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Effect of social and economic drivers on choosing aquaculture as a coastal livelihood

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ABSTRACT

Aquaculture is proposed as a means to income generation and food security in developing nations. Understanding drivers of attitudes and perceptions towards choosing aquaculture as a livelihood is essential to aid policy makers in promoting its development. This paper takes a new approach to establishing a baseline of these social and economic drivers. We used simple metrics familiar to policy makers collected in face-to-face semi-structured interviews – e.g. education level, time availability to work and income level – to predict willingness of individuals to adopt aquaculture as a livelihood. We compared modelling approaches ability to provide insights into effects of social and economic factors on willingness of 422 household decision-makers in coastal villages in Tanzania to participate in sea cucumber aquaculture as an alternative livelihood. Linear regression identified the factors; time available for a supplementary livelihood, gender, social network strength and material style of life as significantly predicting individuals' willingness to adopt aquaculture. A Bayesian Belief Network (BBN) model of community data created using logistic regression results, open response analysis and critical literature appraisal allowed intuitive manipulation of factors to predict the influence of aquaculture uptake drivers and constraints. The BBN model provided quantified predictions of the effect of specific policy interventions to promote aquaculture uptake within the modelled community. The analysis from the BBN model supports its broader use as an assessment tool for informing policy formulation by highlighting key areas of intervention to increase willingness to uptake aquaculture among target groups, such as low income households and women. BBNs provide a modelling approach that allows policy makers to visualise the influence of socio-economic factors on the success of introducing aquaculture in different local contexts.

1. Introduction

Aquaculture is rising up political agendas as a means to providing food security and income generation and considered by many governments as a means to alleviate poverty in developing nations (Holdren, 2011; Smith et al., 2010; Ahmed and Lorica, 2002). Despite this and a long history of attempts to establish various forms of aquaculture, there remains scant evidence that development of aquaculture eradicates poverty in the developing world, particularly amongst lowest income community members (Irz et al., 2007; Stevenson and Irz, 2009; Bergquist, 2007; Lewis, 1997; Bailey, 1988; Hobbs, 2000). While a number of underlying reasons have been identified, we argue that this failing results primarily from weak governance due partly to a lack of appropriately informed policy (Lewis, 1997; Brummett and Williams, 2000; Black, 2001; Primavera, 1997; Rivera-Ferre, 2009; Stonich et al., 1997; Harrison, 2005; Torell et al., 2010; Bush et al., 2009; Kaiser and Stead, 2002).

To-date there are few evidence-based case studies to advise decision-makers and policy formulators on how best to introduce aquaculture and ensure its success as a sustainable livelihood option (Burbridge et al., 2001). This is a global issue. Failure has resulted in the past because many aquaculture livelihood development projects have introduced culture systems without an understanding of or regard for the local socio-economic context (Stonich et al., 1997; Harrison, 1996; Philcox et al., 2010). In particular, initiatives have largely focussed on economic and environmental standards and not identified social and economic drivers

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which underpin individuals' attitudes, perceptions and willingness to embrace an unfamiliar activity like aquaculture (Bush et al., 2009; Kaiser and Stead, 2002).

Policies related to management and development of the aquaculture sector rarely exist, as aquaculture is often poorly defined in formal governance systems. This is compounded by aquaculture being commonly 'managed' under agriculture, environment or fishing departments with equal policy limitations (Urquhart et al., 2010). Furthermore, policies with relevance to aquaculture development are based on natural science data such as recommendations on growing a particular species in certain locations (frequently isolated, rural and with poor infrastructure) under prescribed conditions (Stonich et al., 1997; Espaldon, 2009; Barrett et al., 2001). We argue that the greatest constraints to enabling aquaculture to fulfil its potential in securing food and/or income in many countries include lack of understanding by policy makers of human drivers and associated resources affecting willingness to adopt aquaculture as a livelihood in different local contexts.

