

Conservation of Sarawak peat swamp in an urban landscape by fuzzy inference system

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Received: 29 December 2010 / Accepted: 3 March 2011 / Published online: 15 March 2011
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Abstract Freshwater habitats are one of the planet's most important, yet most manipulated, environments. This is what happens in Sarawak that the environment has been radically changed due to urban developments. This paper is promoting the idea that we do not need a complicated but a simple tool like fuzzy inference system to strike a balance between the existence of peat swamp and the humans who live nearer and nearer to it. Conditions vital to the survival and continuity of a natural wetland system can be adapted as fuzzy rules. These rules are capable of providing indicators of how much wetland can be exploited and at the same time still allow the system to properly functioning as a wetland.

Keywords Disappearing wetlands · Ecological–social interaction · Habitat · Indicator · Natural landscape · Nature conservation

Background

Large parts of the capital Kuching city of Sarawak State, Malaysia, are erected on previously peatland that was transformed for cityscapes. Today, only a fraction of freshwater peat swamp remains at the outskirts of Kuching city in Matang area (see Fig. 1), but more and more houses are built alongside the linking road. Thus, the remnant of peat swamp should be adequately protected and properly

managed. In order to alleviate the rush to convert wetlands to other uses, it should seek to build wetland conservation into future land development plans (Duarte et al. 2008). The idea is to have natural infrastructure approach that emphasizes on providing space for plants and wildlife; at the same time, accommodating human uses, like the one depicted in the inset of Fig. 1.

Tropical wetlands are among the most biologically diverse and productive ecosystems on earth. Plants and animals associated with wetland habitats are integral to many food chain and life support systems. Wetlands also provide valuable services and functions to human population (UNDP 2006). Natural infrastructure in its simplest form comprises of hubs and corridors. A hub or patch is typically large, unfragmented areas that are critical for conserving important ecosystems. Corridors are linear features that serve to connect hubs of plant and animal populations, thus assuring the long-term viability of these populations and the larger ecosystem. Matrix is often developed lands such as cropland or urban areas. This approach creates a framework for environmental decisions that leverage the interactions of man and ecology.

Motivations

The approach often results in identifying a natural infrastructure network of interconnected green spaces (Benedict and McMahon 2001). It emphasizes on ecosystem values and functions to support long-term sustainability (Gill et al. 2007; USEPA 2010). Yet, how wide does the conservation buffer need to be? Unfortunately, there is no ideal buffer width. Management is deemed successful only if it preserves or increases the capacity of an ecosystem to produce the desired services in perpetuity. Current management of

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Fig. 1 Matang deep peat swamp and Kuching city. *Inset* concepts of natural infrastructure approach to be explored in Matang area that signify the balance of human and nature



wetland tends to sacrificing goods or services more valuable than those developments can offer.

Fuzzy inference system (FIS) is presented here to sketch the appropriate limits for human modification of the ecosystem. It mimics how a person who make decisions. In this case, it lends itself to implementation of a desired natural infrastructure approach, relying on an expert's preferences to arrive at a definite conclusion. But FIS itself is a general method. The difference of one fuzzy system to another depends on its customization of input/output relations.

For peat swamp, a resilient system could withstand disturbances without collapsing into a different state and therefore a vibrant and working ecosystem in harmony with economic development (Townsend 2009). Proper functioning condition (PFC) methodology has much in common with resilient theory thus providing a theoretical background to denote the input/output relations: "physical alteration by human cause" in soil and water balance to sustain "hydrophilic vegetations" (the *Inputs*) should be in the range of allowing "properly functioning of a wetland" (the *Output*). FIS is argued here as a tool, with which expert knowledge in PFC is better defined in rule-based fuzzy sets through its capability in providing linguistic description for systemic assessment and indicators (Ocampo-Duque et al. 2006; Tay and Lim 2008a, b).

Fuzzy inference system

In FIS, fuzzy sets are used to handle the imprecision and uncertainty of data, while fuzzy rules to handle inexact reasoning (Salski et al. 2009). Put it in simple terms, take the case of any real wetland, it contains too many components that it is difficult to comprehend. Therefore, the continuous nature of ecological components is compartmentalized into "sets" with not sharply formed boundaries

(Bosserman and Ragade 1982). "Rules" are then used to combine the many potential "sets" to provide essential information for a desired system (Elektorowicz and Qasaimeh 2004; Lei and Yan 2010). These two elements form the grounds for utilizing FIS in wetland management, which can be traced to wetland classification, water quality analysis, and environmental impact assessments.

Popular in the United States and Canada, PFC is a qualitative rapid assessment method whose purpose is to assess how well the physical processes are functioning (Prichard 1998; Rich 2002). Originally, PFC methodology involves assigning scores to wetland conditions and accumulating all the scores to grade the system manually. However, the problems of vagueness in data and expert knowledge persist. An attempt is made here to embrace PFC in a new context. The status of peat swamp in Matang is hypothesized that an evaluation of human disturbances and vegetative cover is sufficient to evaluate its health. Field visual assessment (Ward et al. 2003) and air photographs (Booth et al. 2007) are used to assess the peat swamp. The peat swamp is designated into polygons, and for each polygon, observations are recorded. The PFC scoring can be transformed to "low," "medium," and "high" fuzzy sets (see Table 1).

These fuzzy set conditions are assigned a value from 0 to 1 to translate human fuzziness to numbers that can be used by a computer. The PFC scoring of vegetative cover is adapted straight to fuzzy sets. However, the author needs further adjustment to the attribute of human disturbances. Conventional conservation works call for little alteration of natural systems, generally to a qualitative rating of 0.1–0.2. Note that the ideal "high" fuzzy set for human disturbances has been intentionally tuned higher to 0.45 to accommodate the natural infrastructure approach.

