Development of a Framework for a Functional-Structural Seagrass Transplantation Simulation using GAMA Platform

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Keywords: Agent-based Modelling, Geographic Information System, Seagrass Growth Simulation, Seagrass Transplantation, Plant Growth Modelling, Functional-Structural Approach, GAMA Platform.

Abstract: A massive decrease in seagrass coverage in the Philippines has been observed in the past several years due to coastal eutrophication and typhoons. It is key to observe the changes and probable damage in seagrass habitat and develop a way to scientifically back up recovery strategies such as transplantation to increase the probability of rehabilitation success. This study describes the framework development of a transplantation scenario evaluation tool that performs *Thalassia hemprichii* growth simulation within an uproot site in Palawan as a case study. The growth parameters used include shoot leaf area, spacer length, plastochrone interval, and life expectancy, and horizontal apex density. Base scenario and three scenarios with varying combinations of transplantation density and distribution were applied to the three 4 x 4 grid plots with 24 x 24 cm cell size from classified drone imagery. Results show that transplantation distribution has a greater weight than density with respect to the percent cover responses. Based on the mean and standard deviation of percent cover responses, scenario 1 having 4 transplants with 24 cm intervals is the most suitable for plots 1 and 2, while scenario 2 having 8 transplants (2 per cell) with 24 cm intervals for plot 3.

1 INTRODUCTION

Seagrasses are clonal flowering plants that share the same architecture (Marba, Duarte, Alexandria, & Cabaco, 2004), submerged in shallow marine waters (Florida Fish and Wildlife Conservation Commission, n.d.), usually located on semi-enclosed lagoons and along coastlines, and co-existing with intertidal mangroves and corals (Fortes M. D., A Review: Biodiversity, Distribution and Conservation of Philippine Seagrasses, 2013). They play an important role in providing food and shelter for various marine species (Duarte & Chiscano, 1999; Heiss, Smith, & Probert, 2000), stabilizing the sea bottom (Borowitzka, Lavery, & van Keulen, 2006), maintaining water quality, supporting the livelihood of local economies and holds around 12% of the total ocean carbon stock (UNEP, 2004). Among the thriving species of seagrass in the Philippines, *Thalassia hemprichii* (*T. hemprichii)* is one of the dominant ones that exhibits horizontal expansion typically in a span of approximately 5 to 11 days (Lopez, Unpublished; Vermaat, et al., 1995).

A massive decrease in seagrass coverage in the Philippines has been observed in the past several years. It is key to monitor the changes and probable damage and develop a way to scientifically justify recovery strategies such as transplantation to increase the probability of rehabilitation success. This study aims to develop a framework for simulating seagrass recovery in order to increase the certainty of transplantation spatial strategy success in order to help a seagrass meadow recover from a typhoon damage. It will assist local communities, government authorities, and researchers to formulate effective strategies not only for seagrass recovery but also for its rehabilitation and conservation.

The main question is how can a simulation be applied to possibly increase the certainty of transplantation spatial strategy success and help a seagrass meadow recover from a typhoon damage. The framework aims to answer the following:

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- What are the primary datasets needed?
- What steps must be done to run a seagrass transplantation simulation?

From the results of the transplantation simulation scenarios, the following are the questions aimed to be answered:

- What are the corresponding seagrass percent cover tracks?
- What metrics can be used to describe the behavior of these tracks?
- From the scenario factors considered, which of them are statistically significant? Which have greater bearing on the metrics considered?

2 LITERATURE REVIEW

2.1 Seagrasses

2.1.1 Overview

Seagrasses belong to plants producing flowers known as angiosperms, evolved to thrive in marine waters and typically have ribbon-like, grassy leaves (McKenzie, 2008) with its general structure divided into above-ground including leaf, blade and stem and below-ground consisting of rhizome (horizontal) and root (El Shaffai, 2016). They follow a clonal mechanism called vegetation proliferation sharing similar architecture but with varying plant size and growth rate across species (Marba, Duarte, Alexandria, & Cabaco, 2004).

