2-Tuple Fuzzy Linguistic Model to Evaluate the Risk of Invasive Plant Species

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***Abstract*— Management of invasive species can appear to be a complicated and unending task. In order to manage the spread, these species need to be undergone any risk assessment during their introduction. The aim of this study is to evaluate the aggregate risk of Invasive Alien Species (IAS) using invasive attributes. We use the 2-tuple fuzzy linguistic representation to develop the model without loss of information in which occur in ordinary linguistic operators. These risk values are compared with the National Risk assessment scores which are in the form of Linguistic labels. The proposed model is validated using few known noninvasive species in Sri Lanka. The model gives significant predictions and it is found to be a better tracking system for identifying potential invaders than the conventional risk assessment methods.**

Keywords; ***Invasive Alien Species; Invasive attributes; Risk assessment; Linguistic variables;2-tuple Fuzzy linguistic representation***

I. INTRODUCTION

Invasiveness of an alien species is recognized as the ability to spread, establish beyond its origin while harming the biodiversity of the new environment [1]. Invasive Alien Species (IAS) are therefore considered as a serious threat to the existence of various ecosystems as they alter physical, chemical and biological components of the environment. The screening of risk of invasive plant species is a difficult task due to uncertain and imprecise data. Currently, Risk Assessments (RA) are available worldwide to evaluate the invasion risk of plant species which are found in qualitative or quantitative formats and have both advantages and disadvantages [2].

In these risk assessments, it can be noted that, finding precise numerical values for data related to risk factor are not an easy task. Due to the unavailability of exact and precise values, most of the data are in the form of qualitative. Words mean different things to a different group of people and, so are uncertain [3,4]. The fuzzy linguistic assessment approach is a key tool to capture the uncertainties of qualitative terms. The computational techniques to solve the problems using linguistic information are based on extension principle and symbolic methods. The common drawback of these techniques is the loss of information. To overcome this limitation, Francisco Herrera and Luis Martinez [5] have proposed a 2-tuple fuzzy linguistic representational model which composed by a linguistic term and a number.

In this study, our aim is to develop a 2-tuple fuzzy linguistic risk assessment model to make more precise decisions on risks of IAS than conventional methods.

II. SELECTION OF PARAMETERS

According to the view of biologists, several factors affect the spread of invasive plant species such as its ecology, establishment, invasive potential, management aspects . In conventional risk assessments, these factors are being considered by giving score values. In this work, mainly five factors related to invasive potential have been concerned. These five parameters have been selected by considering the National post Risk Assessment (NRA) for alien invasive plant species in Sri Lanka [6]. Moreover, information on each of the parameters of known 33 invasive alien plants and 3 non-invasive plants and their risk scores (%) from NRA have been provided by the invasive specialist group attached to the Ministry of Environment and Renewable Resources, Sri Lanka. These parameters may be written as below:

- Dispersal Strength (*DIS*)
- Vegetative Reproduction Strength (*VRS*)
- Seed germination requirements (*SGR*)
- Potential to be spread by human activities (*HA*)
- Role of natural and man-made disturbances (*NMD*)

One may note that the parameter Dispersal strength accompanied with four sub parameters. The *DIS* for each plant in the dataset has been taken from [7]. Therefore, all the parameters are in the form of qualitative.

III. THE LINGUISTIC TERMS SET FOR RISK LEVELS

The final output of the linguistic model will be the invasive risk level of plant species where the parameters are qualitative/linguistic variables. Therefore, we need to choose the cardinality of the linguistic term set which is the level of discrimination among the different counting of uncertainty. This linguistic term set presents the plant species' risk levels with respect to invasive attributes. [8,9].

Considering the cardinality of linguistic terms set that has been used by the plant science experts to express their evaluation of linguistic variables that we have selected, a set of seven linguistic term set S has been set up as follows [8]:

$s_0 = U = Unlikely = (0, 0, 0.16)$

$s_1 = VL = Very\ Low = (0, 0.16, 0.34)$

$s_2 = L = Low = (0.16, 0.34, 0.5)$

$s_3 = M = Medium = (0.34, 0.5, 0.66)$

$s_4 = H = High = (0.34, 0.5, 0.66)$

$s_5 = VH = Very\ High = (0.66, 0.84, 1)$

$s_6 = EH = Extremely\ High = (0.84, 1, 1)$

The membership functions of these labels are depicted in Fig. 1. These linguistic terms have been placed symmetrically around the middle term which represents the assessment of "approximately 0.5".