We argue that to successfully develop in any country, aquaculture must be policy-led. This policy must be built on an understanding of the socio-economic drivers, resources (human and natural), and constraints of community members intended to be involved. Willingness to participate in aquaculture or any alternative livelihood is an individual's choice and the factors which underpin the decision-making remain poorly understood in most marine policies despite research outputs showing a need to understand the interplay between poverty and livelihoods in coastal villages in developing countries (Davis and Bezemer, 2003). Coastal community households develop distinct and diverse livelihood strategies in reaction to policy-induced constraints and socio-economic realities (Cinner et al., 2010; Tobey and Torell, 2006). Reduced income variability and effective risk aversion are achieved by individuals' involvement in a range of economic activities with unrelated incomes (Davis and Bezemer, 2003). Livelihood diversification and its root causes underpinning an individual's choice can affect willingness to adopt alternative livelihoods such as aquaculture (Barrett et al., 2001). Livelihood choices and constraints are also linked to asset endowment (e.g. house, land ownership and access) and/or the presence or absence of key material wealth indicators (e.g. high quality housing materials) (Lewis, 1997; Cinner et al., 2010). Furthermore, an individual's or community's asset strength and social welfare is not defined by physical or liquid assets alone but also social capital, i.e. social networks and groups (Scoones, 1998). Village social organisation and group structures have been shown to positively influence the uptake of agriculture, fishing and aquaculture livelihoods (Sesabo and Tol, 2005). Members of social groups are less vulnerable, less risk averse and able to become involved in unknown or novel income generating activities (Cinner and Pollnac, 2004).

A major gap in current marine policy science is knowledge of how to analyse and utilise socio-economic variables to provide a mechanism for policy-makers to easily assess the positive impact of introducing a particular sector like aquaculture in reducing poverty in vulnerable communities. Sustainable aquaculture development supported through science-informed policy will have a greater likelihood of gaining wider community acceptance. To-date, most marine policies rely on biological and/or ecological scientific evidence and rarely include social science metrics like human dependence on declining marine resources and willingness to consider alternative livelihoods (Bostock, 2011; Carneiro, 2011). The analysis of social and economic empirical data that captures many of the unique characteristics of coastal communities – made more difficult to study by complex interactions known to exist in fishery dependent communities – combined with knowledge about locals' attitudes and perceptions towards aquaculture as a livelihood is a prerequisite for effective implementation of aquaculture as a viable livelihood option (Béné et al., 2011).

Marine policy targeting poverty alleviation measures requires an understanding of local contexts and the socio-economic factors which influence ability (e.g. skills match) and willingness of individuals to consider aquaculture as a livelihood. Identifying constraints to aquaculture development, including policy trade-offs and barriers to adoption of aquaculture can further improve uptake, distribute associated benefits more widely within communities and support development of aquaculture in fulfilling its full potential in addressing major policy drivers like food security and income generation.

It is highly probable that the willingness of individuals to engage in aquaculture or other alternative livelihoods is influenced directly and indirectly by a number of personal, social and economic factors. BBN probabilistic modelling is used to aid decision-making in natural systems managements and is being increasingly applied to integrated studies combining sociological data from local experts and natural science data for formulating more targeted management measures that consider local context (Haapasaari and Karjalainen, 2010; Levontin et al., 2011; Nyberg et al., 2006). The BBN approach provides a potentially useful tool in analysing complex community-sourced "scenario" data which is not normal and often confounded, with direct and indirect effects arising from interactions. The ability of BBN to account for such complex interactions means that it is able to reveal relative impacts of various social and personal factors on decisions or responses in a way that linear regression modelling or other parametric methods are incapable of.

We select sea cucumber aquaculture as a model sustainable aquaculture system under considerable development in the Western Indian Ocean (Eriksson et al., 2012a). Exploited sea cucumber populations have proven susceptible to overfishing at both local and regional scales (Dalzell et al., 1996; Toral-Granda and Martínez, 2000; Mgaya et al., 2007). Extremely high consumer demand and good economic returns for fishers, combined with low capital input requirements for harvesting, mean that local populations of sea cucumbers can become rapidly depleted (Mgaya et al., 2007; Uthicke and Conand, 2005). Increasing consumer demand and decreasing wild supply has driven global pricing rapidly upwards and provided strong economic stimulus for the development of sea cucumber aquaculture. In the Tanzanian context of the current study sea cucumber aquaculture is considered highly viable as a model system as it produces a product with recognised high value, it can be conducted in shallow lagoon systems, is non-fed avoiding the need for diet expenditure, and can be conducted with low capital input and simple husbandry methods (Eriksson and et al., 2012a; Robinson and Pascal, 2009).

In this study we quantify human drivers influencing likelihood of uptake of sea cucumber aquaculture as an alternative or supplementary livelihood in vulnerable coastal communities using a BBN model. This empirically based approach provides evidence on how human factors can underpin an individual's choice whether or not to take up aquaculture. We show how BBNs offer a broadly applicable method for providing policy makers with clear information on the types of data they need to consider and integrate in developing marine policies aimed at improving food security and income generation via aquaculture adoption.

