).

VI. CONCLUSION

The methodology of using fractal dimensions of leaves of mangrove species to classify the mangroves themselves is a potentially powerful technique yielding a low misclassification probability (4.5% or less). Leaves belonging to the same mangrove species have equally high similarity index exceeding 95%. Across species, however, the fractal dimensions of mangrove leaves varied significantly beyond the 0.01 probability level.

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