Article

Remote Sensing Analysis of Resilience and Cover Change in the Grand-Pierre Bay Mangrove Forest, Artibonite, Haiti

Alexandre Erich Sébastien Georges [1,†,‡], Mark T. Stacey [1,] and Firstname Lastname [2,‡,*]

[1] Department of Civil and Environmental Engineering; University of California, Berkeley; Berkeley, CA, USA; aao@ce.berkeley.edu
* Correspondence: alexandre_georges@berkeley.edu; Tel.: +16315900387 (A.E.S.G)
† Current address: 2126 California St, Apt 6, Berkeley, CA, USA
‡ These authors contributed equally to this work.

Abstract: The Grand-Pierre Bay, south of Gonaives, Haiti hosts the largest mangrove coverage of the country. It is also unique in the Caribbean region because it is the largest river-fed mangrove forest in the Caribbean islands. As such, it is host to extensive biodiversity and is an important socio-economic resource for the Artibonite region in Haiti. However, it has been a victim of anthropogenic pressure, threatening the biodiversity of the forest and its health and extent. This remote sensing analysis will look at how the density and health of the forest have been evolving for the past decade using satellite images from Landsat and PlanetLabs. Using these Machine Learning classification methods and indices, the mangrove cover and health change will be quantified. A second moment of area metric will be used to represent the extent change in the forests and compared to gross cover loss. Using these methods, we have found that the mangrove forest is retreating from its' coastal front while becoming denser inland. This could point to a mechanistic response of mangrove forests to sea-level rise in this region, which patterns will be important to study further in hydrodynamic studies.

Keywords: mangroves; remote sensing; coasts; Caribbean; Haiti

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1. Introduction

The introduction should briefly place the study in a broad context and highlight why it is important. It should define the purpose of the work and its significance. The current state of the research field should be reviewed carefully and key publications cited. Please highlight controversial and diverging hypotheses when necessary. Finally, briefly mention the main aim of the work and highlight the principal conclusions. As far as possible, please keep the introduction comprehensible to scientists outside your particular field of research. Citing a journal paper [1]. Now citing a book reference [2,3] or other reference types [4–6]. Please use the command [7,8] for the following MDPI journals, which use author–date citation: Administrative Sciences, Arts, Econometrics, Economies, Genealogy, Humanities, IJFS, Journal of Intelligence, Journalism and Media, JRFM, Languages, Laws, Religions, Risks, Social Sciences, Literature.

1.1. Study Site

The Grand-Pierre Bay Mangrove Forest is situated at the estuary of the l'Estere, Artibonite, and La Quinte rivers. It is the largest mangrove cover in Haiti and features a sea -> mangrove -> marsh -> land system.

1.2. Ongoing Conservation Efforts

Discuss ongoing conservation efforts here. Might need to interview Mr. Jean Wiener again.

2. Materials and Methods

This analysis makes use of an array of satellite imagery solutions, indices and image classification methods to detect and quantify mangrove cover change during the period extending from 2010 to 2022. The different datasets, data acquisition, classification and analysis methods are as follow:

2.1. Datasets

2.1.1. Landsat

Landsat 7 and 8 were used to track NDVI changes between the past decade in the region (2010 – 2022). While the resolutions of Landsat 7-8 instruments are lower than other commercially available satellites, it is very convenient for getting numerous readings for long periods of time for a large region. As such, it was mainly used to form time-series of NDVI in the whole forest and certain key regions.

2.1.2. PlanetLabs

PlanetLabs data present much higher resolution (3-5m) but fewer bands for analysis. It is also costly to pull near-weekly data from PlanetLabs. As such, observations around the first 2 months of the year, every 3 years, are taken between 2010 and 2022. This data has been used to monitor mangrove cover and coastline change.

2.2. Workflow

** Add figure showing workflow **

Low Tides -> Image Acquisition -> NDWI masking -> Kmeans Clustering -> Gross Cover Change -> Polar Moment of Area Metric -> NDVI Timeseries -> dNDVI Analysis

2.3. Low-Tide Data Acquisition

The partially submerged nature of mangrove forests can lead to inconsistencies when trying to track their cover using remote sensing, as submerged regions during flood tides can get hidden away from the satellite view depending on the time of observation. As such, it was decided to only get PlanetLabs observations at the lowest tides of the year to observe the maximum cover of the mangrove forests. To get the tidal schedule at our site, we established a 1:1 relationship between it and the tidal schedule at Port-au-Prince, Haiti, located in the same basin of the La Gonave Gulf. This is accomplished via hydrodynamic modeling in Delft3D-Flow, where measurements of the tidal regime in Port-au-Prince are related to the boundary conditions of the basin by regression. ** Make workflow plot explaining this process better **. With the tidal regime at our site in hand, we can then select available satellite imagery at the lowest available tidal ranges every year.

