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Fuzzy Logic Decision Support System for Mangroves Restoration in Eastern Samar, Philippines

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***Abstract*—** Experts claimed that the failure by 80% - 90% of government-initiated mangrove restoration projects were directed towards ignorance of the real mangrove inhabitable environment. Thus, information dissemination recently steered from flyers and manuals to development of mobile and web apps, aiming for lower mortality rates. In this study, a Decision Support System (DSS) was developed that is capable of pinpointing where and when to plant, and what mangrove species to plant at a given location. It aims to give the users some scenarios of how plants will probably grow at a given location, and planted at a given time. The DSS was designed using rule-based system approach, where decision tables was based from studying experts' mangroves ecosystem restoration guidelines. Factors identified were considered user inputs to determine rules for inference engine to check on most appropriate planting techniques, time and locations. To determine accuracy of the DSS, the system output were compared to observed data from 6 local mangrove plantations in the province. Test results showed 86% accuracy from 60 random output comparison from actual situation on field.

***Index Terms*—** *decision support system, mangroves restoration, knowledge-based system, fuzzy logic, inference system*

I. INTRODUCTION

The threat of climate change proved by strong typhoons and other destructive natural calamities awakened the world and triggers numerous actions and planned activities initiated by our government and different non-government organizations in order to respond to this issue. This includes global studies and projects to restore and rehabilitate the mangroves forests that serve as our greenbelt against strong ocean force caused by stronger typhoons and destructive tsunamis [1]. In support to this program, heavy funding for massive restoration and rehabilitation of our mangrove forest continue over the last two decades. In 2014, the Philippine government have allocated345 million pesos fund to support the nationwide project of the Department of Environment and Natural Resources (DENR) for possible restoration and rehabilitation of the country's mangroves ecosystem hit by typhoon Yolanda in 2013 [2]. Along with the government efforts for mangroves restoration and rehabilitation are similar projects of private organizations targeted to plant 19 million seedlings in the damaged coastline. In 2016, DBM released the 1 billion allocated budget for mangroves and beach forest restorations and development for the affected 171 cities and municipalities in the Visayas regions, including some parts of the Bicol region and Region 4B or Mimaropa [3][4].

However, some mangroves restoration and rehabilitation projects of the government and non-government organizations failed. In an article published by Palawan News last August 1, 2018, world-renowned mangrove scientist J. Primavera claimed National Greening Program (NGP) activities of the government are only wasting resources [5]. Scientists claimed that the government is rushing the program to meet targets, planting the wrong mangroves in the wrong areas. In a P500,000-mangrove replanting project in Hernani, Eastern Samar, where bakhaw seedlings did not grow because they couldn't withstand the impact of high waves[6] [7]. Figure 1 below shows, one of the government mangrove plantation projects that failed. They placed seedlings in mudflats, sand flats, or sea grass meadows that cannot support the trees. Some of these areas planted have inadequate nutrients and in other places, strong winds and currents batter the seedlings. This findings indicate that the group of people who were tasked to implement the planting projects, does not have a clear view as to what will happen to their planted seedlings 1 – 12 months after implementation. They have planted mangroves seedlings to any area without a clear understanding on the possibility for high mortality [8]. Similar results indicated loss of almost 90% of the planted mangroves at wrong sites in replantation projects implemented even before typhoon Yolanda [9].

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Fig 1. A 30-hectare mangrove plantation project in Brgy. Carolina, Can-avid Eastern Samar, dead 1 year after planting

