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MODELLING THE IMPACT OF AQUACULTURE ON SETIU WETLAND ECOSYSTEMS USING BAYESIAN BELIEF NETWORK APPROACH

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Abstract: A study was conducted to assess the impact of aquaculture activities on the ecosystem functions in Setiu Wetland, Malaysia. This study develops an ecosystem impact model based on formal (mathematical) relationships between aquaculture activities and Setiu Wetlands ecosystems using Bayesian Belief Network (BBN) approach. To represent different levels and kinds of aquaculture activity three policy options were used - status quo, a more intensive aquaculture production, conservation and ecotourism. The model integrates information gathered from experts and stakeholders. The results revealed that the impact of fish cage culture are likely differ under different management scenarios. The Conservation scenario was identified as the most attractive, followed by Ecotourism and the Status quo. The Intensive Aquaculture was the least desirable, with water column enrichment identified as the variable which is most vulnerable to the different aquaculture conditions. The BBN has indicated that the water column enrichment processes have the greatest effect on the model. Therefore formulating particular policies with regard to aquaculture management in Setiu Wetland would be sensible. Implication of the results is useful for the main stakeholders especially the policy makers in efforts towards managing the natural resources in a sustainable manner.

Keywords: Wetland ecosystems, aquaculture impacts, Bayesian Belief Networks, ecosystem modelling.

Introduction

Aquaculture began in the Setiu Wetlands area in the late 1970s with fish cage culture in Setiu lagoon. The State Government of Terengganu has recognized Setiu lagoon as an ‘aquaculture industry area’ and is planning further development under the Aquaculture Action Plan (Department of Towh and Country Planning 2004). Currently, the Management policies for Setiu Wetlands are focus on aquaculture development, particularly fish cage culture. The cage culture activities in Setiu Wetlands is concentrated particularly in the lagoon, estuary and to a limited extent in rivers. Cage aquaculture in Setiu Wetland grew significantly during the 1990s and has grown particularly strongly from 2000s onwards. In 1995, fish cage culture production was only 0.88 metric tons with 4,774 square meters of cultured area, 482 cages and 14 culturists. This increased to 305.1 metric tons produced, 52,400 square meters of cultured area, 1485 cages and 101 culturists in 2005. Recent figures on total production are available in 2010 with the total production of 1460.17 metric tons and 2012 with the total production 1460.17 metric tons (Department of Fisheries unpublished data).

However, rapid and intensive expansion of cage aquaculture is likely to pose a major threat to the ecosystem functions and processes which underpin delivery of many of Setiu’s other ecosystem service outputs. These threats arise primarily through cage aquaculture’s impacts on nutrient enrichment, mangrove clearance and the risk of invasive species introductions. According to FAO (2005), accumulation of wastes from cages would alter benthic ecology and modify water chemistry because cage culture activities produce large amount of solid wastes, including faeces, excretory material and waste (uneaten) food.

Setiu wetlands have recently experienced significant ecological problems, especially with regard to water quality due to the high intensity of fish cages and development of fish ponds. Realizing the importance of the Setiu Wetlands, a number of studies have been carried out to investigate the environmental impacts caused by the rapid growth of aquaculture activities in this area Setiu Wetlands. Suhaimi *et al.* (2004) assessed the distribution and concentration of inorganic nutrients (including distribution of chlorophyll-a) from anthropogenic activities at the Setiu river. The results showed that nitrogen-based nutrients were present at higher levels, probably due to pollution from domestic wastes, excessive use of fertilizers in agriculture and from aquaculture activities, particularly cage culture, in the Setiu Lagoon (Suhaimi *et al.,* 2004). Meanwhile, Norhayati *et al.* (2006) investigated the distribution and sources of hydrocarbons in lagoon sediments. The results found that hydrocarbons present in the sediments along the lagoon with a minor contribution from marine phytoplankton and bacteria. A study of naked amoebae in the water and sediments of Setiu Wetlands by Nakisah *et al.* (2008) showed a correlation between nutrients and the fine structure of the sediments (clay) at a site.