2.1.2 Disturbances, Rehabilitation, Transplantation and Recovery

Since some are located in deep areas, light becomes crucial and exposure to disturbances becomes higher (Greve & Binzer). These disturbances are caused by anthropogenic activities and natural phenomena (Short & Wyllie-Echeverria, Natural and human-induced disturbances of seagrass, 1996). Oil spill incidents were reported in the Philippines in 1987 (Fortes M. D., 1991), Puerto Rico in 1962 and California in 1969 (Zieman, Orth, Phillips, Thayer, & Thorhaug, 1984). In the U.S., a continuous decrease in percent cover was observed from 2003 to 2008 including a dramatic decline by 2006 due to a storm wave (Buchanan, 2009). In Banate Bay, Philippines, seagrasses were uprooted by typhoon Haiyan (The Philippine Star, 2016). Although, their response to environmental and population changes are species-specific (Marba, Duarte, Alexandria, & Cabaco, 2004), as observed as well by Duarte et al. (1987). Their recovery relies on vegetative growth, regrowth from fragments of transported plants, and recovery from seeds (Vanderklift, et al., 2016). Rollon et al. (1998) showed that the projected duration of post-disturbance recovery ranges from 2 to 10 years in full recovery both for artificially created gaps of 0.25 sq.m. Another study observed gradual recovery within 2 to 6 years after a cyclone and consequent flood (Campbell & McKenzie, 2004).

2.1.3 Thalassia Hemprichii

Genus *Thalassia* consists of two species, *T. testudinum* and *T. hemprichii*, a.k.a. “twin species” because they can only be distinguished through the counts and dimensions of the styles and stamens of their flowers appearance-wise (van Tussenbroek, et al., 2006). Both grow in highly organized and rigid pattern which primarily depends on the active tip of the horizontal (h.) rhizomes called apical meristem or apex for expansion (Tomlinson, 1974). To survive, vertical rhizomes utilize surrounding resources, deploying leaves and roots at the same (Hemminga & Duarte, 2000). *T. hemprichii* is a commonly widespread species and is considered to be stable despite threats and disturbances (Short, et al., 2010). In the Philippines, it commonly thrives on mud-coral-sand or coarse coral-sand substrates and grows up to 6 meters deep (Menez, Phillips, & Calumpong, 1983).

2.2 Agent-based Modeling

2.2.1 Overview

Agent-Based Modeling (ABM) utilizes objects called agents possessing attributes and behaviors, and playing specified roles in the model through specified rules and constraints. Its advantages include capturing of emergent phenomena, provision of a natural environment for the study of certain systems, and flexibility (de Smith, Goodchild, & Longley, 2018). Moreover, it is capable of handling high heterogeneity in characteristics, interactions between agents and environments, and their dynamics, feedbacks and adaptation (Auchincloss & Garcia, 2015). In the past decades, this method has already been widely used in different fields. However, due to lack of awareness in the significant importance of seagrass, studies on seagrass growth simulation employing this method is still relatively sparse.

2.2.2 Gama Platform

GIS Agent-based Modeling Architecture Platform (GAMA) is an open-source environment that combines agent-based simulations with spatial applications (Grignard, et al., 2013). It uses its own programming language GAML (GAMA Modeling Language) coded in Java which makes them similar in syntax and structure (GAML, 2018). In conjunction with the visualization, instantaneous statistics of the agents and the simulation can be displayed using graphs.

2.2.3 Functional-Structural Plant Model

One approach is Cellular Automata which treats a seagrass plot as a grid having each grid cell a value representing percent cover or biomass (Marsili-Libelli & Giusti, 2004). However, this can be quite a generalized approach if the target is to visualize and analyze the components in detail. To achieve these, ABM must be employed wherein Functional-Structural Plant Model (FSPM) can be applied. It is suitable in simulating seagrass growth because the plant is modelled in a much finer detail (Godin & Sinoquet, 2005) such as its roots, leaves and branches to simulate the higher-level outcomes (Dejong, Da Silva, Vos, & Escobar-Gutiérrez, 2011). Related studies include the works of Sintes et al. (2005), Renton et al. (2011), and Whitehead et al. (2018).