Mangrove experts held the technical know-how geared for a successful mangroves restoration projects. Collected data from papers, research findings, blogs, articles, presentations and survey results conducted by mangrove experts can help overcome with the high mortality rate of mangrove replantation programs. However, these mangroves facts and technical planting guides do not obviously reached the concerned people on the field and hence, projects resulted to waste in resources. This study developed an online repository of mangroves re-plantation facts and techniques which were consolidated to come up with a feasible decision-making guide for people in the field to check if an area is suited for a chosen mangrove species. Specifically, this aims to give the mangroves restoration project implementers such as the Local Government Units, DENR personnel, and the local farmers, the technical know-how needed for mangroves restoration project implementation, such as (1) which area in the province are suited for mangroves plantation?, (2) what mangrove species best suits a given area?, (3) when is the best time to plant mangroves?, (4) how a given species could be best planted?, and (5) how planted species will probably grow at a given time estimate. The researchers believe that this system will be able to help the local mangroves farmers in planting and growing mangroves successfully, thereby re-growing a healthier environment and restoring the greenbelt that once have protected the Visayas community.

II. METHODOLOGY

A. *Rule-Based DSS*

The design of the DSS was based on knowledge-based system approach, where decision-makings and condition analysis were based on knowledge and data methods from mangroves replantation references and solutions presented by mangroves experts in published planting guidelines. The mangroves planting facts, techniques and methods were captured from manuals approved and recommended by mangroves experts in the Philippines, and some mangroves guides released and distributed by Ecosystem Research and Development Bureau (ERDB) and the Department of Environment and Natural Resources (DENR). Data on tides came from Tide Table of the Philippines, and the map of bodies of water in the country taken from National Mapping and Resource Information Authority (NAMRIA), which was necessary to determine availability of adjacent rivers along plantation sites. To determine the kind of soil at the plantation or target site, the soil map of the Philippines was used from Bureau of Soils.

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These seven (7) factors identified namely: mangrove type, zone, tide level, soil type, presence of an adjacent river, seedling height and existing species were the user inputs to determine rules for inference engine to check on most appropriate planting techniques, time and locations. Figure 1 below shows the required input necessary to arrive at best planting strategies. To determine best plantation area, data on mangrove type, zone, tide level, soil type, availability of adjacent river, and the existing species are needed, while to check for best planting schedule, only the tide level based on tide table at a given time and date of planting is needed

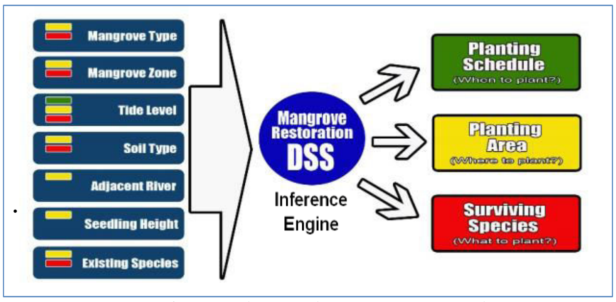

Fig. 2. Rule-Based System Framework

TABLE I
RATE OF RESTORATION PARAMETER

Variable		Classes	Rhizophoraceae Rate	Avicenniaceae Rate	Sonneratiaceae Rate
Soil Type	Mu	Area soil is muddy	1	9	3
	SM	Area soil is sandy-muddy	3	6	6
	Sa	Area soil is sandy	6	3	3
	Ro	Area soil is rocky or coralline	9	3	3
Zone	LW	Landward (Negligibly Saline)	9	5	9
	MZ	Midzone (Fairly Saline)	5	5	5
	SW	Seaward ((Highly Saline)	1	5	1
Adjacent River	No	No existing river in	1	1	1

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		the plantation zone			
	Yes	There is an existing river in the plantation zone	9	9	9
Tide Level	VD	Very deep	1	1	1
	DP	Deep	3	3	3
	MD	Moderate	6	6	6
	SH	Shallow	9	9	9
Existing Mangroves	AV	AvicenniaceaeFamily	1	6	3
	SO	Sonneratiaceae Family	3	3	6
	RH	Rhizophoraceae Family	6	1	1
Seedling Height	S1	<= 0.2 m	1	1	1
	S2	0.3 to 0.4 with less than 6 leaves	3	3	6
	S3	>= 0.5 m with 6 to 10 leaves Not more than 0.5 m (for sonneratiaceae family)	6	6	3

Input values are enumerated in table 1. Target outputs shown in green, yellow and red boxes shown right in the diagram, which require specific data as its color corresponds to inputs shown in blue boxes on the left. Hence, the fuzzy inference framework shown in figure 3, 4, and 5 below.

