COMPLEXITY OF MARINE ESTUARIES IN CANTILAN AND CARRASCAL AREAS CONTIGIOUS TO MINING OPERATIONS

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ABSTRACT

The study attempted to assess the complexity of marine estuaries of the three areas of Surigao del Sur through fractal dimension analysis. Results showed that, of the three marine estuaries in Surigao del Sur, Cantilan has higher complexity of marine estuary with a fractal dimension of 1.9315, showing that its topographical structure is more rugged and rough. Thus, instead of rich biodiversity, the area appears to be deprived of dissolved oxygen necessary to support diverse marine life.

Keywords: *fractal complexity, estuaries, mining, water, parameters*

1.0 Introduction

Estuaries are formed from the mixing of fresh and salt water from rivers and oceans. While estuaries are among the most productive habitats in the world (Kaiser et al., 2005), they are also the most compromised in terms of their ability to replenish marine resources (Robertsons et al., 1997) because they serve as catch basins to household and industry wastes. The presence of industrial and household wastes induces changes in the physical characteristics of the estuaries because of sedimentation. Mining operations, in particular, expose nearby seas and rivers to this sedimentation, heavy siltation and numerous forms of contamination. Such changes create a harsh environment for a large number of organisms especially phytoplankton which are large producers of dissolved oxygen to marine life.

The health and diversity of marine life can, therefore, be deduced from the prevalence of phytoplankton which in turn depends on the complexity of the marine estuaries where they abound. Sedimentation and siltation occurring in the estuaries cause changes in the complexity of the marine estuaries nearby because of heavy mining operations. We are interested in assessing these fractal complexity changes.

Fractal analysis, as a scientific tool for measuring roughness, irregularities and fragmentation, is a relatively new addition to the arsenal of researchers and scientists. Benoit Mandelbrot (1967) in his book: *Fractals: The Geometry of Nature* first introduced this scientific tool as a challenge to investigate the concept of "roughness in nature". Since then, several applications of fractal geometry were made in numerous and diverse fields of study: Cohen (1987, used the idea in signal reception and communication systems; Krommel, et al., 1983) used fractal analysis in forest science and landscape ecology; Palmer, et al., (1989) developed methods of measuring fractal

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dimensions by Geographic Information System (GIS), and others.

Krommel et al., (1987) for instance, averred that organisms behave in accordance with the fractal dimensions of their environment. Thus, highly diverse and healthy environments tend to have high fractal dimensions. Patchiness or fragmentations, concepts useful in landscape ecology, are also best examined through the lens of fractal geometry.

Following this ecological principle, this paper provides an initial assessment of the changes induced by heavy mining operations on the fractal complexity of the marine estuaries in Carrascal and Cantilan.

2.0 Conceptual Framework

The conceptual framework of the study is illustrated below:

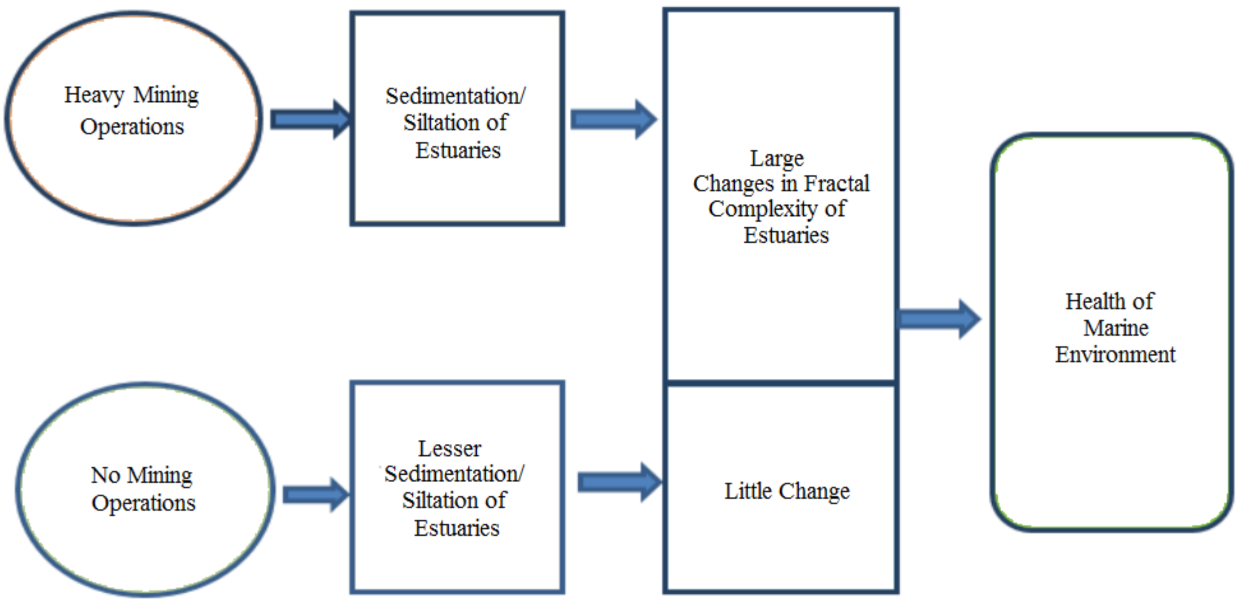

Figure 1. Conceptual framework of the study

3.0 Research Design and Methods

The study is designed to assess the fractal complexity of the marine estuaries of three areas in Surigao del Sur, namely, Doyos and Bon-ot in the municipality of Carrascal and the municipality of Cantilan (figure 2).