2.4. Image Classification

2.4.1. K-means Clustering

"k-means clustering is a method of vector quantization, originally from signal processing, that aims to partition n observations into k clusters in which each observation belongs to the cluster with the nearest mean (cluster centers or cluster centroid), serving as a prototype of the cluster. This results in a partitioning of the data space into Voronoi cells. k-means clustering minimizes within-cluster variances (squared Euclidean distances), but not regular Euclidean distances, which would be the more difficult Weber problem: the mean optimizes squared errors, whereas only the geometric median minimizes Euclidean distances. For instance, better Euclidean solutions can be found using k-medians and k-medoids."

We use K-means clustering on the surface reflectance values to classify the different land cover into 4 types: open water, mangrove vegetation, bare soil 1 (bare sand), and bare soil 2 (mud flat). After masking out the open water and bare soil covers, the remaining mangrove vegetation covers are compared over years to track the patterns in mangrove cover change.

2.4.2. Deep Learning Classification

??? (Potential Future Work.)

2.4.3. Gross Cover Loss and Second Moment of Area

Using the final mangrove cover extents, we calculate two metrics to quantify and characterize the cover change patterns in subregions: gross cover loss and polar moment of area. With Gross Cover Loss (GCL), we simply take the difference in covered pixels between 2022 and 2010, multiplying that number of pixels by the unit pixel area to obtain an area in km sq.

The polar moment of area (MOA) on the other looks at the distribution of those pixels related to the center of the extent of a subregion. The second moment of area (2MOA) of the mangrove cover is calculated in relation to the center x and y axes as a sum of the 2MOAs of all pixels:

$$I_x = \sum A \times d_x^2$$
$$I_y = \sum A \times d_y^2$$

The overall MOA metric is then the sum of I_x and I_y:

$$MOA(J_z) = I_x + I_z$$

2.5. Indices

2.5.1. NDWI Masking Pre-Processing

To simplify the clustering process of, we mask out the open water regions surrounding the mangrove forest. This is done using the green and NIR bands of PlanetLabs, following the relation defined by McFeeters (1996):

$$NDWI = \frac{Xgreen - Xnir}{Xgreen + Xnir}$$

The resulting masked out images are then used in our classifications and analyses.

2.5.2. NDVI Analysis

The land surfaces that we find after masking out open water using NDWI are analyzed by NDVI to gauge the change in health of the forest. NDVI (Normalized Difference Vegetation Index) is a simple indicator of the presence, density and health of green vegetation. This index uses the green and near-infrared bands of observations as follow:

$$NDVI = \frac{Xnir - Xred}{Xnir + Xred}$$

To gauge the change in health, we look at the spatial difference of the NDVI distribution between 2022 and 2010:

$$dNDVI = NDVI_{2022} - NDVI_{2010}$$

Additionally, the average NDVI of Landsat observations over that time period are used for time-series showing trends of NDVI change in more detail.