The output is rated as "properly functioning," "functional at risk," and "non-functioning." Then, simple, plain-language *IF x AND y THEN z* rules are used to emulate the

Table 1 Adjusting PFC scoring to fuzzy sets

Attributes	PFC scoring (ESG 2010)	Fuzzy sets
Human disturbances	No physical alteration = 3	<0.45 = high
	Slight human alteration = 2	0.45–0.75 = medium
	Moderate alteration = 1	>0.75 = low
	Severe alteration = 0	
Vegetative cover	>95% plant covered = 6	>0.85 plant covered = high
	85–95% covered = 4	0.75–0.85 covered = medium
	75–85% covered = 2	<0.75 covered = low
	<75% covered = 0	

“mind of an expert” rather than attempting to model a system mathematically. A detailed description can be found in the Zadeh (2002).

Results and discussion

For demonstration, a FIS diagram is depicted in Fig. 2 with 2 variables and 3 rules. In this method, the 2 attributes of human disturbances and vegetative cover are fed into the model to see how events related to that pattern would unfold. A value of 0.4 for disturbances belongs to “high” and “medium” fuzzy sets with membership degrees of 0.2 and 0.8, respectively. Similarly, a value of 0.7 for vegetation belongs to “high” and “medium” fuzzy sets with membership degrees of 0.5 and 0.5, respectively.

Wetland conditions are computer-weighted like a human mind according to fuzzy rules that warranted for ecological continuity. The potentials of FIS concepts really lie here in

making qualitative assertions, while as a way of processing data, it is guided by rules that are self-defined by an expert according to conservation priority. Take the example in Fig. 2, the author’s desired range of disturbances is 0.0–0.3 and most wanted vegetation is 0.6–1.0. Allowing such choice, it reflects how much the natural wetlands could tolerate the natural infrastructure approach and thus describes the attributes of the criterion in objective, verifiable, and unambiguous manners. Hence, it produced:

- Rule 1* IF disturbances > 0.3 AND vegetation > 0.6 THEN “properly functioning”
- Rule 2* IF disturbances > 0.3 AND vegetation < 0.6 THEN “functioning at risk”
- Rule 3* IF disturbances > 0.3 AND vegetation < 0.4 THEN “non-functioning”.

Eventually, a degree of support is given to every rule. It generated 0.0 degree of support for “non-functioning,” 0.5 for “functioning at risk,” and 0.2 for “properly

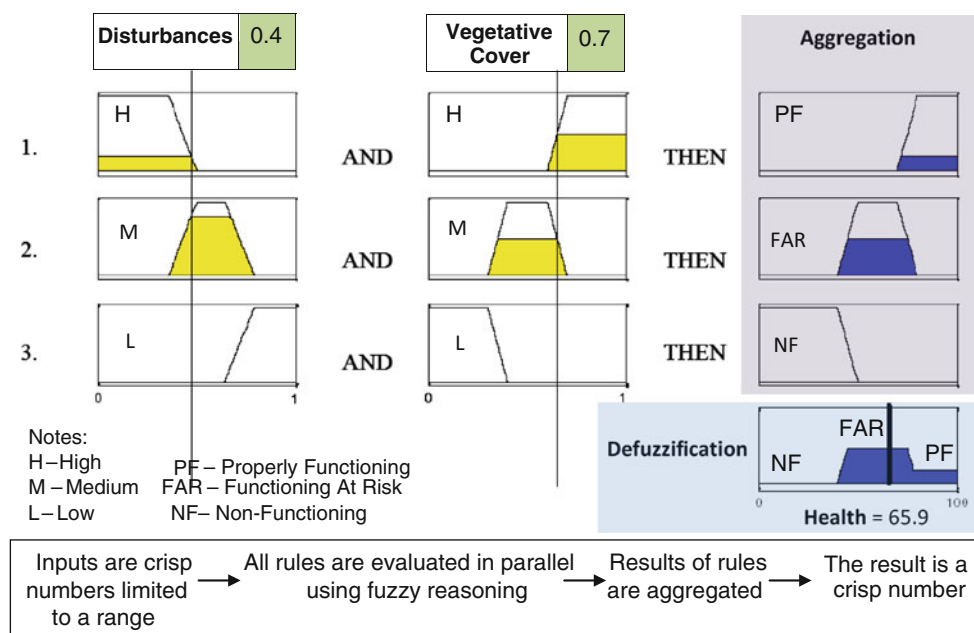


Fig. 2 FIS diagram for wetland health

functioning,” respectively. Since decisions are based on the testing of all the rules in the system, these must be aggregated and defuzzified. The end score determines what level of health status of a wetland system, and thus, the degree of resilience the system can sustain. The FIS assessment has produced an end value of 65.9 for the system under study, which gives an indication of “functioning at risk” but leaning toward a positive upper end.

Conclusion

The approach of FIS-based proper functioning condition assessment involves mechanism to weight wetland health based on rules. These rules are the fundamental environmental values to ensure functionality of natural systems. The model is capable to absorb the desired qualities in the mentioned attributes by applying fuzzy sets and language-guided rules for assessment, a key component lacking in the conventional method. Applying this approach has enabled us to incorporate environmental and ecological interpretive knowledge to the conservation of wetland systems. In this paper, the two attributes are assumed equally important. For future works, a subsequent study is needed to determine the appropriate weight of each input to the generation of output, seeing that some variable may carry higher influence than others.

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