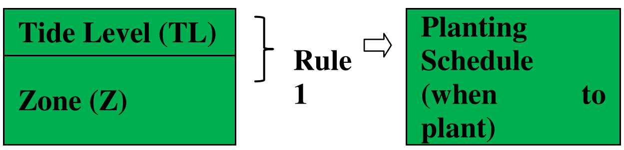

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Fig. 3: Planting Schedule – Fuzzy Inference Framework

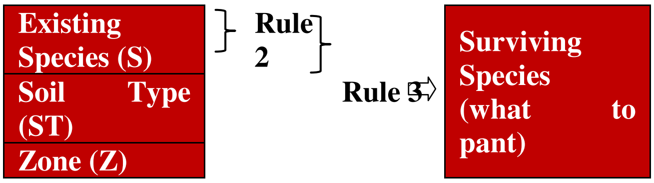

Fig. 4: Surviving Species – Fuzzy Inference Framework

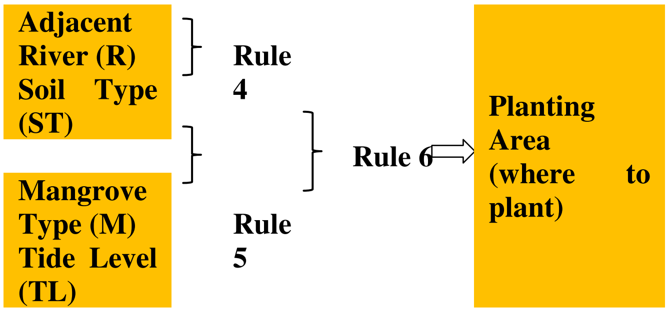

Fig. 5: Planting Area – Fuzzy Inference Framework

Decision results were determined following the fuzzy inference system known as fuzzy DSS [10], containing 3 parts: (1) fuzzy rules, (2) database, and (3) the inference process. Rules were extracted from planting manual with respect to the experts' opinions, and were fed into the database and served as reference in the inference process.

TABLE II
FUZZY SET RULES USED

RULE No.	ALGORITHMS
1	IF TL is low AND Z = seaward THEN Planting Schedule = time of low tide – 0.5 IF TL is low AND Z = midzone THEN Planting Schedule = time of low tide +- 0.5 IF TL is low AND Z = landward THEN Planting Schedule < time of low tide – 1 OTHERWISE no planting schedule suggested
2	IF S = Avicenniaceae AND ST = Muddy THEN RC1 IF S = Avicenniaceae AND ST = Coralline THEN RC2 IF S = Avicenniaceae AND ST = Sandy THEN RC3 IF S = Sonneratiaceae AND ST = Coralline THEN RC4 IF S = Sonneratiaceae AND ST = Sandy THEN RC5 IF S = Sonneratiaceae AND ST = Muddy THEN RC6 IF S = Rhizophoraceae AND ST = Muddy