2. Materials and methods

2.1. Survey design

Willingness of fishers to consider sea cucumber aquaculture as an alternative livelihood was determined in face-to-face interviews with 422 coastal village heads of households in four coastal villages in Tanzania (Unguja Ukuu, Ununio, Kunduchi and Buyuni) between March, and December 2010 (Fig. 1). Study sites were identified based on their economic status, proximity to the coast and dependence on small-scale fisheries. To summarise:

- Unguja Ukuu on the southern coast of Zanzibar, 31.6 km from its capital Stone Town (est. popn. 800, 132 households).
- Ununio approximately 20 km north of Dar-es-Salaam (est. popn. 1050, 168 households).
- Kunduchi 15 km north of Dar-es-Salaam (est. popn. 1370, 212 households).
- Buyuni 50 km south of Dar-es-Salaam, (est. popn. 1100, 204 households).

Kunduchi and Ununio are ('diffuse') peri-urban fishing villages fringing Dar es Salaam, with encroachment of urban expansion on land area for agriculture and construction (Iaquinta and Drescher, 2000). Buyuni is rural, and requires 3–4 h travel to reach Dar es Salaam. Unguja Ukuu is rural and the only village included in the study with active (seaweed) aquaculture. Ununio and Buyuni experienced failed seaweed aquaculture projects in 2004–5.

Villages were mapped using available satellite images as a reference and ground-proofing to create a full hand-drawn map of all roads and pathways and dwellings. The map was used to systematically sample (numbered) households within each community. The head of household in every third house (by numerical code) was interviewed in Unguja Ukuu. In Ununio, Kunduchi and Buyuni were mapped as above and the head of household of every second house was interviewed. Interviews were carried out at fish landing sites in Buyuni and Kunduchi with approximately 40 fishers and fishmongers in each village. Fishers' houses which had participated in interviews conducted at landing sites were excluded from household interviewing.

'Household' was defined as a unit of people that share a house (Sesabo and Tol, 2005). Heads of households were interviewed where possible as decision-makers were considered to hold more detailed information about current livelihoods and associated costs

Fig. 1. Map of central coast of Tanzania indicating position of coastal villages from North to South: A. Unguja Ukuu, B. Ununio, C. Kunduchi, and D. Buyuni.

of living. If the head of household was not available at the second visit, interviewers requested to interview an adult from the household fully informed about the household's full range of income-related activities and livelihoods.

Data collected from the interviews described respondents' marine resource dependence, perceptions of marine health and governing instruments, current economic status and employment along with willingness to include sea cucumber aquaculture in livelihood activities. Household income and household possessions and utilities, such as electricity, mobile phone and other physical assets such as house construction types (e.g. cement) and land and house ownership were recorded.

Differences between villages were ascertained by proportional distribution of categorised response (willing to become involved in sea cucumber aquaculture? "yes" or "no") using a 2-sided z-test comparing column proportions (alpha $= 0.05$) with Bonferroni adjusted p-values for multiple comparisons.

2.2. Material style of life

A single material style of life (MSL) measure was calculated on the basis of rotated component (asset presence or absence) weightings obtained using a factor analysis with Varimax rotation applied to all data values for presence or absence of key assets (Cinner et al., 2009). The key assets examined were all data those available from interviews regarding household possessions and utilities. These were equivalent to the selection in previous analysis of fisher village survey data as detailed by Cinner et al (2009) with the addition of land ownership, ownership of mobile phones, availability of water services and availability of electricity. Key assets with weightings between 0.3 or -0.3 in both first and second components after Varimax rotation were excluded from summation to calculate a compact MSL score. Factor weightings for all individuals were summed to create a compact MSL score for each respondent household.

2.3. Binary logistic regression

Estimated MSL and nine further predicted explanatory variables were selected from the data and tested for significant explanatory strength by fitting a binary logistic regression model (backward stepwise logistic regression) to the binary response variable of probability of respondents "willingness to participate in sea cucumber aquaculture". Hypothesised explanatory variables were; material style of life, weekly income per person in household, age, years of education, occupational diversity, occupational multiplicity, social network strength, gender, time availability to be involved in alternative livelihood and highest ranked household income source.

2.4. Bayesian Belief Network (BBN) models

A Bayesian Belief Network (BBN) modelling approach was applied to further analyse the available data. The BBN modelling approach exceeds the analysis undertaken in logistic regression as it takes into account interactions and indirect influences of modelled factors. BBN models can incorporate, model and combine complex, and diverse data types, e.g. quantitative data, local knowledge and outputs from other models (Goudie et al., 2011; Daniel et al., 2007). This modelling technique is thus well-suited to analysis of the diverse social, economic, opinion, livelihood and social network data available in the current study. BBN models also graphically represent a set of variables and can be manipulated in real-time to explore and display causal relationships between factors based on Bayesian principles. As graphic modelling solutions BBN models clearly display final outcomes of a system, allowing effective knowledge representation and communication of decision outcomes to target users, in the current study marine policy-makers (Kragt, 2009; Korb et al., 2011; Pollino and Henderson, 2010).