3.1. Estimation of the Fractal Dimension of Marine Estuaries

Photographs of the three (3) marine estuaries were taken by the researchers in the month of October, 2012 at various angles. These photographs were then saved as pictures and used as bases for analyzing their fractal dimensions. The various fractal dimensions computed for each marine estuary were averaged and taken as a representative fractal dimension for the estuary. The software used for analyzing the fractal dimension was the freeware FRAK.OUT.

Figure 2. Location map of the study areas

3.2 Sampling of Water Parameters and Phytoplanktons

Ten (10) samples were established from each of the three(3) estuaries, and the following water parameters were determined: temperature at various times (12:00, 1:55 and 4:30); total dissolved solids (in parts per million), and salinity (in parts per million). The initial intent was to include the water pH, but later results showed that all have the same pH levels and so this was later abandoned in the analysis.

Sampling of phytoplankton for each of the marine estuaries was likewise undertaken, and four (4) groups were targeted: cyanobacteria and pigmented flagellates, green algae and diatoms. The first two (2) are considered indicators of pollution and unhealthy environment while the last two (2) are indicators of good environmental conditions.

3.3 Description of the Riverine System

A rich watershed flows from the mountainous areas of neighbor municipality, Madrid to the rivers that pass through vast tracts of agricultural land towards Cantilan Bay and other rivers flowing towards Carrascal.

Some areas in Madrid have been identified to engage in small scale mining while large scale mining has been going on in the municipality of Carrascal. Activities directly related to mining have spoken the quality of water in the rivers.

4.0 Results and Discussions

Table 1. Summary of water parameters and Shannon indices

Place	Temperature (°C)	Salinity	Total Dissolved Solids	Shannon Index
Doyos	33.1	13	583	.83122
Bon-ot	33.42	25	548	.69116
Cantilan	30	26	725	.74952

Table 2. Summary of fractal dimensions of marine estuaries

Estuary	Width, Height	Cover or Bright Diff	R (n)	Fractal Dimension
Cantilan	640, 480	57.3	-0.9999(8)	1.9315
Doyos	624, 468	37.9	-0.9997(8)	1.8343
Bon-ot	640, 480	54.0	-0.9997(8)	1.8861

The highest index revealed at .83122 for Doyos shows relative abundance of different species in Doyos and Cantilan, two areas located a few kilometers farther from the mining site. Bon-ot which is most contiguous to the mined area has the lowest. However, Bon-ot appears to have the lowest Total Dissolved Solids (TDS) at 548 ppm. Cantilan, on the other hand, has the highest TDS level at 725 ppm.

The average of the fractal dimensions derived from photographs of the estuaries showed that Cantilan has the highest fractal dimension. With this roughness, Cantilan emerged to have a higher capacity to receive and accommodate whatever is brought into its environment from connecting water systems. The higher complexity of the Cantilan marine estuary (fractal dimension of 1.9315) shows that its topographical structure is more rugged and rough. Ideally, this should result in higher biodiversity, but results appear to be on the contrary.

The mathematical measure of the rarity and commonness of species in a community shows evidence of diversity in the marine estuaries. Shannon Index and Fractal Analysis exposed the complexity of the estuarine environments under study in relation to the water's salinity and amount of total dissolved solids. It is noted that in terms of its ability to replenish marine resources, the two estuaries (Bon-ot and Doyos) nearest to the mining site have more productive habitats compared to Cantilan. The TDS count is reflective of either the abundance or scarcity of dissolved oxygen essential to marine life. The lower the TDS, the higher is the presence of dissolved oxygen. In the case of Cantilan, the TDS is highest which means that the environment cannot be rich in biodiversity. Thus, the fractal complexity of the Cantilan marine estuary connects with the higher TDS, viz, the ruggedness of the area tended to trap dissolved solids.

Similarly, in terms of salinity, the less saline an area is, the higher is the abundance of nutrients needed by the marine community. Having the lowest salinity at 13ppm, Doyos mirrors a bountiful environment than the two other estuaries. Fresh river water that flows into the estuary brings with it nutrients that sustain marine life, while Cantilan is a non-mining municipality; it is surprising to note that it is the most affected. Heavy siltation and sedimentation as illustrated in the high level of Total Dissolved Solids provide an inadequate supply of dissolved oxygen that sustains marine life.

There is a clear indication that an outlying estuarine environment is not guaranteed safe from contamination due to the interconnectivity of its water systems. Thus, despite Cantilan's remoteness from the mining areas, it continues to be at risk of depleting its marine resources because of its high level of fractality. This ruggedness traps total dissolved solids and the Cantilan estuary appears to act like a catch basin.

5.0 Conclusion

The higher fractal dimension of Cantilan marine estuary reflects its topographic roughness. This area ruggedness resulted in the estuary's capacity to trap dissolved solids. Thus, instead of rich biodiversity, the area appears to be deprived of dissolved oxygen necessary to support diverse marine life. This marine and freshwater water dynamics also contributed to the "catch basin" role of the Cantilan marine estuary.

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