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Using Bayesian Belief Networks for Ecological Assessment in EIA

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Abstract. A development project will be declined in an environmental impact assessment (EIA), once it is predicted to cause significant impact on the environment, society, economy, culture or ecology. One of important criteria on determining the significance is the impact on the survival of rare animals. However, it is very difficult to find a tool that can quantitatively predict the possible effect on rare animals, because it should be able to simultaneously take a variety of stressors (external intervention and change on physical, chemical, biological and habitat environment) into account. Therefore, expert knowledge and judgment is heavily relied on in the ecological assessment of rare animals in an EIA. To improve the credibility of expert judgment, this study uses the Bayesian belief networks (BBN) to visually represent expert knowledge and clearly explain the inference behind the judgment. Finally, the future population status of the Pheasant-tailed Jacanas is assessed using the BBN model in the case of the construction of the Taiwan High-Speed Rail.

Keywords: Bayesian belief networks, Ecological assessment, Environmental impact assessment, PHEASANT-tailed Jacanas.

1. Introduction

To minimize the environmental impact of human activity, the Taiwan Environmental Impact Assessment (EIA) Act was promulgated in 1994 and was amended in 2003. In accordance with this act, each new development proposal or government policy for which there is concern of adverse impact on the environment should prepare an environmental impact statement (EIS) for the first-stage EIA, and then forward the EIS to the EIA committee for review. The EIS should base on scientific surveys, forecasting, analyses and evaluations to address the potential impacts on the physical and chemical environment, ecology, scenery and recreation, social economy and culture. The developer should edit an environmental impact assessment report (EIRA) for the second-stage EIA for those circumstances in which the review conclusion of the EIS is concerned with a 'significant impact' on the environment.

The survival of rare animals is an important criterion on determining whether the impact, which is caused by a development activity, is significant. Although the Guideline for Animal Evaluation Technique is provided by Taiwan EPA, it does not suggest any quantitative tool for impact assessment. In practice, what tools are usually used to help estimate the levels of the impacts on protected or rare animals? After investigating the 34 EISs of road construction from recent five years (2007-2011), the findings indicate that most of them relied heavily on expert knowledge and judgment, alone with limited empirical data. Despite

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the continued advances in empirical or statistical methods of complex and dynamic ecosystems, why most of EISs still used expert option when rating the impacts on rare animals? One possible reason is that they have difficulties in obtaining sufficient scientific information, to establish the cause-effect relationships between a variety of stressors (external intervention and change on physical, chemical, biological and habitat environment) and a receptor (a specific rare animal), so that the way in which human changes will affect the rare animal cannot be adequately quantified. On the contrary, experts are capable to qualitatively forecast the possible consequence on the rare animal, due to a development activity. Not only for rare animals, expert judgment has been widely used in the science and practice of biological conservation, partially because of the complexity of problems, relative lack of data, and the imminent nature of many conservation decisions [1].

Although expert judgment has the ability to assess the impacts on rare animals in an EIS, it usually is criticized that it makes decisions under a black-box, based on intuition or conjecture, if it cannot clearly explain the inference behind the judgment. To ease the concern, tools that can explicitly express expert knowledge, and clearly explain the process of inference are beneficial. Several studies have demonstrated the utility of Bayesian belief networks (BBN) [2] in capturing and integrating expert knowledge and empirical data in ecological issues. The BBN is a directed acyclic graph with nodes denoting a set of random variables as nodes and arrows indicating their probabilistic cause-effect dependencies. The BBN has a number of properties that make it particularly useful for ecological applications. It can combine qualitative knowledge and quantitative data [3], which make it easy to handle missing data. The BBN models can be constructed using observed data, other models, or expert knowledge. It is also a promising tool for risk assessment because it explicitly incorporates uncertainty in relationships. For ecological risk management, it also allows us to know the effects given the causes and the causes given the effects which can be used either directly or interactively [4].