In this kind of an ordered structure, it is often required that the linguistic term set satisfies the following additional characteristics as defined in [8]:

- There is a negation operator, e.g., *Neg*(s_i)= s_j, $j = T - i$($T + 1$ is the cardinality).
- Maximization operator: $\text{Max}(s_i, s_j) = s_i$ if $s_i \geq s_j$.
- Minimization operator: $\text{Min}(s_i, s_j) = s_i$ if $s_i \leq s_j$.

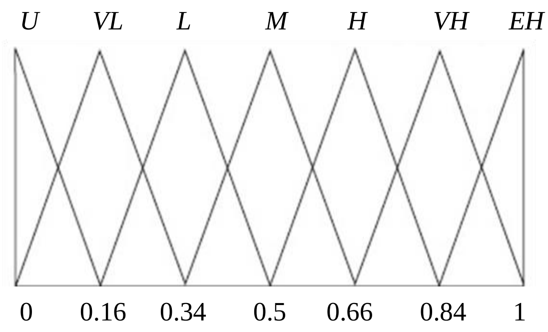

Figure 1. Membership functions of linguistic term set *S*

- balance dimensionally. If one may use mixed units, the units for each quantity need to be stated clearly.

In the next section, we present the sub model which evaluates the risk of dispersal related factors of invasive species.

IV. FORMULATION OF THE 2-TUPLE FUZZY LINGUISTIC MODEL

A. Linguistic 2-tuple representation

It represents the linguistic information by means of a pair of values (s, α), where s is a linguistic term and α is a numeric value representing the symbolic translation.

B. Symbolic translation of 2-Tuple Fuzzy Linguistic Representation

In this study, the concept of symbolic translation has been considered for the 2-Tuple representation. The symbolic translation of 2-tuple fuzzy linguistic representation function has been reproduced in the Def. 1 as in [5].

Definition 1[5]: Let $S = \{s_0, ..., s_g\}$ be a linguistic term set and $\beta \in [0, g]$ a value representing the result of a symbolic aggregation operation, then the 2-tuple that expresses the equivalent information to β is obtained with the following function:

$$\Delta : [0, g] \to S \times [-0.5, 0.5)$$

$$\Delta(\beta) = (s_i, \alpha) \text{ with}$$

$$\begin{cases} s_i, & i = \text{round}(\beta) \\ \alpha = \beta - i, & \alpha \in [-0.5, 0.5) \end{cases}$$

where the round $(\cdot)$ is the usual round operation, s_i has the closest index label to "β," and "α," is the value of the symbolic translation.

C. The Aggergation operator

In this study, the arithmetic mean operator has been selected among the linguistic 2-tuples based on classical aggregation operators [5].

The Arithmetic mean operator equivalent to linguistic 2-tuple is defined as in Def. 2.

Definition 2[5]: Let $x = \{(r_1, \alpha_1), ..., (r_n, \alpha_n)\}$ be a set of 2-tuples, the 2-tuple arithmetic mean $\bar{x}^e$ is computed as

$$\bar{x}^e = \Delta\left(\sum_{i=1}^{n} \frac{1}{n} \Delta^{-1}(r_i, \alpha_i)\right) = \Delta\left(\frac{1}{n}\sum_{i=1}^{n} \beta_i\right)$$

This operator allows us to compute the mean of a set of linguistic values without any loss of information.

D. Model Formulation

- The qualitative data of each parameter of the plant species in the dataset have been transformed into 2-tuples
- To obtain the invasion risk level of each species, aggregate the 2-tuples in each parameter using the 2-tuple arithmetic mean.
- The results have been compared with the NRA scores. For this comparison, the NRA scores have been converted into linguistic labels using the numeric-linguistic transformation function in [10]. The same linguistic term set in Fig. 1 has been used for this purpose.

V. RESULTS & DISCUSSION

The model has been validated using few known non-invasive species and the results are shown in Table II.

According to Table 1, it can be seen that the species such as *Alstonia macrophylla*, *Austroeupatorium inulifolium*, *Lantana camara* and *Acacia mearnsii*, their risks produced from the model are exactly same as NRA risks.

For species, the NRA and linguistic label (s) in 2-tuple is same but different in symbolic translation (α). For example, consider the 2-tuples of species *Dillenia suffructicosa and Ageratina riparia* as depited in Fig. 2.