A few studies have also been undertaken in this area to assess aquaculture impacts on human health. Najiah *et al.* (2008) identified the presence of seven different bacteria and recorded a high concentration of copper, zinc (seven times more than the maximum permitted for a seafood product) and cadmium concentrations (which were slightly higher than the maximum permitted levels). In a separate study, Najiah *et al.* (2010) identified wild mud crabs containing antibiotic resistant bacteria and suggested occurrence of faecal contamination in the Setiu Wetlands area.

The Application of BBN Approach in Ecosystem Modelling

The Setiu Wetlands ecosystems such as other natural ecosystems are composed of non-linear, highly interconnected and complex networks. Ecological models can be utilized to understand and simplify the complexity, uncertainty and variability of the interactions that occur within the ecosystems. However, data on the Setiu Wetlands are insufficient to construct a formal deterministic model of the impacts of fish cage culture activities on the ecosystems. Therefore, a less formal and less deterministic modelling approaches are required.

This research constructs a model using BBN approach for Setiu Wetlands in an attempt to explore the likely consequences of different policies for the management of the area. There are four management options: leaving things as they are (status quo), a more intensive aquaculture production, conservation and ecotourism. These options can be represented by different levels and kinds of aquaculture activity. A BBN approach was taken because of the lack of empirical data and of formal (mathematical) relationships between the various relationships between aquaculture, environmental effects and livelihoods.

BBNs are being used increasingly in ecological studies and have been recognized as an appropriate modelling framework for representing complexity and handling uncertainty and variability within ecosystems. BBNs have recently been proposed for modelling uncertain and complex fields of study such as ecosystems and environmental management (Uusitalo, 2007). For example, BBNs have been applied to studies of ecological interactions within the water column and in sediments and benthic environments. Reckhow (1999) used the graphical probability network model in BBNs for predicting and modelling water quality and eutrophication of the Neuse River estuary in North Carolina. Meanwhile, Borsuk *et al.* (2004) tried to understand the causal relationships associated with eutrophication processes of the Neuse River estuary in North Carolina. Giles (2008) studied the ecological effects of aquaculture activities on the benthic environment by utilizing a BBN approach.

This research aims to examine the impact of caged fish aquaculture activity on the Setiu Wetlands ecosystem in a manner that can help to inform policy makers to promote sustainable management. A probabilistic BBN-based model of aquaculture impacts on the Setiu Wetlands ecosystem can contribute to this objective by quantifying how the wetland ecosystem is likely to respond to potential future management scenarios and by providing probabilistic predictions of ecosystem service delivery under those potential management scenarios.

A Framework of Aquaculture Impact Model for the Setiu Wetlands

At the initial stage of this study, a Driver-Pressure-State-Impact-Response (DPSIR) framework was used to investigate the impact of fish cage culture in Setiu Wetlands by exploring the interactions and relationships that occur between natural and human elements within the Setiu Wetlands ecosystem. This framework provides a conceptual starting point for the implementation of a BBN-based model of the Setiu Wetlands aquaculture system. A total of 14 important variables were identified in this ecological impact model through literature review, expert opinion and consultation with stakeholders. Figure 1 illustrates a DPSIR framework and the variables for aquaculture impact in Setiu Wetlands. A BBN-based model of the impacts of aquaculture on the Setiu Wetland ecosystem must embody the cause-effect relationships in the DPSIR diagram of Figure 1. The elements of this framework were then represented as the boxes within the BBN and the links between them were added (see Figure 2).

In converting the DPSIR diagram into a BBN model, DPSIR drivers (rectangular boxes) correspond to BBN decision variables (called ‘decision nodes’ in BBN terminology), whereas DPSIR pressures and states (oval boxes) both correspond to BBN ‘nature nodes’ comprising both ‘parent nodes’ and child nodes’. DPSIR impacts (square boxes) correspond to BBN ‘utility nodes’ or ‘outcome nodes’ whose state is determined by the relevant ‘nature nodes’.