3. Results

3.1. Mangrove Detection and Cover Change Metrics

Cover change visualizations here **GCL and MOA tables and figures here**

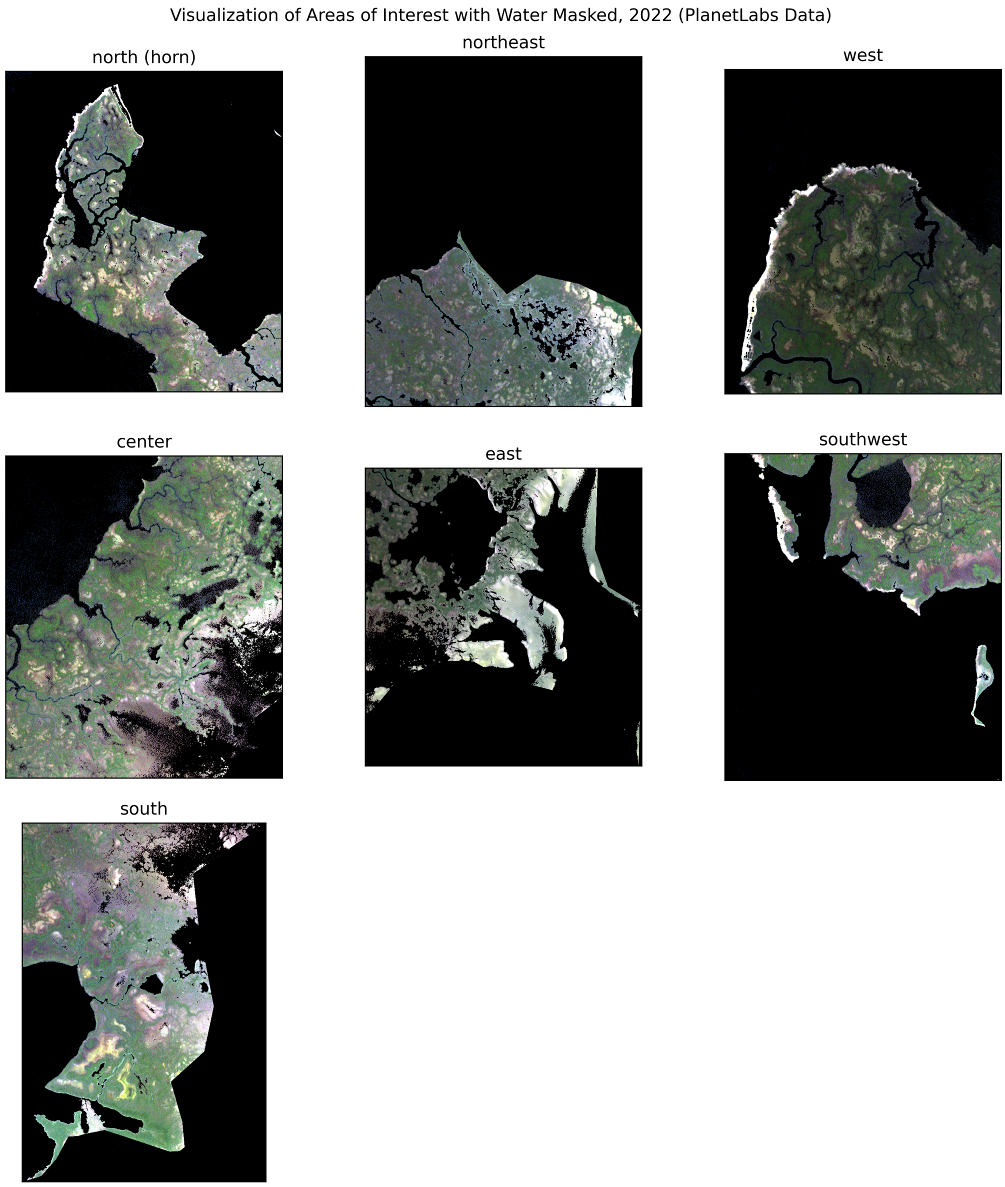

Figure 1. Visualization of areas of interest with open water masked. The mangrove forest was divided in 7 subregions from a 3x3 grid which were named according to their cardinal directions.