TABLE I. TEST RESULTS

Invasive species	**NRA**	**Fuzzy Linguistic Model**
Alternanthera philoxeroides	*H*	[*H*,-0.4]
Clidemia hirta	*H*	[*M*,0]
Miconia calvescens	*H*	[*H*,-0.4]
Alstonia macrophylla	*M*	[*M*,0]
Annona glabra	*M*	[*M*,-0.4]
Clusia rosea	*M*	[*L*,0.4]
Dillenia suffructicosa	*M*	[*M*,-0.4]
Ageratina riparia	*M*	[*M*,0.4]
Mimosa invisa	*H*	[*M*,0]
Myroxylon balsamum	*M*	[*M*,-0.4]
Tithonia diversiflora	*M*	[*M*,-0.2]
Mikania micrantha	*H*	[*H*,-0.2]
Prosopis juliflora	*H*	[*M*,0.4]
Ulex europaeus	*M*	[*L*,0.4]
Mimosa pigra	*H*	[*M*,0]
Chromolaena odorata	*H*	[*M*,0.4]
Parthenium hysterophorus	*H*	[*M*,0.4]
Lantana camara	*M*	[*M*,0]
Imperata cylindrical	*VH*	[*H*,0]
Opuntia stricta	*H*	[*M*,0.2]
Colubrina asiatica	*M*	[*L*,0.4]
Pennisetum polystachion	*M*	[*M*,0.4]
Sphagneticola trilobata	*M*	[*M*,-0.2]
Zizigium marutinum	*L*	[*L*,0.2]
Eichhornia crassipes	*H*	[*M*,0.4]
Pistia stratiotes	*H*	[*M*,0.4]
Leucaena leucocephala	*M*	[*M*,-0.2]
Austroeupatorium inulifolium	*M*	[*M*,0]
Panicum maximum	*H*	[*M*,0.2]
Cuscuta campestris	*H*	[*M*,0.4]
Pueraria montana	*H*	[*H*,-0.2]
Acacia mearnsii	*M*	[*M*,0]
Myrica faya	*M*	[*M*,-0.4]

Fig. 2 clearly interpret that *Ageratina riparia* is more aggressive than *Dillenia suffructicosa because its risk stands point 0.4 beyond the label 'Medium' where Dillenia suffructicosa stands point 0.4 behind on the same label. Similarly, the risks of species, i.e. Alternanthera philoxeroides,* and *Mikania micrantha* can be compared.

TABLE II. VALIDATION RESULTS

Non Invasive species	NRA	Fuzzy Linguistic Model
Cassia fistula	*M*	[*M*, -0.2]
Cissus rotundifolia	*L*	[*L*, 0.4]
Hedychium gardnerianum	*L*	[*L*, 0.2]
Magnefera indica	*M*	[*M*, -0.4]

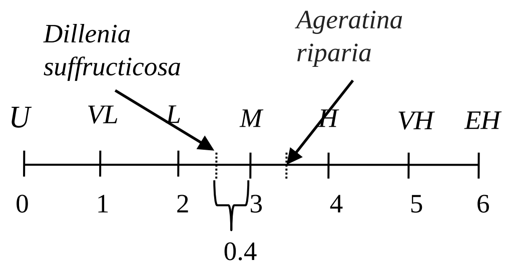

Figure 2. Comparison of Model output with NRA Risk Levels

One may note that risk label in the 2-tuple is different from NRA Label. Consider species *Panicum maximum* and *Cuscuta campestris* which show '*High*' risk in NRA but obtained '*Medium*' from the model. But the value of symbolic translation is between the labels '*Medium*' and '*High*.'

Now let us consider the non invasive species *Cassia fistula* and *Magnfera indica* which show Medium risk in NRA (see Table 2). In reality, we expect *Low* or below risk level for this species category. From our model, it can be clearly seen that the values of symbolic translation of *Cassia fistula* and *Magnefera indica* stay behind to the Medium risk level 0.2, 0.4 respectively.

VI. CONCLUSION

In this paper, a model has been constructed to assess the invasion risk of IAS. 2-Tuple fuzzy linguistic representation model was developed to aggregate the qualitative parameters without loss of information.

The proposed model gives a significant prediction of risks of invasive alien species if its invasion is dominated by invasive attributes. In this study, we have considered the selected parameters are equally important to the invasiveness of plant species. But in reality, the effect of a particular risk attribute towards invasiveness differs from attribute to attribute. Therefore model needs to be improved to overcome the deviations such as incorporating the important weights of the model parameters etc. Also, it is worth mentioning that model needs to be modified by incorporating the risk factors other than invasive attributes, e.g. ecology, establishment, management aspects etc to evaluate overall invasion risk.

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