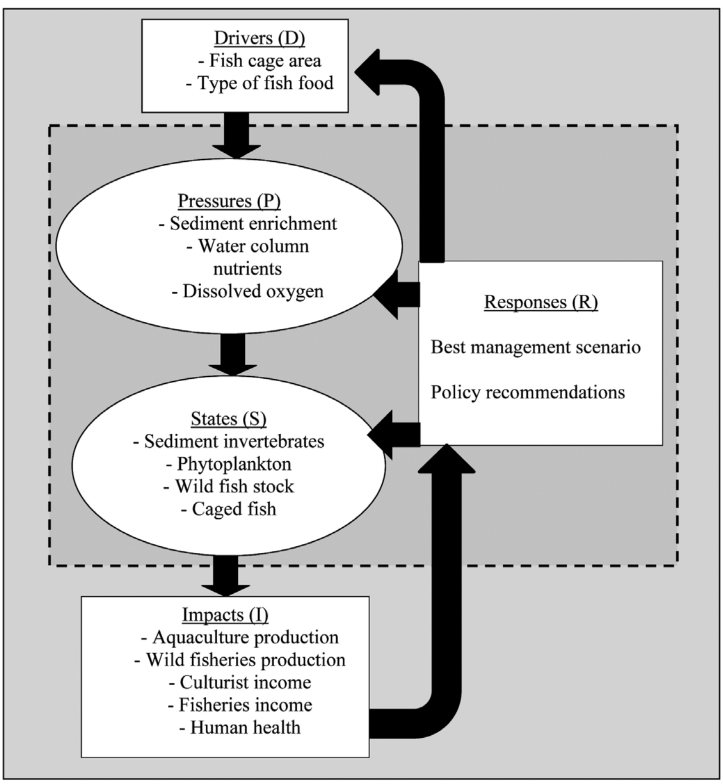


Figure 1: DPSIR and BBN framework for exploring the impact of aquaculture activity in Setiu Wetland