3 MATERIALS AND METHODS

This research is divided into three main procedures namely 1) Pre-processing, 2) Data Processing and Visualization, and 3) Analysis and Validation.

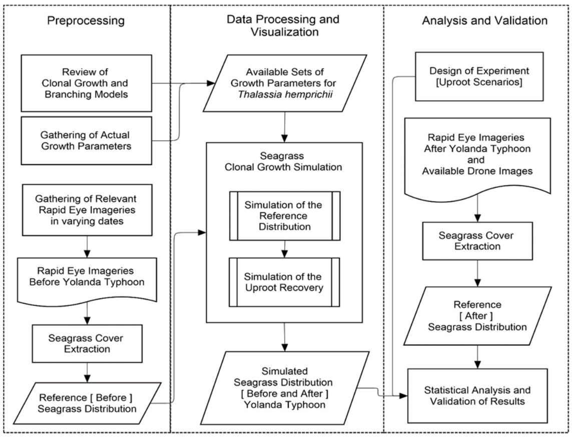


Figure 1: This is the research workflow for the development of the seagrass transplantation simulation framework.

3.1 Pre-processing

This stage involves literature review, gathering of growth parameters (Table 1), gathering of site datasets shown in Figure 2, seagrass percent cover extraction using Mixed-Tuned Matched Filtering (MTMF) method in ENVI software, and identification of three random plots within the blowout scenarios that will represent three plots or the number of repetitions of the transplantation simulation runs.

Table 1: *T. hemprichii* parameters used in the developed transplantation simulation are summarized below as adapted and derived from the work of Vermaat, et al., (1995), and from Ms. Rose Lopez and Dr. Rene Rollon.

Parameter	Value	Standard deviation
Shoot leaf area (sq.cm, single-sided)	26.56	0.02
Shoot spacing along rhizome (spacer length, cm)	6.77	2.90
Shoot plastochrone interval (PI, days)	4.03	0.34
Shoot life expectancy (days)	229	17
Rhizome apex density per sq. m	58	-
Rhizome life expectancy (years)	4	-

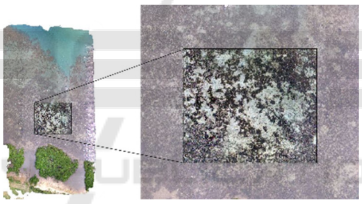
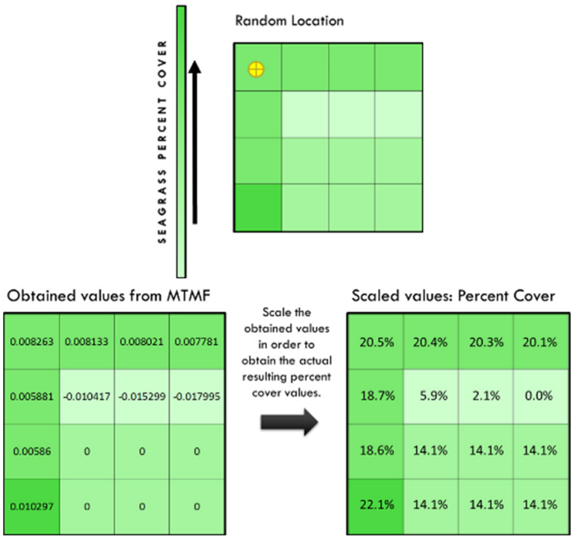


Figure 2: This is a drone imagery captured by a project team under the IAMBlueCECAM Program on September 2017 on a seagrass blowout site in Palawan, Philippines.

In the seagrass extraction, two drone image spatial resolutions were used: the original resolution 6 cm and the resampled 24 cm. To obtain the grids, ArcMap Fishnet tool was used to generate a 24 x 24-cm grid resolution. To determine the three random plots within the blowout that will represent three transplantation simulation repetitions, ArcMap Create Random Points tool was used. The extent for the previously generated grid served as a coverage constraint in order to ensure that the points will not fall outside the blowout site. Minimum allowable distance from each of the points was set to 20 meters to avoid them from being too close to each other. The grid cell where these points fell into are the upper left corner of the 4 x 4 grid, having cells with dimensions 24 x 24 cm. In Figure 3, the preparation for the input grids is demonstrated. Values in percent are converted to their decimal format and used in the transplantation simulation as comma-separated (csv) files.