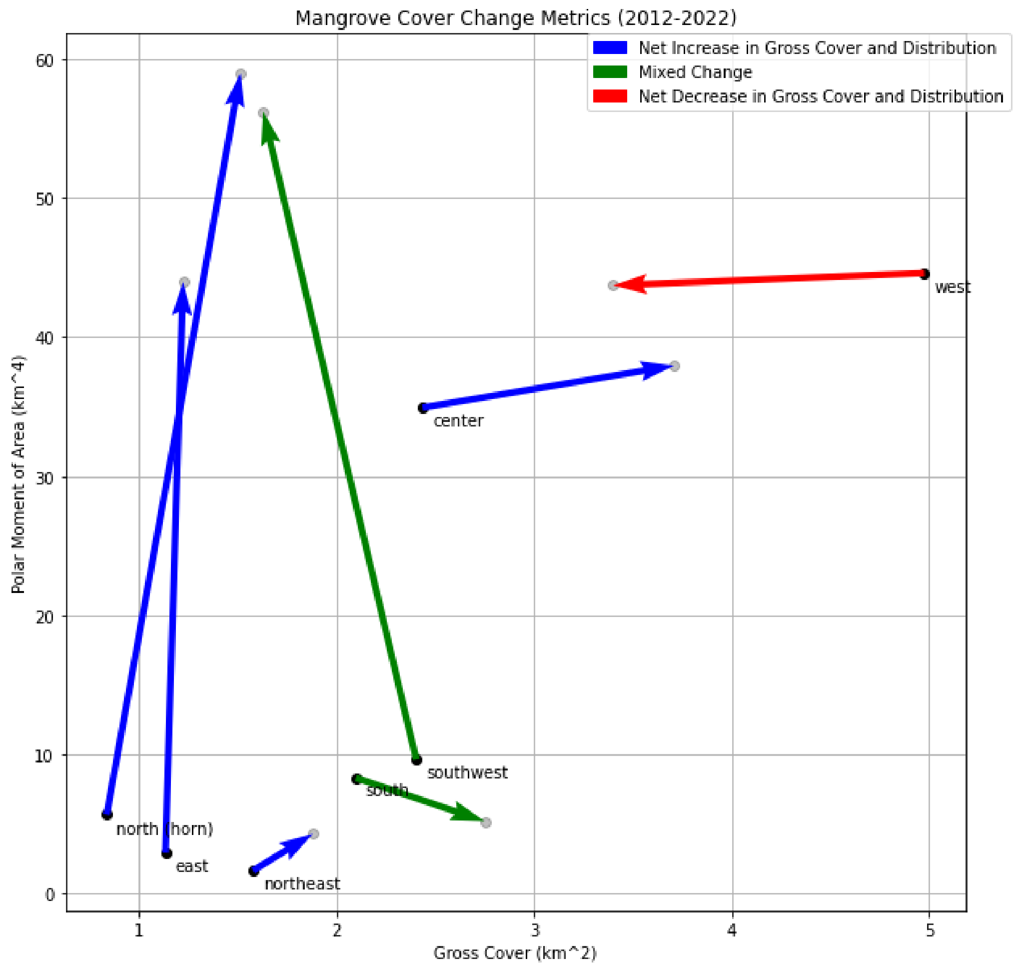

Figure 2. Metrics displaying the change patterns in the mangrove cover in the different subregions.