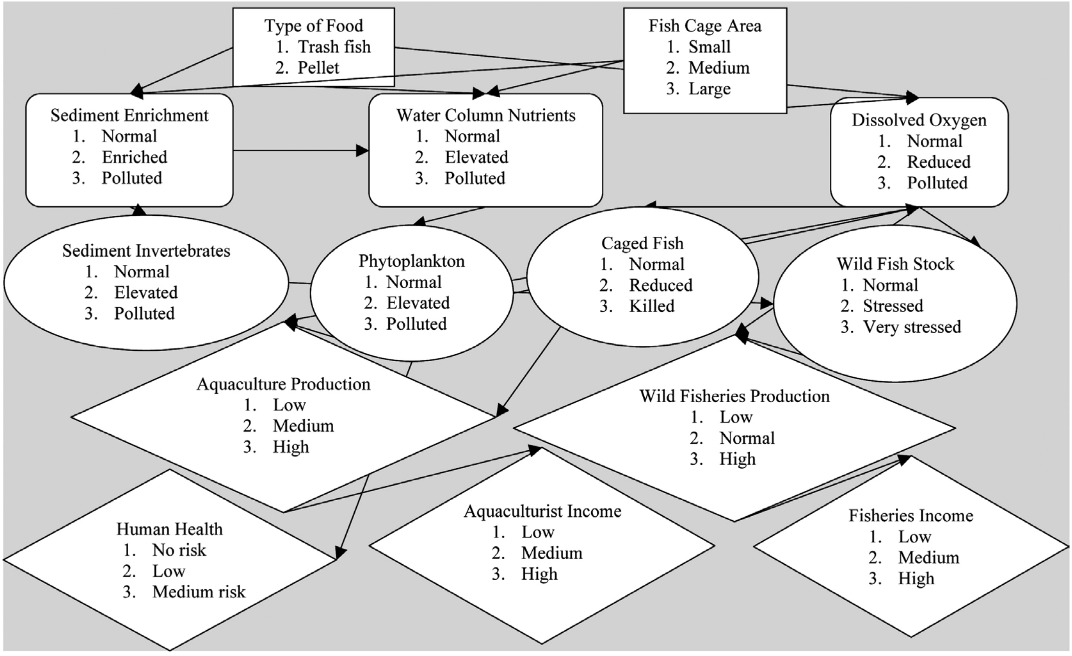


Figure 2: BBN cause-effect model for cage culture activity in the Setiu Wetlands

The Implementation of BBN-Based Aquaculture Impact Model

The implementation of BBN cause-effect model of aquaculture on the Setiu Wetland system proceeded via the following step by step process starting with: 1) define objectives and required outputs, 2) determine the structure of the model, 3) identify key variables and the states of those variables, 4) estimate conditional probabilities and finally 5) implement the network (see for example studies by Reckhow 1999; Marcot *et al.,* 2001; Cain 2001; Borsuk *et al.,* 2004; Marcot *et al.,* 2006). The initial step in BBN model development is to construct a structure of the cause-effect network using a graphical diagram (see Figure 2). This influence diagram network portrays 14 key ecological variables as boxes (nodes) which are linked by arrows (linkages). The structure uses two input nodes (variables) to represent the causal variables (impacts) derived from fish cage culture activity in the Setiu lagoons.

Having defined the structure of the network and its states, the next step is the estimation of the probabilities of particular outcomes given the states of the parent variables. The conditional probability tables (CPTs) which provide these probability 'look up' tables take different forms depending on the type of node to which they refer. Parentless nodes have unconditional probability tables (for example the decision nodes) while child nodes have CPTs which report that node's state occurrence probabilities for all possible combinations of all states of its parent nodes.

The estimation of conditional probabilities is based on the availability of data and expert scientific judgement supported by other sources such as stakeholder interviews and consultations. The estimated conditional probabilities for the impact of fish cage culture activity in Setiu Lagoon are summarized in Figure 3, in the form of conditional probability tables.

Once its CPTs have been fully specified, the final step in BBN model development is to compile the network using Netica Software. At this stage, the behaviour of the CPTs were tested by introducing different combinations of input values and observing the resulting probabilities in each intermediate node or the final output node(s). The final compiled BBN is shown in Figure 3. Using the model, four policy scenarios were explored for Setiu Wetlands: the status quo, intensive aquaculture, conservation and ecotourism. These scenarios are driven by changes in the states of two parent nodes representing the kind of food supplied to caged fish (trash fish or pellets) and the area under cages (small scale, medium scale and large scale) (Table 1). Each of these scenarios will be explored in turn.

Results and Discussion

The following results were obtained by changing the states of the decision node variables fish cage area and type of food which are the main causal variables (drivers) in the model. Table 2 shows the probabilities for all states of each node (variable) under each of the four management scenarios (see Table 1). These probability are summarized quantitatively using a "traffic light" scheme in Table 3. Each node is coloured to indicate the most likely outcome for that node under the specified management scenario: red denotes that the "worst" outcome, green denotes that the "best" outcome and amber denotes that the 'middle' outcome.

The Conservation scenario is the only scenario in which all the nodes are coloured solely green, indicating that biodiversity-related outcomes, human health considerations and stakeholder incomes are most likely to be maximized simultaneously under this scenario. In other words, fish cage culture activity potentially generates the highest impact on nutrient cycling, waste treatment and food production through absorbing and filtering dissolved nutrients in water and soil (sediments) and producing wild and cultured fish. High impacts are also generate on provisioning of food (wild and cultured fish) and nutrition (animal protein from fish) to human, supplying fresh and clean water to living organisms (including humans), maintaining human health (reduced the risk of food poisoning and eutrophication) and indirectly increases human well-being (via high income).

The Status quo and Ecotourism scenarios produce similar outcomes. These two management scenarios are also most likely to deliver biodiversity-related benefits, health benefits and high aquaculture incomes. The Status quo and Ecotourism scenarios are more likely to produce higher nutrient enrichment in sediments (enriched sediments) with a potential for elevated sediment invertebrates compared to the Conservation scenario.

This scenario will influence the capacity of the lagoon ecosystem to generate nutrient cycling and waste treatment in terms of absorbing and filtering dissolved nutrients in the water and sediments. As a result, the ecosystem service delivery for supplying fresh and clean water to living organisms and reducing the risk of food poisoning and eutrophication will also be affected.