2. Bayesian belief networks

A Bayesian belief network (BBN) consists of a directed acyclic graph whose nodes represent random variables (X_i) with several possible states while arrows connect pairs of nodes to display their probabilistic cause-effect relationships. Fig. 1 is the BBN of the case study. Usually, the values for each node in BBN are categorized into the finite number of levels and, in practice, 2-10 levels are reported in ecological studies. Most of the nodes (the variables) in Fig. 1 are non-quantifiable; therefore, their possible states are divided into five qualitative levels. For example, the amount of the brush and shrubbery is divided into five levels: very scanty, scanty, acceptable, abundant and very abundant. Each node with parents has a conditional probability table (CPT) that quantifies the uncertain effects the parents have on the node; and those nodes without parent has a probability distribution over all possible states. These probabilities are evaluated from historical data, expert judgment, or their combination. A BBN has an associated computational structure, so that it can calculate the bi-directional propagations of beliefs between nodes and ultimately obtained a probability distribution over possible states for each node, while given a set of evidences. This feature can facilitate the test of scenarios, whether under data-driven or goal-driven circumstance.

3. Case Study and the BBN Model

The construction work on the Taiwan High-Speed Rail (THSR) system began on March 27, 2000. The THSR project is not only one of the most challenging infrastructure projects in the world to date but also the largest private-sector-invested public construction project concurrently. The total construction investment needed is approximately USD 18 billion. The planned system is 344.68 km in length, including 252 km of overpasses and 48 km of tunnels. The THSR line runs from Taipei to Kaohsiung, passing 14 major cities and counties and 77 townships and regions, including Guantian. Guantian is an agricultural town in Tainan, well known for its water caltrop farms and produces. Due to the abundant of water caltrop farms and other water-based vegetation farms, Guantian is also an important habitat for many species of waterbirds especially the rare Pheasant-tailed Jacana.

Pheasant-tailed Jacana breeders are found in Southern China, the Philippines and the Middle South Peninsula, as well as Taiwan. The Jacana's hind neck is gold in color, and its firs are dazzling. The males take on the responsibility for the incubation of the eggs and the care of the hatchlings, which is one of this bird. The Jacana is a conspicuous and unmistakable bird that builds its nest on the water caltrops, lotus leaves and other floating vegetation in order to prevent attack from land predators. Several essential survival factors influencing the future population status of the Pheasant-tailed Jacana are shown in Fig. 1. Brushwood and shrubbery provide buffering space against enemy; swampland is a place for nesting; embankment protects breeding from disturbance and also provides a shelter against cold wind; water caltrop is an important place for nesting, foraging and resting; muddiness is a survival factor for the suitability of foraging during winter; rice is the secondary food source; water quality will influence their survival; and finally, exotic threat from human disturbance or predator will also affect their future population status. These factors determine the suitabilities of breeding environment, hibernacula surrounding, condition and habitat.