3.2. dNDVI Analysis 103

dNDVI figures here 104

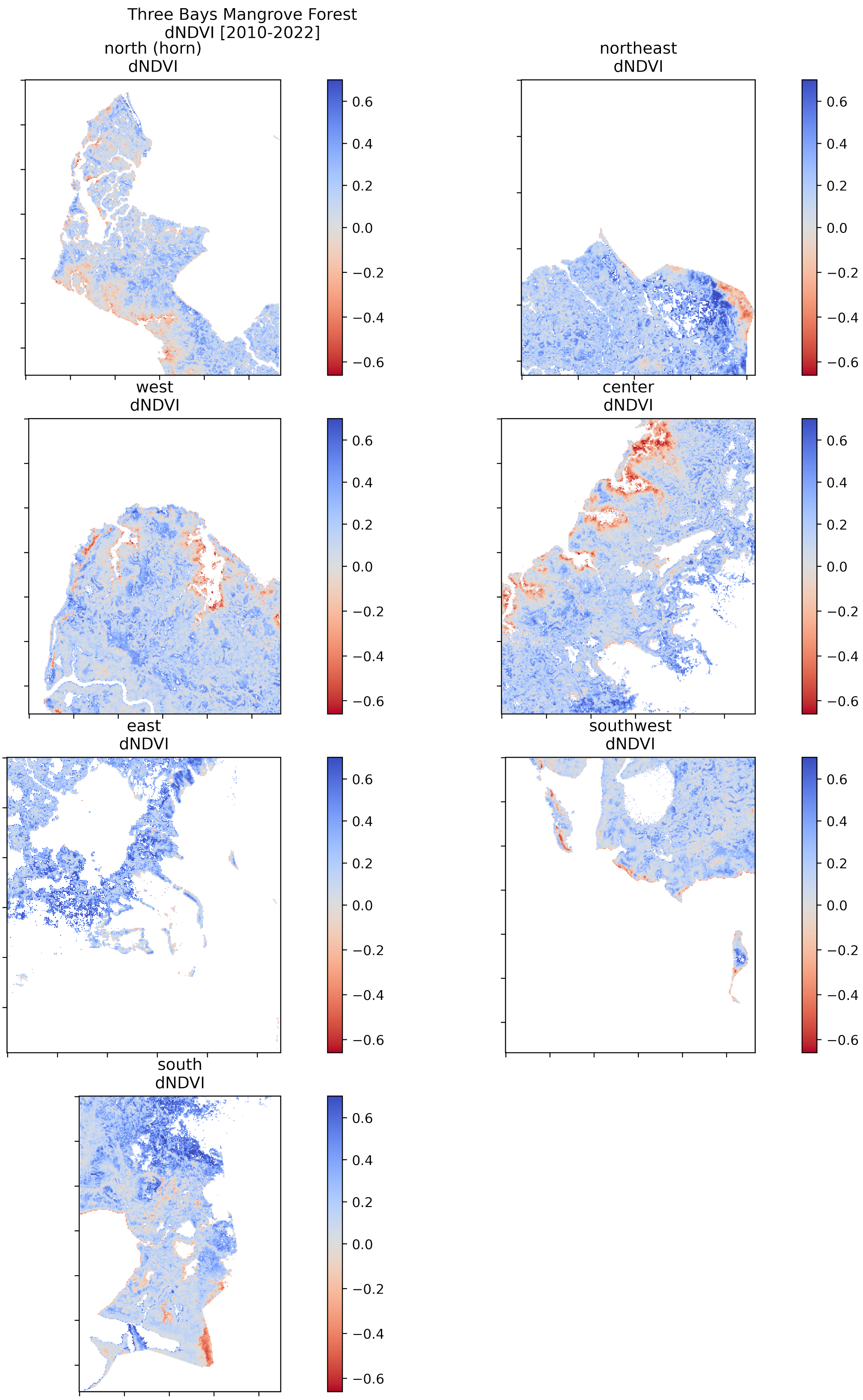

Figure 3. dNDVI graphical analysis of the different subregions between 2022 and 2010.

3.3. NDVI Timeseries Analysis

NDVI timeseries here Timeseries of the mean and maximum NDVI in the Grand-Pierre Bay have been taken. Areas of interest were the mangrove forest, the Gulf of Gonave coast of the forest, and the "brackish Grand Pierre" lake coast.

The text continues here.

All figures and tables should be cited in the main text as Figure 1, Table 1, Table 2, etc.

Table 1. Gross Cover Change in Forest Subregions

AOI	Gross Cover Change	Gross Percent Change
North (Horn)	0.678195	81.123
Northeast	0.302	19.132
West	-1.577	-31.681
Center	1.274	52.298
East	0.0899	7.936
Southwest	-0.775	-32.265
South	0.652	31.094

Table 2. This is a wide table.

AOI	Gross Cover Change	Gross Percent Change	Polar 2MOA Change	Polar 2MOA Percent Change
North (Horn)	0.678195	81.123	53.295	941.644
Northeast	0.302	19.132	2.631	1260.764
West	-1.577	-31.681	-0.887	-1.989
Center	1.274	52.298	3.016	8.638
East	0.0899	7.936	41.043	1408.445
Southwest	-0.775	-32.265	46.579	483.698
South	0.652	31.094	-3.114	-37.524

[1] This is a table footnote.

Text.
Text.

3.4. Formatting of Mathematical Components

This is the example 1 of equation:

$$a = 1, \tag{1}$$

the text following an equation need not be a new paragraph. Please punctuate equations as regular text.

This is the example 2 of equation:

$$a = b + c + d + e + f + g + h + i + j + k + l + m + n + o + p + q + r + s + t + u + v + w + x + y + z \tag{2}$$