Table 1: List of scenarios for cage culture cause-effect model

No.	Area	Food Type	Scenario
1	Large	Trash fish	Intensive aquaculture
2	Large	Pellet	-
3	Medium	Trash fish	-
4	Medium	Trash fish (50 %) Pellet (50 %)	Status quo
5	Medium	Pellet	Ecotourism
6	Small	Trash fish	-
7	Small	Pellet	Conservation

Area	
Small	0
Medium	100
Large	0

Food	
Trash fish	50
Pellet	50

Water Column Nutrients (WCN)					
Food	Area	SE	Normal	Elevated	Polluted
Trash fish	Small	Normal	30	70	0
Trash fish	Small	Enriched	25	55	20
Trash fish	Small	Polluted	20	40	40
Trash fish	Medium	Normal	25	45	30
Trash fish	Medium	Enriched	20	40	40
Trash fish	Medium	Polluted	15	35	50
Trash fish	Large	Normal	10	30	60
Trash fish	Large	Enriched	5	25	70
Trash fish	Large	Polluted	0	20	80
Pellet	Small	Normal	80	20	0
Pellet	Small	Enriched	50	25	25
Pellet	Small	Polluted	20	30	50
Pellet	Medium	Normal	45	35	20
Pellet	Medium	Enriched	30	30	40
Pellet	Medium	Polluted	15	25	60
Pellet	Large	Normal	30	30	40
Pellet	Large	Enriched	20	25	55
Pellet	Large	Polluted	10	20	70

Dissolved Oxygen (DO)					
Food	Area	Phytoplankton	Normal	Reduced	Low
Trash fish	Small	Normal	70	30	0
Trash fish	Small	Elevated	50	45	5
Trash fish	Small	Bloom	20	70	10
Trash fish	Medium	Normal	60	40	0
Trash fish	Medium	Elevated	40	55	5
Trash fish	Medium	Bloom	10	75	15
Trash fish	Large	Normal	50	30	20
Trash fish	Large	Elevated	30	30	40
Trash fish	Large	Bloom	10	20	70
Pellet	Small	Normal	80	20	0
Pellet	Small	Elevated	60	40	0
Pellet	Small	Bloom	30	70	0
Pellet	Medium	Normal	70	25	5
Pellet	Medium	Elevated	50	40	10
Pellet	Medium	Bloom	40	45	15
Pellet	Large	Normal	60	30	10
Pellet	Large	Elevated	40	40	20
Pellet	Large	Bloom	20	40	40

Sediment Enrichment (SE)				
Food	Area	Normal	Enriched	Polluted
Trash fish	Small	60	40	0
Trash fish	Medium	30	50	20
Trash fish	Large	10	50	40
Pellet	Small	70	30	0
Pellet	Medium	40	40	20
Pellet	Large	20	50	30

Phytoplankton			
WCN	Normal	Elevated	Bloom
Normal	85	10	5
Elevated	50	30	20
Polluted	10	50	40

Cage Fish			
DO	Normal	Reduced	Killed
Normal	100	0	0
Reduced	30	60	10
Low	10	30	60

Wild Fish Stock (WFS)				
DO	SI	Normal	Stressed	Very Stressed
Normal	Normal	70	30	0
Normal	Elevated	80	20	0
Normal	Reduced	60	30	10
Reduced	Normal	40	50	10
Reduced	Elevated	50	40	10
Reduced	Reduced	40	30	30
Low	Normal	20	60	20
Low	Elevated	0	60	40
Low	Reduced	0	40	60