Initially a probabilistic Bayesian Belief Network (BBN) model was constructed – as an alpha, or theoretical model – based on analysis of available literature and results of the afore-mentioned binary logistic regression, combined with findings from the qualitative analysis of open response interview data. BBN probabilistic models indicate the probabilities of various predictor variables, intermediate variable (i.e. prior probabilities or input) and response variables (i.e. posterior probabilities or output) (Jensen, 2001) The BBN model consists of natural nodes (factors potentially affecting each other and – indirectly or directly – a response variable) networked to one another and to the utility node (response variable) 'willingness to participate in aquaculture' by arcs (arrows) indicating influence. Any node which has an arrow coming out of it towards any other node is a predictor variable, and any node which has no outward arrows is a response variable. The model predicts probabilities of states within all nodes (i.e. the values of all variables within the model) based on Bayesian principles.

The model was created using Netica software available from www.norsys.com. For algorithm descriptions see Spiegelhalter et al. (1993). The model was further developed by incorporating all valid cases (i.e. containing responses to all variables, $N = 360$) from the 422 interviews completed into the model. This incorporation of data characterises the Conditional Probability Tables underlying each node. The Model Explanation Strength was increased by model learning using the Explanation Maximisation (EM) learning function in Netica to allow the nodes to further learn from the data in the 422 interview cases. The network structure was then refined using sensitivity testing and elimination order testing of nodes. The network was also refined using periodic testing of the model with random subsets of case data (25% of all included cases selected randomly) this allowed verification of the predictive accuracy of the model. Nodes and arcs were removed where appropriate, and the model re-iterated and retested to create a beta model. The resulting model was once again verified for predictive accuracy using a new subset of categorised data (25% of all cases selected randomly as above).

Sensitivity analysis of the response variable "willingness to incorporate sea cucumber aquaculture into livelihoods" to all nodes within the final model was performed to reveal strength of explanatory factors within the model. Manipulation of nodes in the beta model was carried out to show changes to key socio-economic factors required to improve the predicted likelihood of aquaculture uptake particularly amongst targeted low income community members. For clarity the term 'factor' will be used throughout the remainder of this paper. The term 'factor' will also be used when discussing manipulation of 'nodes' within the model.

3. Results

3.1. Dependency on marine resources

All villages exhibited high dependence on marine and coastal resources, with between 37% (Buyuni) and 73% (Kunduchi) of households in each village ranking fishing or fish marketing as their main income source (Table 1). The peri-urban villages as defined in the methods, Kunduchi (TZS 37061 $\pm$ 4425 SE) and Ununio (TZS 23071 $\pm$ 2566 SE), had higher per capita income than the two rural villages Buyuni (TZS 21089 $\pm$ 2416) and Unguja Ukuu (TZS 17548 $\pm$ 2895). Unguja Ukuu was the only village not to exceed the national mean rural per capita income of TZS 19,787 (calculated as

Table 1
Mean values of demographic data, response variable and key socio-economic indicators by village. Superscript letters indicate significant differences in proportional distribution of responses between villages as determined by 2-sided *z*-test e.g. Buyuni, Kunduchi and Unguja Ukuu all differ significantly in response distribution from Ununio (d).

Factor/variable	Village				
	Buyuni	Kunduchi	Unguja Ukuu	Ununio	All villages
	%/Mean	%/Mean	%/Mean	%/Mean	%/Mean
Respondent – Male	51.6%	66.0%	52.5%	52.3%	56.6%
Respondent – Female	48.4%	34.0%	47.5%	47.7%	43.4%
Age	40.43	40.48	37.15	37.00	39.41
Years of education	4.76	5.28	8.82	6.07	5.59
Weekly income per person (TZS)	20189.82	37061.07	17548.93	23070.73	26096.36
Total household (HH) inhabitants	5.51	6.20	5.12	6.26	5.86
Material style of life	−0.45	2.15	1.16	1.90	1.06
Occupation diversity of HH	1.84	1.75	2.38	2.01	1.90
Occupational multiplicity of HH	2.58	2.94	2.75	3.39	2.88
Social network strength	0.95	1.14	1.78	1.10	1.12
HHs with main income via fishery	37.2%	73.6%	53.3%	46.5%	53.2%
Yes – willing aquaculture	69.1%[d]	72.3%[d]	87.5%[d]	46.0%[abc]	67.1%
No – willing aquaculture	30.9%	27.7%	12.5%	54.0%	32.9%