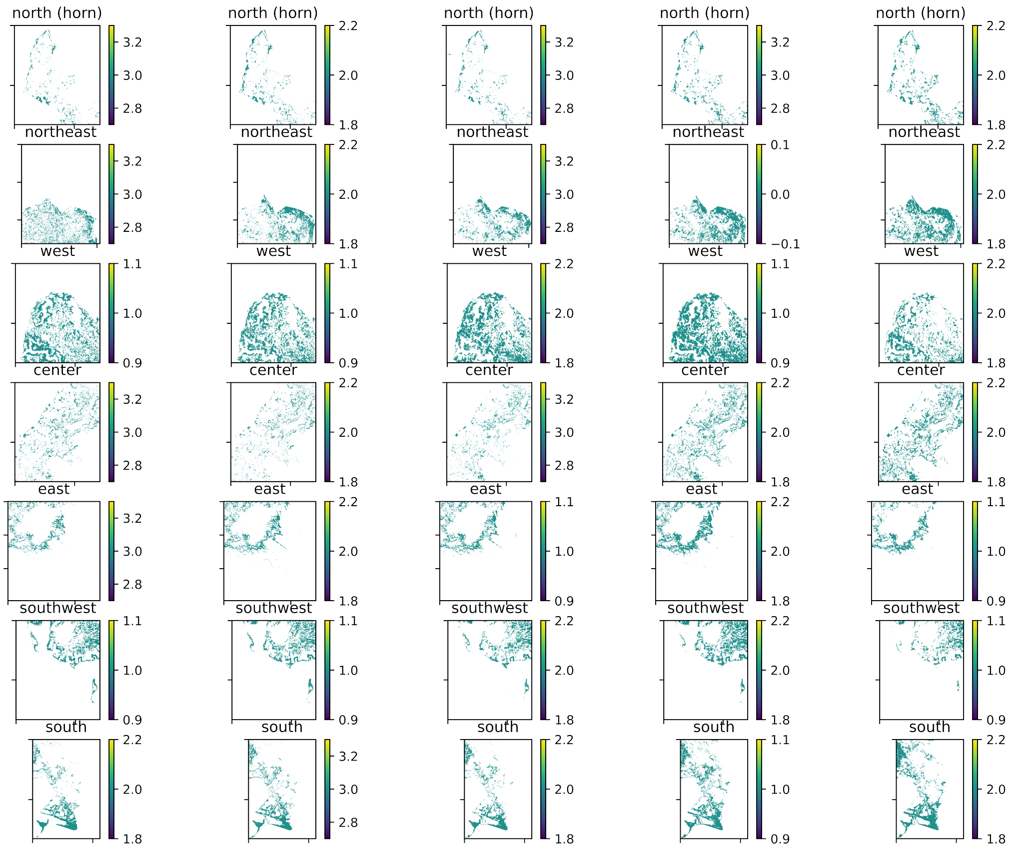

Figure 4. Masked mangrove covers from observations.

Please punctuate equations as regular text. Theorem-type environments (including propositions, lemmas, corollaries etc.) can be formatted as follows:

Theorem 1. *Example text of a theorem.*

The text continues here. Proofs must be formatted as follows:

Proof of Theorem 1. Text of the proof. Note that the phrase "of Theorem 1" is optional if it is clear which theorem is being referred to. □

The text continues here.

4. Discussion

Authors should discuss the results and how they can be interpreted from the perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

5. Conclusions

This section is not mandatory, but can be added to the manuscript if the discussion is unusually long or complex.

6. Patents

This section is not mandatory, but may be added if there are patents resulting from the work reported in this manuscript.

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Abbreviations

The following abbreviations are used in this manuscript:

MDPI	Multidisciplinary Digital Publishing Institute
DOAJ	Directory of open access journals
TLA	Three letter acronym
LD	Linear dichroism

Appendix A

Appendix A.1

The appendix is an optional section that can contain details and data supplemental to the main text—for example, explanations of experimental details that would disrupt the flow of the main text but nonetheless remain crucial to understanding and reproducing the research shown; figures of replicates for experiments of which representative data are shown in the main text can be added here if brief, or as Supplementary Data. Mathematical proofs of results not central to the paper can be added as an appendix.

Table A1. This is a table caption.

Title 1	Title 2	Title 3
Entry 1	Data	Data
Entry 2	Data	Data

Appendix B

All appendix sections must be cited in the main text. In the appendices, Figures, Tables, etc. should be labeled, starting with "A"—e.g., Figure A1, Figure A2, etc.

References

1. Author 1, T. The title of the cited article. *Journal Abbreviation* **2008**, *10*, 142–149.
2. Author 2, L. The title of the cited contribution. In *The Book Title*; Editor 1, F., Editor 2, A., Eds.; Publishing House: City, Country, 2007; pp. 32–58.
3. Author 1, A.; Author 2, B. *Book Title*, 3rd ed.; Publisher: Publisher Location, Country, 2008; pp. 154–196.
4. Author 1, A.B.; Author 2, C. Title of Unpublished Work. *Abbreviated Journal Name* year, *phrase indicating stage of publication (submitted; accepted; in press)*.
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