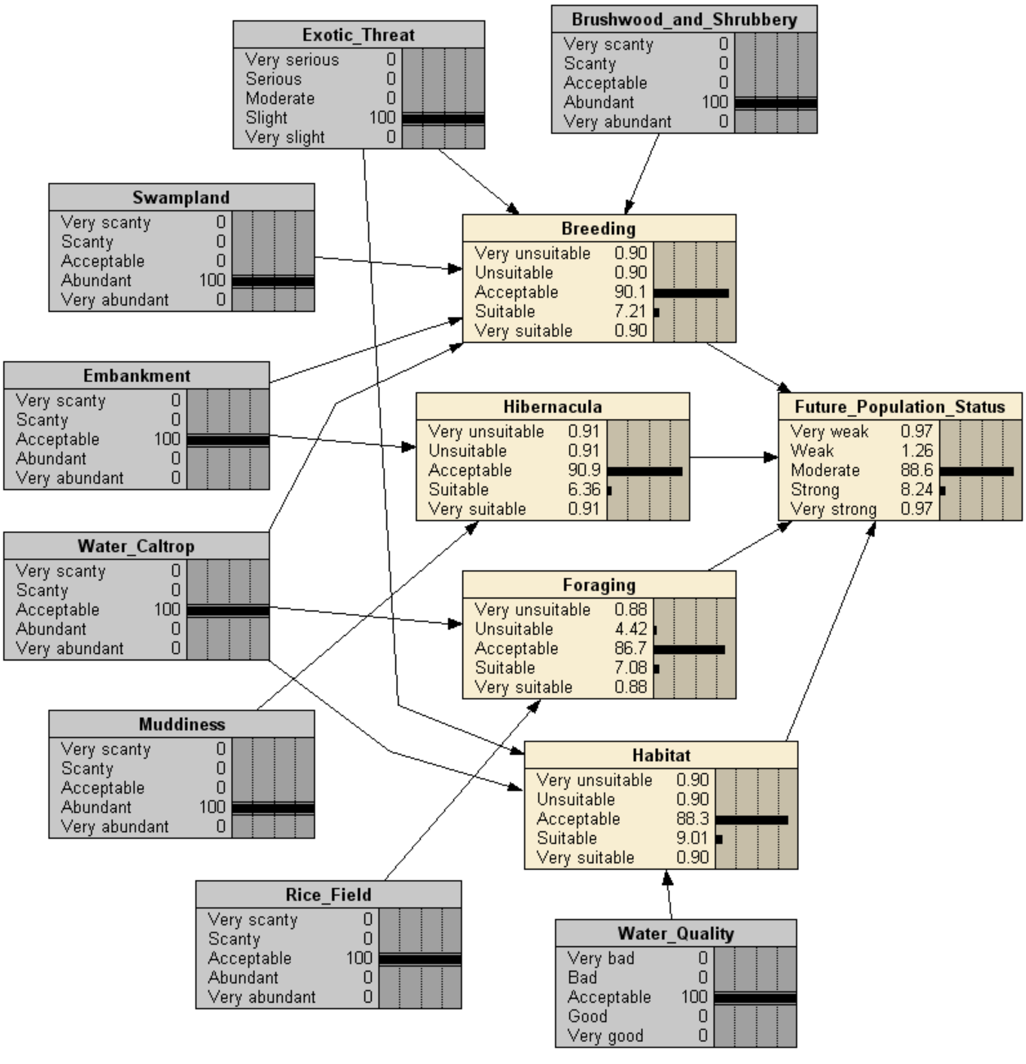

Fig. 1: The BBN Model for the future population status of the Pheasant-tailed Jacana.

Originally, the Pheasant-tailed Jacanas were quite a common sight on farmlands in Taiwan. However, the development of freeways through different pond, farmland and other water caltrop production regions, causing wetlands to decrease, has resulted in a severe reduction in their numbers. Today, the Pheasant-tailed Jacana is one of the most endangered species of bird in the world. Therefore, the number of the Pheasant-tailed Jacana is set to become an indicator for the success of the ecosystem; where the Pheasant-tailed is to be found, a complete fully functioning wetland ecosystem. Unfortunately, the THSR was designed to be built cross the most of important place, the Hulu pond, for the Pheasant-tailed Jacana, and many water caltrop farms and Jacana's natural habitat were disturbed.

In this study, three scenarios about the future population status of the Pheasant-tailed Jacanas are discussed in the EIA report. The first scenario is the baseline condition (BC). The Hulu pond is the largest, stable habitat for the jacana because it cultivates a large amount of water chestnut. However, in winter, water chestnut wilt and no floating leaves are available, so that jacana must be living in ditches, abandoned fish pond or river beaches, leading to be hunt by dogs or other animals. Suitable ponds for the jacana usually have deep embankments; while in the Hulu pond many embankments are shallow, causing a lack of shelters to minimize the interference from the outside. In addition, the illegal industry wastewater from the nearby Kuantien Industrial Park was discharged into the pond, leading to the eutrophication in the pond. And excessive use of pesticides in the around agricultural areas, making the water polluted. The second scenario is the prediction of the impact without mitigation measures (PIWOM). During the construction of the THSR, personnel, vehicles and construction equipment will cause noise, vibration and pollution, which will seriously affect the suitabilities of breeding, foraging, habitat and hibernacula of the jacana. The third scenario is the prediction of the impact with mitigation measures (PIWM). The mitigation measures include reducing the construction scale in the same area, using low noise construction equipment/technology, avoiding building piers in the pond. Besides, not to pollute the water, the wastesoil and wastewater are not allowed to be discharged into the pond. The detail information of the scenarios is shown in Table 1.

Table 1: The detail information of the scenarios

Scenario	BC	PIWOM	PIWM
Brushwood and Shrubbery	Abundant	Acceptable	Acceptable
Exotic Threat	Slight	Serious	Moderate
Swampland	Abundant	Scanty	Acceptable
Embankment	Acceptable	Scanty	Scanty
Water Caltrop	Acceptable	Scanty	Acceptable
Muddiness	Abundant	Scanty	Acceptable
Rice Field	Acceptable	Acceptable	Acceptable
Water Quality	Acceptable	Bad	Acceptable