2000/01 National Bureau of Statistics official values adjusted for non-compounded inflation of 40% – 2001–2010) however only Kunduchi exceed the average income of mainland Tanzania TZS 25,099 (National Bureau of Statistics, 2001). Peri-urban villages also had higher available infrastructure – piped water and electricity – due to their proximity to urban infrastructure networks (Table 1). Respondents from Unguja Ukuu had the highest number of years of education (8.8 ± 0.52 SE) and social network (measured as combined score for participation in groups and involvement in decisions at group and village level) strength score (1.78 ± 0.19 SE).

Willingness to be involved in aquaculture overall was high with 67.1% of all respondents willing to be involved, but was significantly lower in Ununio compared to all other villages (2-sided *z*-test, $p < .05$ – Table 1). However, despite a general stated 'willingness to participate in aquaculture', less than 5% of respondents considered aquaculture a desirable future occupation for their children and only 18% of respondents said the same of fishing (Fig. 2).

3.2. Material style of life and binary logistic regression

Assets included in the calculation of MSL are based on those outlined by Cinner et al. (2009) and resulted in a single variable (component) explaining 50.4% of variation. Factor loadings were strongest for floor and wall materials used in dwellings (Table 2). Kunduchi village exhibited the highest mean MSL score of 2.15 (**± 0.06 SE**) while Buyuni had the lowest MSL score of −0.45 (**± 0.52 SE**).

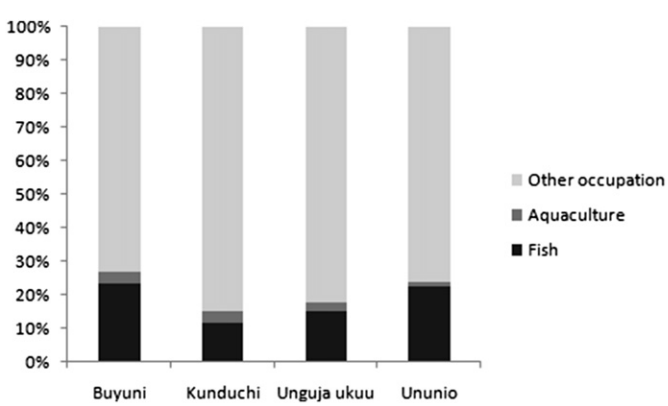

Fig. 2. Distribution of occupations respondents would encourage their children to take up in future. Responses separated by village.

Binary logistic regression analysis revealed four significant explanatory factors for the response variables for all interviews; gender ($p < .001$), MSL ($p < .05$) social network strength ($p < .001$) and time available to be involved in an alternative livelihood ($p < .001$) (Table 3). Time available to be involved in an alternative livelihood was regrouped during analysis as a binary factor with the highest value (20 + h/week) as 1 and all other values (0–20 h/week) grouped as 0.

When gender was removed as a variable and respondents separated into males and females, binary logistic regression analysis revealed that time available to be involved in an alternative livelihood as a significant explanatory variable and household income as closely but not significantly correlated amongst all males (Table 3). Social network strength, MSL and per person household income were significant factors among female respondents. Amongst the lowest income earners (the third of respondents with weekly per person incomes less than 10,000 Tanzanian shillings) years of education was the only statistically significant explanatory factor (Table 3).

3.3. Bayesian Belief Network (BBN) models

Six factors were considered to directly affect individuals' willingness to participate in sea cucumber aquaculture in the final BBN model which was developed (Fig. 3):

- MSL
- Years of education
- Income
- Gender
- Social network strength
- Time available for additional livelihood

Table 2
Factor loadings for physical assets included in calculation of Material Style of Life (MSL) estimate.

Physical asset	Component level	
	1	2
Radio/cassette	−0.059	0.739
Toilet available	0.128	0.665
Roof material metal	0.739	0.173
Roof material thatch	−0.803	−0.122
Floor material cement	0.856	0.057
Floor material dirt	−0.858	−0.096
Wall material cement	0.833	−0.076
Wall material coral mix	−0.802	0.100

Table 3
Binary logistic regression results for factors explaining 'willingness to participate in aquaculture'. All respondents, male and female.