Obtained values from MTMF

0.008263	0.008133	0.008021	0.007781
0.005881	-0.010417	-0.015299	-0.017995
0.00586	0	0	0
0.010297	0	0	0

Scaled values: Percent Cover

20.5%	20.4%	20.3%	20.1%
18.7%	5.9%	2.1%	0.0%
18.6%	14.1%	14.1%	14.1%
22.1%	14.1%	14.1%	14.1%

Figure 3: Obtaining the input percent cover grids from the MTMF classification output and the randomly generated locations: Illustrations above represent a single random plot from a random location shown as yellow marker at the upper leftmost cell of the 4 x 4 grid.

3.2 Data Processing and Visualization

In this stage, parameters in Table 1 and the extracted seagrass percent cover for each plot are the input for the seagrass transplantation simulation. Prior to the simulation proper, the input csv files for each scenario of the three random plots must be prepared. Following Table 2, four scenarios of varying level combinations for low and high of factors a) planting distribution and b) planting density. Low level (L) for the planting distribution means wide intervals between plants and high level (H) corresponds to closer intervals. On the other hand, L for planting density denotes 1 plant per grid cell of 24 x 24 cm and H indicates 2 plants per cell. There will be five percent cover responses: Sum, Mean, Standard Deviation, Minimum, and Number of Extreme Drops.

To represent these scenarios as input files for the transplantation simulation, corresponding template for each were created by computing their density (per grid cell of size 24 x 24 cm) contributions as shown below by the equations 2 and 3. These templates are grids with values having the dimensions with the plots. The shoot leaf area from Table 1 cannot be directly used since it assumes that the leaf is completely horizontal, facing the drone upon imagery capture. Due to water depth and current, seagrass leaves are angled, if not upright. Thus, we use a reduction factor which in this case is 1/3 according to our consultation with Dr. Rollon as demonstrated in equation 1.

Table 2: This table illustrates the Design of Experiments (DOE) for the four seagrass transplantation scenarios with varying level combinations for low and high of factors a) planting distribution and b) planting density.

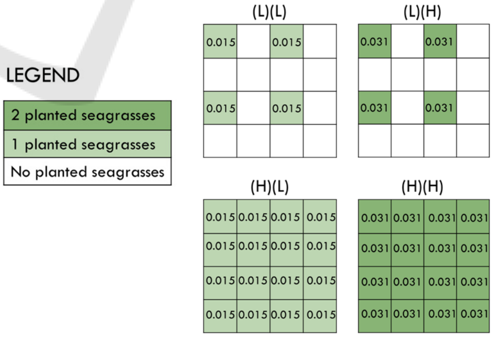
Scenario	Planting Distribution		Planting Density		Percent Cover Response
	L	H	L	H	
1	×		×		R1
2	×			×	R2
3		×	×		R3
4		×		×	R4

$$\text{Derived shoot leaf area per plant (sq.cm.)} = (1/3)26.56 = 8.85 \tag{1}$$

$$\text{Derived shoot leaf area density for Planting Density (L)} = (1 \text{ plant x } 8.85)/(24 \text{ x } 24) = 0.015 \tag{2}$$

$$\text{Derived shoot leaf area density for Planting Density (H)} = (2 \text{ plants x } 8.85)/(24 \text{ x } 24) = 0.031 \tag{3}$$

In Figure 4, L stands for low factor level and H the high factor level. The first letter denotes the level of factor a) planting distribution while the second letter for b) planting density such that (L)(L) stands for transplantation scenario #1 from Table 2. These scenario grids are added to each of the three random plots creating five transplantation simulation runs for each namely: i) scenario 0 - base scenario or the actual percent cover based on the drone-obtained imagery, and ii) scenario 1 to 4. They are then converted to csv files as inputs for the reference meadow with percent cover values.