4. Results and Discussion

For every scenario, its detail information (Table 1) is inputted into the BBN model and the probability distribution over all possible states for each survival factor is then obtained, as shown in Table 2. For the BC, the most probable suitability of ‘breeding’ is ‘acceptable’, with the highest probability 90.09%; the most probable suitability of ‘foraging’ is ‘acceptable’, with the highest probability 86.73%; the most probable suitability of ‘habitat’ is ‘acceptable’, with the highest probability 88.29%; the most probable suitability of ‘hibernacula’ is ‘acceptable’, with the highest probability 90.91%; ultimately, the most probable status of future population of the Pheasant-tailed Jacanas is ‘moderate’, with the highest probability 88.56%, as shown in Fig. 1 and the BC column of Table 2. Because of the construction work of the Taiwan High-Speed Rail, the most probable suitabilities of ‘breeding’, ‘foraging’, ‘habitat’ and ‘hibernacula’ are shifted one level, being ‘unsuitable’, ‘unsuitable’, ‘unsuitable’ and ‘unsuitable’, respectively, and the most probable status of future population of the Pheasant-tailed Jacanas is further rated as ‘weak’, with the highest probability 84.01%, as shown in the PIWON column of Table 2. If the mitigation measures are taken, the analysis result shows that only the suitability of habitat will be improved from ‘unsuitable’ to ‘acceptable’, because mitigation measures primarily reduce construction disturbance (exotic threat) and water pollution. The future population of the Pheasant-tailed Jacanas is then considered as the combination of ‘weak’, with the probability 62.53%, and ‘moderate’, with the probability 34.39%, as shown in the PIWN column of Table 2. This result implies that the PIWN is not satisfactory. A useful feature of the BBN can help to mange environmental or ecological risk, by testing causes given the hypothetical effects (Hart and Pollino 2008). Assumed that the EIA committee ask the developer to keep the suitabilities of ‘breeding’, ‘foraging’, ‘hibernacula’ and ‘habitat’ to be ‘acceptable’ during the construction work, the BBN model suggest the condition of exotic threat should be improved to the level of ‘very slight’ , with the highest probability 79.84%. This ‘very slight’ exotic threat is very difficult or very costly to reach during the construction work, because it is better than the ‘slight’ exotic threat in the BC.

5. Conclusions

This study proposed a BBN model for ecological assessment in EIA, with features including the representation of probabilistic relationships between survival factors and adverse ecological effects through the graph structures of the BBN, the construction of stress-response relationships by CPTs of the BBN, and the capability of predicting the population status of a rare animal with the inference mechanism of the BBN. For the case study, the status of future population of the Pheasant-tailed Jacanas is concerned in the construction work of the THSR. For the BC, the most probable status of future population is 'moderate' (88.56%), but it will go down to 'weak' (84.01%), in the construction phase. It will be slightly improved to 'weak' (62.53%), if the mitigation measures are taken, but the PIWN result is not satisfactory.

Table 2: The derived probability distributions of survival factors for the scenarios

Survival factor	State	BC	PIWOM	PIWM
Breeding	Very unsuitable	0.90%	0.93%	0.94%
	Unsuitable	0.90%	87.85%	86.79%
	Acceptable	90.09%	9.35%	10.38%
	Suitable	7.21%	0.93%	0.94%
	Very suitable	0.90%	0.93%	0.94%
Foraging	Very unsuitable	0.88%	0.92%	0.92%
	Unsuitable	4.42%	88.07%	88.07%
	Acceptable	86.73%	9.17%	9.17%
	Suitable	7.08%	0.92%	0.92%
	Very suitable	0.88%	0.92%	0.92%
Habitat	Very unsuitable	0.90%	1.06%	0.95%
	Unsuitable	0.90%	94.68%	4.76%
	Acceptable	88.29%	2.13%	92.38%
	Suitable	9.01%	1.06%	0.95%
	Very suitable	0.90%	1.06%	0.95%
Hibernacula	Very unsuitable	0.90%	2.63%	2.63%
	Unsuitable	0.90%	87.72%	87.72%
	Acceptable	90.91%	7.89%	7.89%
	Suitable	6.36%	0.88%	0.88%
	Very suitable	0.90%	0.88%	0.88%
Future Population Status	Very weak	0.97%	1.04%	0.96%
	Weak	1.26%	84.01%	62.53%
	Moderate	88.56%	12.78%	34.39%
	Strong	8.24%	1.12%	1.15%
	Very strong	0.97%	1.04%	0.96%

6. Acknowledgements

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7. Reference

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