Variables in the equation						
Respondents	Factor	Coefficient	S.E.	*z*-value	*df*	*p*-value
All respondents	Social network strength	0.362	0.116	−3.113	1	0.001
	MSL	−0.133	0.066	2.029	1	0.043
	Gender	−0.959	0.230	4.154	1	0.000
	Time available (0/1)	0.707	0.238	−2.967	1	0.003
Males	Time available	0.321	0.116	7.689	1	0.006
Females	MSL	−0.227	0.109	4.351	1	0.037
	Social network strength	0.542	0.183	8.787	1	0.003
	Weekly income PP	0.000	0.000	5.255	1	0.022
Low income households	Years of education	0.120	0.060	4.012	1	0.045

Null deviance: 483.64 on 392 degrees of freedom.
Residual deviance: 446.67 on 388 degrees of freedom.
AIC: 456.67.
2 × Log likelihood: 354.9.

When the correctness of prediction by the model was tested with a data subset (25% of the interview data randomly selected) the final model returned an overall error rate of 14.14% or 85.76% correctness of prediction of response – yes or no – to 'willingness to participate in aquaculture' within the tested data subset.

Sensitivity analysis of the final model revealed time available to be involved in an alternative livelihood, gender and years of education as the factors with strongest impact on predicted response variable 'willingness to participate in aquaculture' overall (Table 4).

When sensitivity analysis of the response variable 'willingness to participate in aquaculture' was conducted, selecting low income respondents only, the factors; years of education, time available to be involved in an alternative livelihood and MSL showed strongest impact (Table 5).

Table 4
Sensitivity of results of 'willingness to participate in aquaculture' to key factors for all respondents. Variance reduction is a measure of the effect of the factor on the overall measure of willingness.

Factor	Variance reduction	Percent	Mutual info	Percent	Variance of beliefs
Time	0.005913	2.4	0.01739	1.76	0.0059129
Gender	0.003032	1.23	0.00888	0.898	0.0030318
Years of educations	0.001924	0.781	0.00564	0.57	0.0019241
MSL	0.0008514	0.346	0.00250	0.253	0.0008515
Social	0.0003488	0.142	0.00102	0.103	0.0003488
Age	0.0003409	0.138	0.00100	0.101	0.0003409
Occup. div.	0.0002804	0.114	0.00082	0.0828	0.0002803
Occup. multi.	0.0002478	0.101	0.00072	0.0733	0.0002476
Income	0.0001642	0.0667	0.00048	0.0487	0.0001642

Manipulation of the factor 'years of education to primary level' increased predicted 'willingness to participate in aquaculture' among low income respondents from 55.1% to 63.3% (Fig. 4). Commensurately adjusting time available to more than 25 h a week increased predicted 'willingness to participate in aquaculture' from 63.3% to 77.3% (Fig. 4). MSL proved more complex in its effect on willingness, with adjustment of MSL to the highest rating (3) reducing 'willingness to participate in aquaculture' among lowest income respondents from 55.1% to 47.9%.

4. Discussion

The current research shows for the first time the applicability of BBN modelling techniques aiding policy makers in identifying and assessing drivers for aquaculture uptake among communities intended to benefit from its introduction as a livelihood choice. By combining established socio-economic research methods including questions exploring individuals' willingness to be involved in aquaculture, the research outputs support future use of BBN models in their role as policy assessment tools that consider local scale