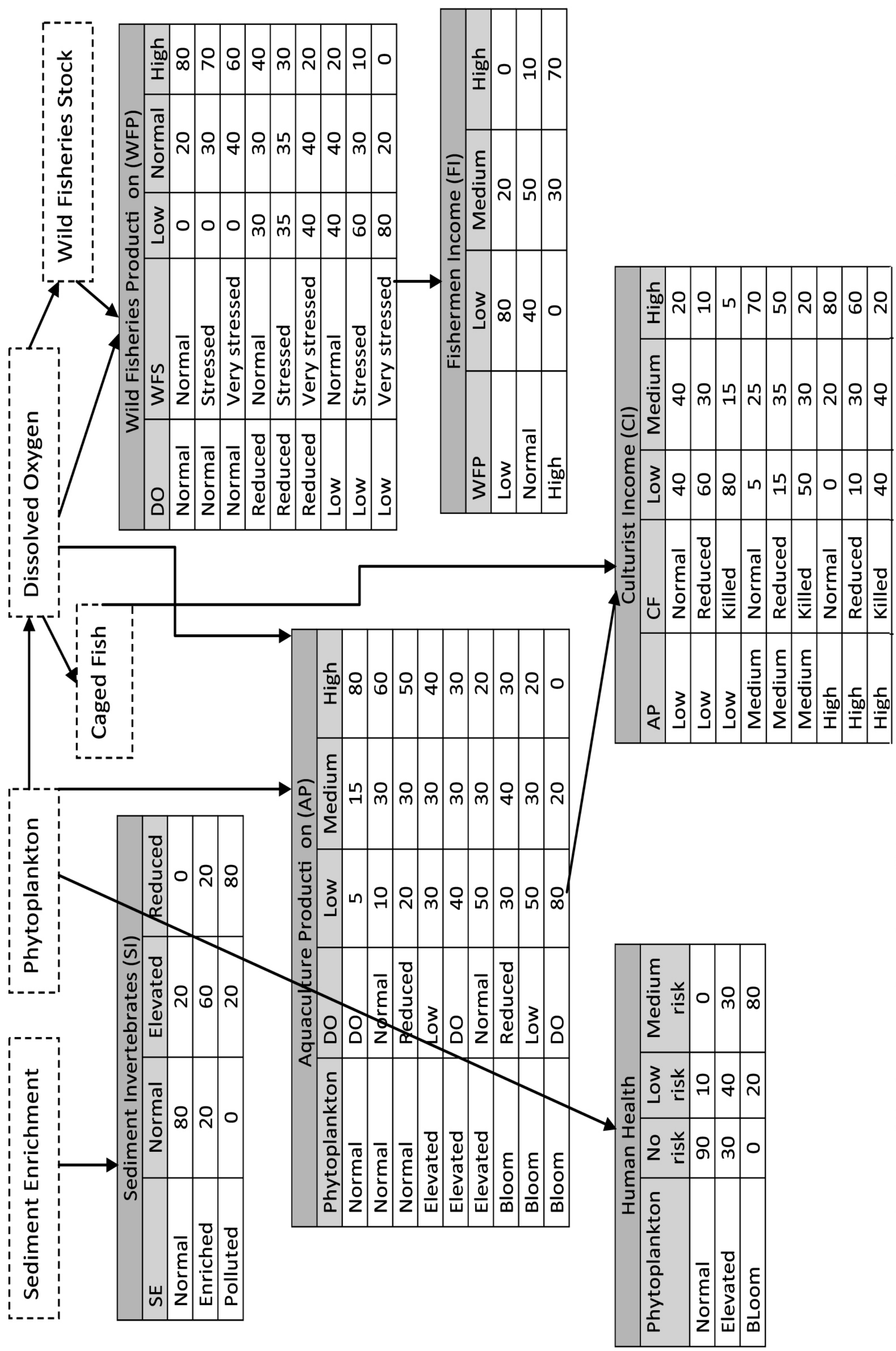
Sediment Invertebrates

Human Health

Aquaculture Production

Culturist Income

Wild Fisheries Production



Sediment Invertebrates (SI)

SE	Normal	Elevated	Reduced
Normal	80	20	0
Enriched	20	60	20
Polluted	0	20	80

Aquaculture Producti on (AP)

Phytoplankton	DO	Low	Medium	High
Normal	DO	5	15	80
Normal	Normal	10	30	60
Normal	Reduced	20	30	50
Elevated	Low	30	30	40
Elevated	DO	40	30	30
Elevated	Normal	50	30	20
Bloom	Reduced	30	40	30
Bloom	Low	50	30	20
Bloom	DO	80	20	0