(L)(L)

0.015		0.015	
0.015		0.015	

(L)(H)

0.031		0.031	
0.031		0.031	

(H)(L)

0.015	0.015	0.015	0.015
0.015	0.015	0.015	0.015
0.015	0.015	0.015	0.015
0.015	0.015	0.015	0.015

(H)(H)

0.031	0.031	0.031	0.031
0.031	0.031	0.031	0.031
0.031	0.031	0.031	0.031
0.031	0.031	0.031	0.031

Figure 4: Seagrass transplantation scenario templates with the computed values of the percent cover contribution of the seagrasses to be planted.

Figure 5 describes the flow of the simulation starting from the initial pairs of h. rhizome and shoot. Due to the lack of firm literary basis for the initial seagrass plants per unit area that may populate and turn into a meadow, the chosen ratio between the number of initial pairs to the percent cover is 1:10.

Though this is a part of the assumptions, this ratio is still reasonable since it partially and relatively describes the reference meadow.

Every transplantation simulation cycle, new h. rhizomes will emerge from the locations of the apices in a random direction. Randomized runner production probability determines whether there will be one or two emerging rhizomes. If the probability is ≤ 10%, a runner is produced and two new h. rhizomes will be created. From the current apex agents, shoot agents will grow on the next cycle. In addition, old apex agents will die (disappear in the transplantation simulation) and new apex agents will grow from the tips of the new h. rhizomes. Previously created shoot and h. rhizome agents will remain until they reach the maximum age imposed. Every cycle, agent count and percent cover value are logged and graphed.

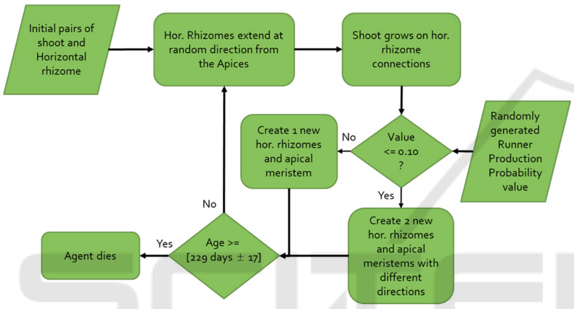


Figure 5: Seagrass Transplantation Simulation Implementation Workflow.

The geo-simulation uses agents to represent the main components of seagrass growth, namely the apical meristem or apex, the h. rhizome and the shoot as illustrated in Figure 6. Apex (apical meristem) is represented as red circle, shoot as green circle and h. rhizome as brown line. The growing tip or meristem of a shoot is represented by the Apex which can produce new rhizomes and apices. Shoots grow at the nodes of h. rhizomes. Since the simulation is limited to two-dimensional top view visualization, shoots are simplified and represented as green circles.

The transplantation simulation parameters used include apex density, plastochrone interval (denoted by P.I.; number of days within which h. rhizome is produced), horizontal elongation rate, branching rate, h. rhizomes between shoots, shoot spacing along rhizome and median maximum age of shoot and rhizome. The time step used is 4.03 ± 0.34 days which represents the duration of rhizome growth and a threshold of 58 apices denoting the maximum number in an almost 1 sqm. plot. Simulation run starts from randomly distributed pairs of apex and rhizome over a specified relatively small plot and grow into meadows covering a spatial distribution with respect to a corresponding reference seagrass percent cover.

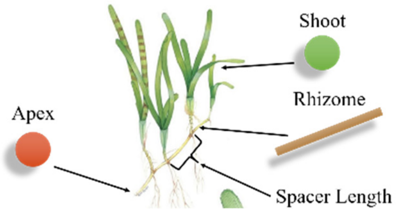


Figure 6: A simplified top view representations of seagrass agents *T.hemprichii* with its photo adapted from (SeagrassWatch.org).