	THEN RC7 IF S = Rhizophoraceae AND ST = Sandy THEN RC8 IF S = Rhizophoraceae AND ST = Coralline THEN RC9
3	IF RC1 AND Z = Seaward THEN Surviving Species = AA or AO or AM IF RC2 AND Z = Midzone THEN Surviving Species = AA or AO or AM IF RC3 AND Z = Landward THEN Surviving Species = AA or AO or AM IF RC4 AND Z = Seaward THEN Surviving Species = SA IF RC5 AND Z = Midzone THEN Surviving Species = SA IF RC6 AND Z = Seaward THEN Surviving Species = SA IF RC7 AND Z = Midzone THEN Surviving Species = RA or RS or RM IF RC8 AND Z = Midzone THEN Surviving Species = RA or RS or RM IF RC9 AND Z = Landward THEN Surviving Species = RA or RS or RM
4	IF R = Yes AND ST = Muddy THEN RC10 IF R = Yes AND ST = Sandy THEN RC11 IF R = Yes AND ST = Coralline THEN RC12 OTHERWISE, AREA IS NOT HABITABLE
5	IF M = Avicenniaceae OR Sonneratiaceae OR Rhizophoraceae AND TL = DP THEN RC13 IF M = Avicenniaceae OR Sonneratiaceae OR Rhizophoraceae AND TL = MD THEN RC14 IF M = Avicenniaceae OR Sonneratiaceae OR Rhizophoraceae AND TL = SH THEN RC15 IF M = Avicenniaceae OR Sonneratiaceae OR Rhizophoraceae AND TL = NW THEN RC16
6	IF RC10 AND RC13 THEN Planting Area = NL IF RC11 AND RC13 THEN Planting Area = NL IF RC12 AND RC13 THEN Planting Area = NL IF RC10 AND RC14 THEN Planting Area = NL

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	IF RC11 AND RC14 THEN Planting Area = LL IF RC12 AND RC14 THEN Planting Area = LL IF RC10 AND RC15 THEN Planting Area = NL IF RC11 AND RC15 THEN Planting Area = ML IF RC12 AND RC15 THEN Planting Area = ML IF RC10 AND RC16 THEN Planting Area = ML IF RC11 AND RC16 THEN Planting Area = HL IF RC12 AND RC16 THEN Planting Area = HL

B. Accuracy Test

Accuracy of the DSS was checked in two ways: (1) mangrove experts' accuracy check approval, and (2) comparison of system results to actual data as observed on field. Accuracy were based on the capability of the DSS to produce correct answers and recommendations, as perceived by the knowledge of the experts on the following questions:

a. Which area in the province are suited for mangroves plantation?
b. What mangrove species best suits a given area?
c. When is the best time to plant mangroves?
d. How a given species could be best planted?

System results were compared to the actual measurements of the mangroves growth as recorded and observed by CENRO Eastern Samar Provincial Office. Mangroves were measured according to its height, number of leaves, number of branches, root length and number of flowers and propagules. Measuring were done on 3 consecutive mid-years starting from the time it was planted. Among the identified plantation sites which served as basis for comparison are shown in table 3 below:

TABLE III
MANGROVES PLANTATION SITES USED FOR OUTPUT COMPARISON

Location (Eastern Samar)	**Data Planted**	**Species Planted**	**Area Planted**	**No. Of Propagules Planted**	**Area Characteristics**	
					Type of Soil/ Location	**Tide Height**
Brgy. Japitan	Feb 201	Rhizophora	0.7	1750	Rocky,	3.5 feet

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					Type of Soil/ Location	**Tide Height**
, Dolores	5	Mucronata	has.		Seaward	
Brgy. Dapdap, Dolores	Sept 2014	Rhizophora Mucronata	0.3 has.	750	Sandy - Muddy, Midzone	3.5 feet
Brgy. Carolina, Can-avid	July 2015	Rhizophora Stylosa	30 has.	75,000	Muddy-Rocky, Seaward	3.5 ft.
Brgy. Del Remedio, Sulat	Feb 2015	Rhizophora Stylosa	25 has.	50,000	Sandy - Muddy, Seaward	4 ft.
Brgy. Canteros, Can-avid	Aug 2015	Rhizophora Stylosa	75 has.	180,000	Sandy - Muddy, Seaward	3 ft.
Brgy. San Luis, Taft	Aug 2015	Rhizophora Stylosa	7.5 has.	18,750	Muddy, Seaward	4.5 ft.