Human Health

Phytoplankton	No risk	Low risk	Medium risk
Normal	90	10	0
Elevated	30	40	30
BLoom	0	20	80

Wild Fisheries Producti on (WFP)

DO	WFS	Low	Normal	High
Normal	Normal	0	20	80
Normal	Stressed	0	30	70
Normal	Very stressed	0	40	60
Reduced	Normal	30	30	40
Reduced	Stressed	35	35	30
Reduced	Very stressed	40	40	20
Low	Normal	40	40	20
Low	Stressed	60	30	10
Low	Very stressed	80	20	0

Fishermen Income (FI)

WFP	Low	Medium	High
Low	80	20	0
Normal	40	50	10
High	0	30	70

Culturist Income (CI)

AP	CF	Low	Medium	High
Low	Normal	40	40	20
Low	Reduced	60	30	10
Low	Killed	80	15	5
Medium	Normal	5	25	70
Medium	Reduced	15	35	50
Medium	Killed	50	30	20
High	Normal	0	20	80
High	Reduced	10	30	60
High	Killed	40	40	20

Figure 3: The graphical network and conditional probability tables (CPTs) of BBN cause-effect model for Setiu Wetlands

Table 2: Summary of probabilities for the impact of fish cage culture activity on Setiu lagoon ecosystem services under four different scenarios

No.	Nodes	States of Nodes	Intensive Aquaculture	Conservation	Ecotourism	Status Quo
			Probability	**Probability**	**Probability**	**Probability**
1	Sediment enrichment	Normal	10.0	70.0	40.0	38.3
		Enriched	50.0	30.0	40.0	43.3
		Polluted	40.0	0.00	20.0	18.3
2	Water column nutrients	Normal	3.50	71.0	33.0	29.2
		Elevated	23.5	21.5	31.0	34.2
		Polluted	73.0	7.50	36.0	36.7
3	Dissolved oxygen	Normal	27.6	71.1	57.2	49.0
		Reduced	26.6	28.9	34.0	36.8
		Polluted	45.8	0.00	8.75	14.2
4	Sediment invertebrates	Normal	18.0	62.0	40.0	39.3
		Elevated	40.0	32.0	36.0	37.3
		Reduced	42.0	6.00	24.0	23.3
5	Phytoplankton	Normal	22.0	71.9	47.1	45.5
		Elevated	43.9	17.3	30.6	31.5
		Bloom	34.1	10.8	22.3	23.0
6	Cage fish	Normal	40.1	79.8	68.3	61.5
		Reduced	29.7	17.3	23.1	26.3
		Killed	30.1	2.89	8.66	12.2
7	Wild fish stock	Normal	32.6	64.1	56.3	51.9
		Stressed	40.7	32.2	34.0	35.7
		Very stressed	26.7	3.69	9.75	12.4
8	Aquaculture production	Low	43.6	15.0	24.7	27.7
		Medium	26.3	21.7	25.6	25.1
		High	30.1	63.3	49.7	47.2
9	Wild fisheries production	Low	40.3	9.65	17.2	21.9
		Normal	27.3	25.9	27.0	27.3
		High	32.5	64.5	55.8	50.7
10	Culturist income	Low	35.6	10.5	17.8	21.0
		Medium	26.9	24.9	26.5	26.5
		High	37.5	64.6	55.6	52.5
11	Fisheries income	Low	43.1	18.1	24.6	28.5
		Medium	31.4	34.2	33.7	33.3
		High	25.5	47.7	41.7	38.2
12	Human health	No risk	33.0	69.9	51.6	50.4
		Low risk	26.6	16.3	21.4	21.7
		Medium risk	40.6	13.9	27.0	27.8

Table 3: Summary of probabilities for the impact of fish cage culture activity on Setiu lagoon ecosystem services under four different scenarios