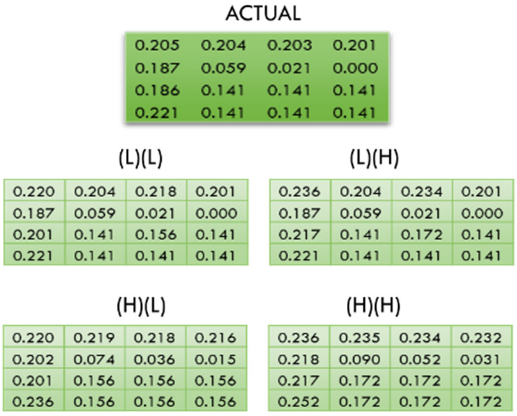
3.3 Analysis

The final stage of the methodology is the analysis in which the graphs for each of the plot's scenario result was observed and the trends of the values are discussed and explained. Using Design Expert software, the analysis of variance (ANOVA) and interaction among factor levels were examined. This will show if the factors and their levels are significant.

4 RESULTS AND DISCUSSION

4.1 Reference Seagrass Meadows

Figure 7 summarizes the actual or the reference percent cover plots (scenario 0) and their four scenarios obtained by taking into account the combinations of the levels of the two factors in the DOE table (Table 2). Each row of the said figure represents a repetition (or the plots as discussed in Section 3.1). All of these are formatted as csv files and were used as inputs in the transplantation simulation.



ACTUAL

0.205	0.204	0.203	0.201
0.187	0.059	0.021	0.000
0.186	0.141	0.141	0.141
0.221	0.141	0.141	0.141

(L)(L)

0.220	0.204	0.218	0.201
0.187	0.059	0.021	0.000
0.201	0.141	0.156	0.141
0.221	0.141	0.141	0.141

(L)(H)

0.236	0.204	0.234	0.201
0.187	0.059	0.021	0.000
0.217	0.141	0.172	0.141
0.221	0.141	0.141	0.141

(H)(L)

0.220	0.219	0.218	0.216
0.202	0.074	0.036	0.015
0.201	0.156	0.156	0.156
0.236	0.156	0.156	0.156

(H)(H)

0.236	0.235	0.234	0.232
0.218	0.090	0.052	0.031
0.217	0.172	0.172	0.172
0.252	0.172	0.172	0.172

Figure 7: Percent cover grid per plot for the actual values and the scenario factor levels.

4.2 Seagrass Transplantation Simulation Results

In the transplantation simulation, four quantities were kept track over time (1 transplantation simulation cycle = 1 P.I. from Table 1) for a total span of 5 years namely percent cover, and shoot, horizontal rhizome and apical meristem counts. For each plot scenario, the maximum potential seagrass percent cover is 66%. This is due to the agent constraints which are imposed based on the maximum number of apical meristems per plot and the agents' respective lifespans according to Vermaat, et. al. (1995) and Dr. Rollon. Since percent cover is calculated from an orthogonal viewpoint wherein only the shoots are visible, the percent cover progression can be derived from the trend of the shoots. Abrupt percent cover drops result from a number of shoot agents that occur simultaneously which in turn dies simultaneously. Hence, extreme percent cover drops do not necessarily mean that the seagrass meadow will continuously thin.

In choosing the best planting scenario, standard deviation and mean were considered. Standard deviation accounts for the fluctuations of the percent cover values. Hence, the best planting scenario per study plot is characterized by low standard deviation and high mean. Figure 8 illustrates the comparison between two scenarios. Apparently, scenario 1 is better than scenario 4 in this case (Figure 9).

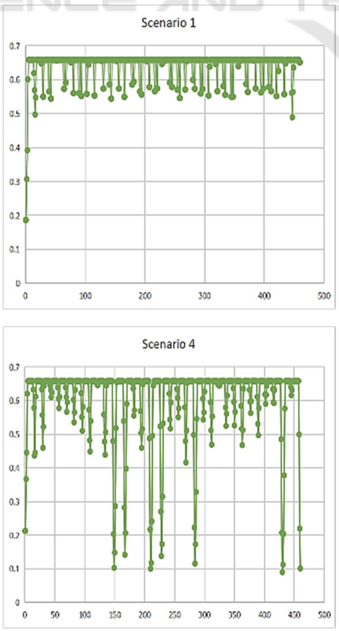


Figure 8: This figure compares two scenarios (1 and 4) in order to choose the better planting scenario. Note that the comparisons are among the four scenarios per plot.