III. RESULTS AND DISCUSSIONS

This study used experts' data to determine best mangroves replantation guides. This data served as basis for the design of rules necessary to identify features of the fuzzy DSS application than can (1) determine which mangroves species best suits a given location, (2) when is the appropriate time to plant, (3) give locations that are mangrove habitable. Below are the derived fuzzy sets for each expected output. For planting schedule at low tide of the monthly tide table of the area, decision were made according to (HL) - Highly Likely, (ML) – Moderately Likely,

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(LL) – Less Likely, and (NL) – Not Likely. The same linguistic terms were used for the other two expected output, surviving species, and planting area.

TABLE IV. FUZZY RULE BASE FOR PLANTING SCHEDULE AT LOW TIDE

		Mangrove Zone (Z)		
		Seaward	Midzone	Landward
Tide level (TL)	Deep	NL	NL	NL
	Moderate	LL	LL	ML
	Shallow	ML	ML	HL
	No water	HL	HL	HL

Table 5. Fuzzy Rule Base for Surviving Species

		Mangrove Zone (Z)								
		Rhizophoraceae			Avicenniaceae			Sonneratiaceae		
		Sea	Mid	Land	Sea	Mid	Land	Sea	Mid	Land
Rule 3	RC1	NL	ML	LL	HL	HL	HL	ML	ML	LL
	RC2	NL	ML	LL	HL	HL	HL	ML	ML	LL
	RC3	NL	ML	LL	HL	HL	HL	ML	ML	LL
	RC4	NL	ML	LL	ML	ML	ML	HL	HL	HL
	RC5	NL	ML	LL	ML	ML	ML	HL	HL	HL
	RC6	NL	ML	LL	ML	ML	ML	HL	HL	HL
	RC7	HL	HL	HL	ML	LL	LL	ML	ML	ML
	RC8	HL	HL	HL	LL	LL	LL	ML	ML	ML
	RC9	HL	HL	HL	LL	LL	LL	ML	ML	ML

TABLE 6. FUZZY RULE BASE FOR PLANTING AREA

		Rule 5			
		RC13	RC14	RC15	RC16
Rule 4	RC10	NL	NL	NL	ML
	RC11	NL	LL	ML	HL
	RC12	NL	LL	ML	HL

System result was also compared to average results of data collected from identified plantation sites in Eastern Samar at 3 consecutive plantation visits. 10 randomly selected plants growing among the sites were counted and

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measured, to include height (cm) of the plant, number of leaves, aerial root length (cm), number of branches and number of flowers or propagules. Average measurements were taken and was compared to the system results to determine accuracy. Table 3 below shows sample data collected from sites.

TABLE IV
SAMPLE OBSERVED DATA FROM PLANTED PROPAGULES

Plant No.	Height (cm)	No. of Leaves	Root Length (cm)	No. of Branches	No. of Flowers/ Propagules	
1	40	2	0	0	0	
2	23	1	0	0	0	
3	31	2	0	0	0	
4	63	6	0	0	0	
5	57	5	0	0	0	
6	38	4	0	0	0	
7	55	4	0	0	0	
8	61	6	0	0	0	
9	29	2	0	0	0	
10	44	2	0	0	0	
average height in first survey			22	No. of Leaves		2
average height in second survey			44	No. of Leaves		3
height increase in 3 months			9 - 26 cm			

86% of the randomly selected comparisons matched between the actual observed data and the system result. Table 3 shows 44 cm average height as compared to 68 cm perceived height of a 1 year old mangrove at the DSS, shown in figure 6. This inconsistency is due to some other factors that contribute to mangroves growth in its actual ecosystem which includes nutrients, and actual wave inundation, These 2 factors were not considered as a counting factor in the DSS, but has significant contribution to mangroves growth.

IV. CONCLUSIONS

A DSS was developed that can determine (1) which area in the province is best suited for a given mangrove species, (2) which mangrove species can thrive in a given area, (3) when is the best time to plant, to ensure lower mortality.

Only 86% of the observed actual data from site matches the system results. Though we arrived at positive majority result, 14% of inaccuracy matters in system development. Other factors on mangroves growth may be considered for future researches like nutrient intake and wave inundation, to ensure higher accuracy results.

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