Nodes	States of Nodes	Status Quo	Intensive Aquaculture	Conservation	Ecotourism
Sediment enrichment	Normal				
	Enriched				
	Polluted				
Water column nutrients	Normal				
	Elevated				
	Polluted				
Dissolved oxygen	Normal				
	Reduced				
	Polluted				
Sediment invertebrates	Normal				
	Elevated				
	Reduced				
Phytoplankton	Normal				
	Elevated				
	Bloom				
Cage fish	Normal				
	Reduced				
	Killed				
Wild fish stock	Normal				
	Stressed				
	Very stressed				
Aquaculture production	Low				
	Medium				
	High				
Wild fisheries production	Low				
	Normal				
	High				
Culturist income	Low				
	Medium				
	High				
Fisheries income	Low				
	Medium				
	High				
Human health	No risk				
	Low risk				
	Medium risk				

Under the Intensive Aquaculture scenario, a number of nodes are coloured either amber (sediment enrichment) or red (water column nutrients, dissolved oxygen, aquaculture production and fisheries income) indicating that undesired outcomes are most likely to occur (Table 3). The results for these nodes demonstrate potential significant impact derived by intensive cage culture activities in this area. These results are as expected as discussed in a number of studies regarding the impact of aquaculture on the aquatic ecosystems (see for example Dahlbäck and Gunnarsson 1981; Brown *et al.,* 1987; Tsutsumi *et al.,* 1991; Rosenthal, 1988, Holmer *et al.,* 2005; Hargrave, 2010).

In Malaysia, fish cages are usually located in protected and shallow areas with low water circulation and a longer flushing time, which makes them vulnerable to sediment enrichment and eutrophication due to nutrient enrichment from the enriched bottom sediment (Yusoff & Shar 1987; Yusoff & Patimah 1994; Yusoff *et al.,* 1997; Yusoff 2003, Noor Azhar Mohd Shazili & Sulong Ibrahim in Nakisah & Fauziah 2003, Nakisah *et al.,* 2008; Norhayati *et al.,* 2010). In Malaysia, degradation of water quality occurs as a consequence of increasing the number of cages in narrow and sheltered areas (Arulampalam *et al.,* 1998) resulting in annual mass mortality of fish. In Saguling hydoelectric resevior, Indonesia, a rapid expansion of cage culture (from 756 in 1988 to 4425 in 1995) resulted a high mortality of fish due to low oxygen levels and deterioration of water quality (Djuagsih *et al.,* 1999).

Intensive aquaculture will also affect the local fisheries activity with high probability of low fisheries production (40.3%) and low fisheries income (43.1%). For this scenario, the outcome is sensible based on the current condition of the physical, biological and chemical characteristics of the Setiu lagoon. Increasing the number of fish cages in the lagoon ecosystem have the potential to affect the lagoon as a habitat and for breeding and nursery grounds for some wild species and wild fishery stocks in the lagoon. The intensity of this activity has significantly decreased the supply of natural fish seed/fry and wild fish production from this area (Fisheries officer, personal communication, April 2008; local fishermen, personal communication, April 2008). For that reason there is a high probability of low fisheries income.

Conclusion

In summary, the BBN approach revealed that, for the model as parameterised, the impacts of fish cage culture are likely to be quite different under the different management scenarios. The Conservation scenario was identified as the most attractive, followed by Ecotourism and the Status quo whereas Intensive Aquaculture was seen as undesirable with water column enrichment identified as the variable which is most vulnerable to the different aquaculture conditions. As such, the BBN has indicated that in making future recommendations for particular policies or management scenarios for wetlands, it would be sensible to research further the key processes surrounding water column enrichment, since these processes have the greatest effect on the model.

This research generated new insights into the management of natural ecosystems, specifically wetlands. The aim is to promote sustainable management of natural resources by integrating knowledge from the natural and social sciences. The findings from this research can be used by the policy makers to determine the most efficient, sustainable and equitable way in managing wetland ecosystem and other the natural resources in Malaysia. This approach could be potentially applied to envisage the impact of aquaculture activity in other wetlands throughout Malaysia or in other countries and also in other ecosystems such as coral reefs, islands, lakes and forests.

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