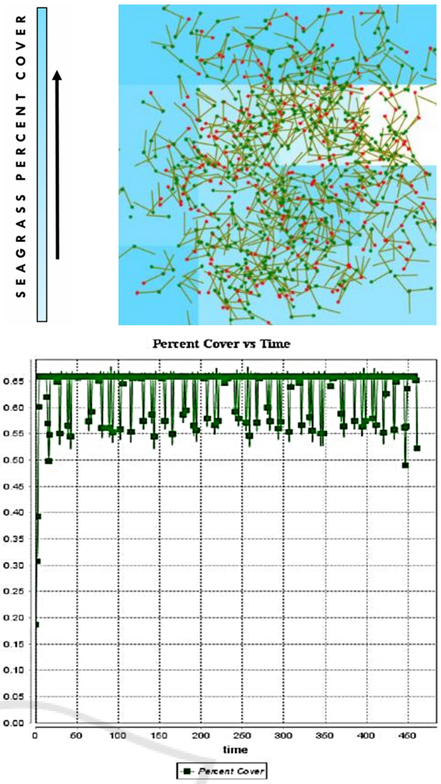


Figure 9: This shows the transplantation simulation results of Plot 1 with Scenario 1 as the best scenario.

4.3 DOE Results

The importance of the factors with respect to the responses by observing their relative significance through their corresponding weights summarized in Table 3. Sum and Mean are the most and least significant percent cover response, respectively, both to the planting distribution and planting density. Furthermore, the factors were found to be independent of each other a factor can be examined separately without considering the other.

Table 3: This table contains the weight of each percent cover responses shown.

Percent Cover Response	Planting Distribution	Planting Density
Sum	0.993	0.548
Mean	0.002	0.001
Standard Dev.	0.005	0.003
Minimum	0.009	0.012
No. of Extreme Drops	0.750	0.375

The DOE table as shown in Table 2 was completed with five percent cover responses sum, mean, standard deviation, minimum, and number of extreme percent cover drops. It was observed that the model factors planting distribution and planting density, and levels in this case study are not significant using 95% confidence level with respect to the previously enumerated responses. However, based on how seagrass transplantation are practically planned and carried out, these factors are still viewed as worthy of research attention. It is just unfortunate that this result may be due to a number of study limitations brought about by the short duration and lack of fieldwork budget of the project under which this study was undertaken. These limitations include the lack of field-obtained datasets such as drone images in varying dates which can facilitate a formulation of a sophisticated calibration and validation procedure. Another is the lack of powerful computers to simulate larger seagrass plots in longer period. Nonetheless, these can serve as areas of improvement for future researchers.

5 CONCLUSIONS AND RECOMMENDATIONS

The study was able to develop and demonstrate a framework for seagrass transplantation simulation. The two factors planting distribution and planting density appeared to be insignificant in the setup of this study due to the presented limitations. However, the importance (weight) of the factors with respect to the responses can be observed based on the coefficients derive from the DOE analysis. Majority of the responses show that planting distribution has a greater weight than planting density. Mean and standard deviation were used to determine which scenario will fit given the initial percent cover of a plot -- Scenario 1 having 4 plants with 24 cm intervals for Plots 1 and 2, while Scenario 2 having 8 plants (2 plants per grid cell) with 24 cm intervals for Plot 3.

Visualization techniques such 3D view of seagrass agents closer to their real appearances can be used in order to make non-technical persons understand more easily the simulation outcomes. Furthermore, a stand-alone software with more user-friendly interface can be developed for government and academic purposes. These future programs must be optimized for usage efficiency to account for machine capability limitations.

For the validation, it is highly encouraged to use imageries of the same resolution as the reference imagery. One method is to extract and compare percent covers from the "after the simulation date" imageries and compare them to the simulation percent cover outcome.

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