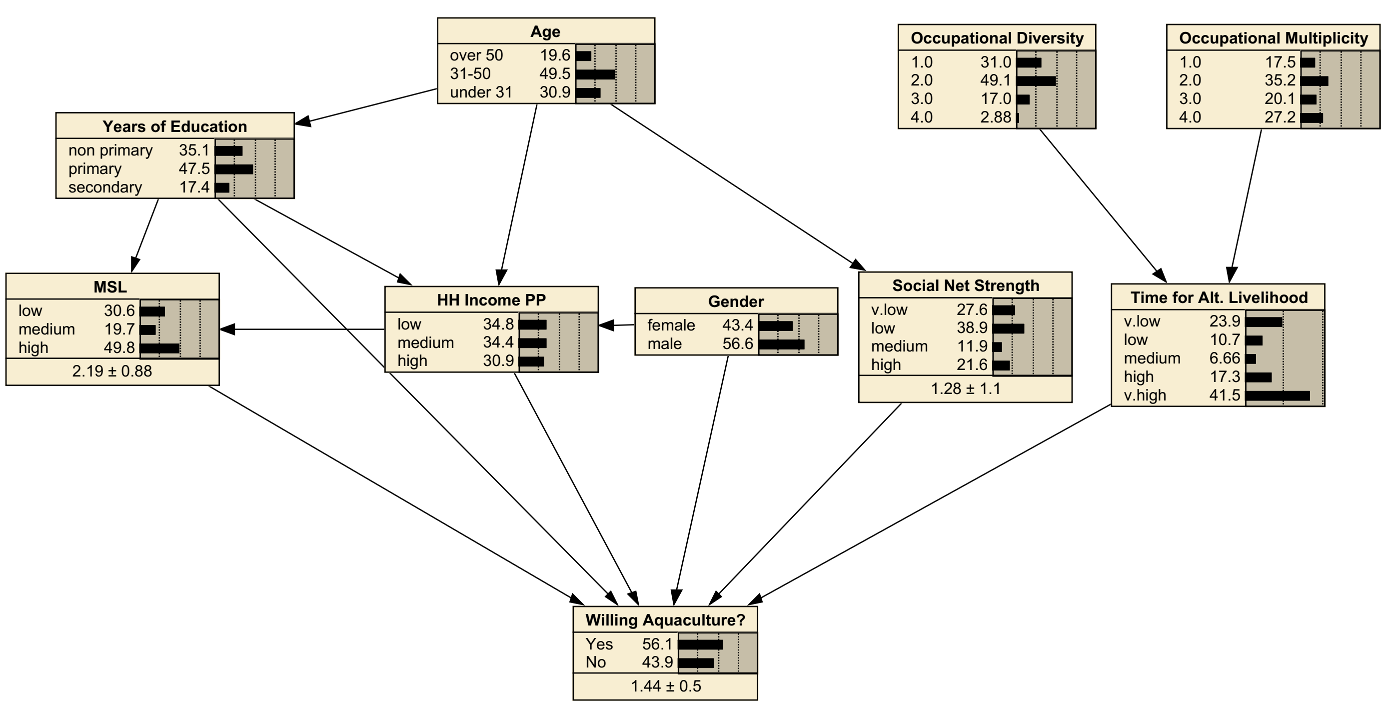

Fig. 3. Graphic representation of final (*beta*) Bayesian Belief Network model showing decision nodes and links affecting 'willingness to participate in aquaculture'.

Table 5
Sensitivity of results of 'willingness to participate in aquaculture' to key factors for all low income respondents.

Factor	Variance reduction	Percent	Mutual info	Percent	Variance of beliefs
Years of education	0.005551	2.24	0.01627	1.64	0.005551
Time	0.003519	1.42	0.01029	1.04	0.003519
MSL	0.003488	1.41	0.01016	1.02	0.003488
Age	0.001082	0.437	0.00315	0.317	0.001082
Social	0.000949	0.384	0.00277	0.279	0.000949
Gender	0.000178	0.072	0.00052	0.0523	0.000178
Occup. multi.	0.000123	0.0496	0.00036	0.036	0.000123
Occup. div.	9.86E-05	0.0399	0.00029	0.0289	9.86E-05
Income	0	0	0	0	0

effects, that is, community level, in gauging effectiveness of proposed poverty alleviation measures.

At the community level, the identification with binary logistic regression of the drivers gender, MSL and social network strength is generally in good agreement with previous studies indicating that uptake and benefit from aquaculture is strongest among wealthier and well networked men (Lewis, 1997; Harrison, 1996; Sesabo and Tol, 2005; Cinner and Pollnac, 2004). The results differ, however, from previous research indicating that livelihood flexibility is strongly affected by income and occupational multiplicity (Cinner et al., 2009). This deviation is best explained by the BBN model's identification of pragmatic factors such as simply the time respondents perceive they have available to become involved in an alternative livelihood, which exist as interim factors (or 'nodes') in our model, but are driven in the model by previously identified multiplicity and diversity of livelihoods. Such results reiterate the strength of BBN modelling over previously applied methods in its capacity to identify indirect interactions between factors and drivers.

Although the initial statistical analysis of binary logistic regression provided an insight into identifying the key factors affecting willingness to participate in aquaculture – gender, MSL, social network strength and time available for an alternative livelihood, the binary logistic regression approach lacks the capacity of the BBN model to integrate and consider qualitative information in resultant inferences. The BBN model integrated subjective or "human" information along with more quantitative data, and allowed for richer analysis of the results (Levontin et al., 2011). The resultant BBN model created added understanding of interactions between factors and drivers which established methods cannot and allowed us to address inherent uncertainties in human interactions and decisions thus providing a better context for assessing model outputs.

For aquaculture to fulfil its potential of providing food security and poverty alleviation especially in fishery dependent communities then socio-economic considerations are required to evaluate appropriateness of introducing aquaculture as a livelihood choice (Bush et al., 2009; Burbridge et al., 2001; Ha and Bush, 2010). Knowledge of drivers that can influence uptake of aquaculture, particularly among the poorest of the poor in vulnerable coastal communities, is useful for informing future policy measures needed to support sustainable aquaculture development (Bush et al., 2009). We found that the predictive decision-supporting value of the BBN modelling approach was most evident when manipulations of factors were undertaken on the final model.

The wider applicability of the BBN method of integrating social and economic factors into a decision-making tool for aquaculture uptake is evident in the availability of clearly predicted effects of social interventions at a policy level and thus has the potential for improving policy support for aquaculture development. In our model, policy-makers are able to see that any livelihood policy measure to promote aquaculture uptake would not only benefit from attempts to improve basic educational provision to primary level, but would also benefit markedly from ensuring participants felt they had the time available to carry out an alternative livelihood

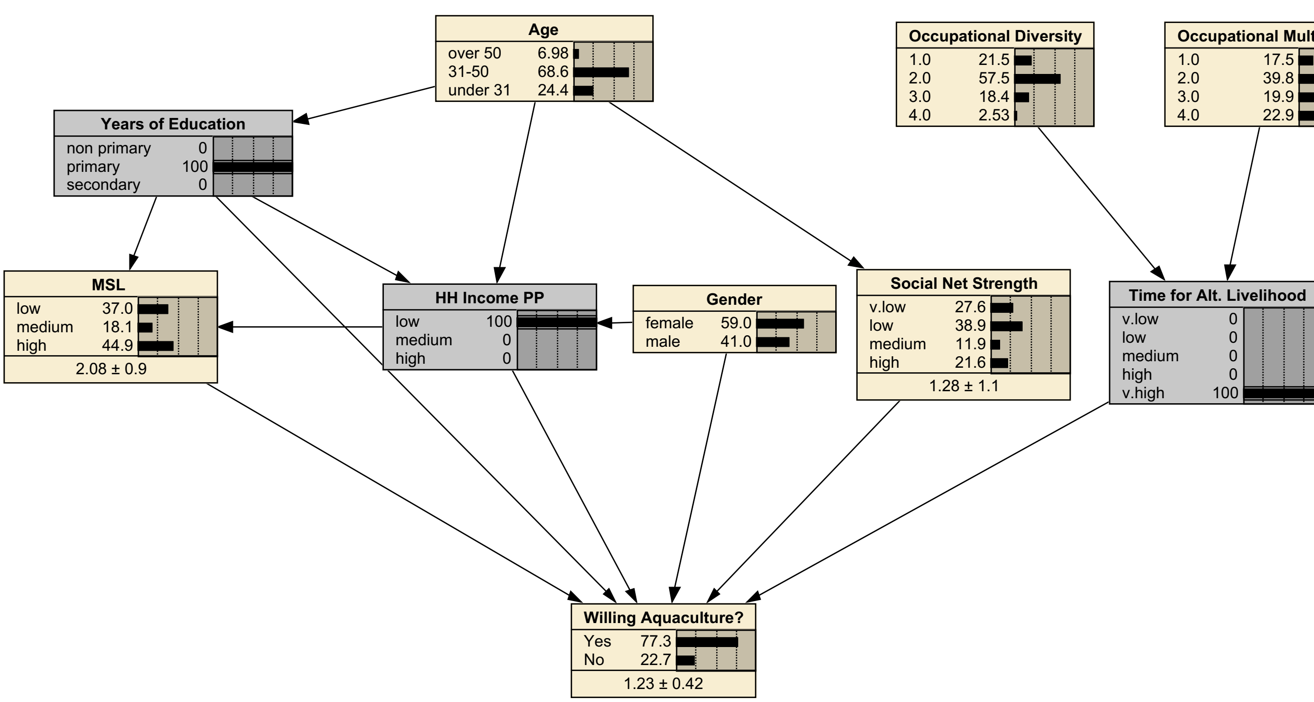

Fig. 4. Graphic representation of manipulation of final (*beta*) Bayesian Belief Network model showing decision nodes and links affecting 'willingness to participate in aquaculture'. The node for household income per person has been manipulated to select the lowest income respondents. Adjusting the value of the node years of education to "primary" and time available for an alternative livelihood to "very high" (25 + hours per week) increases 'willingness to participate in aquaculture' from 55.1% to 77.3%.

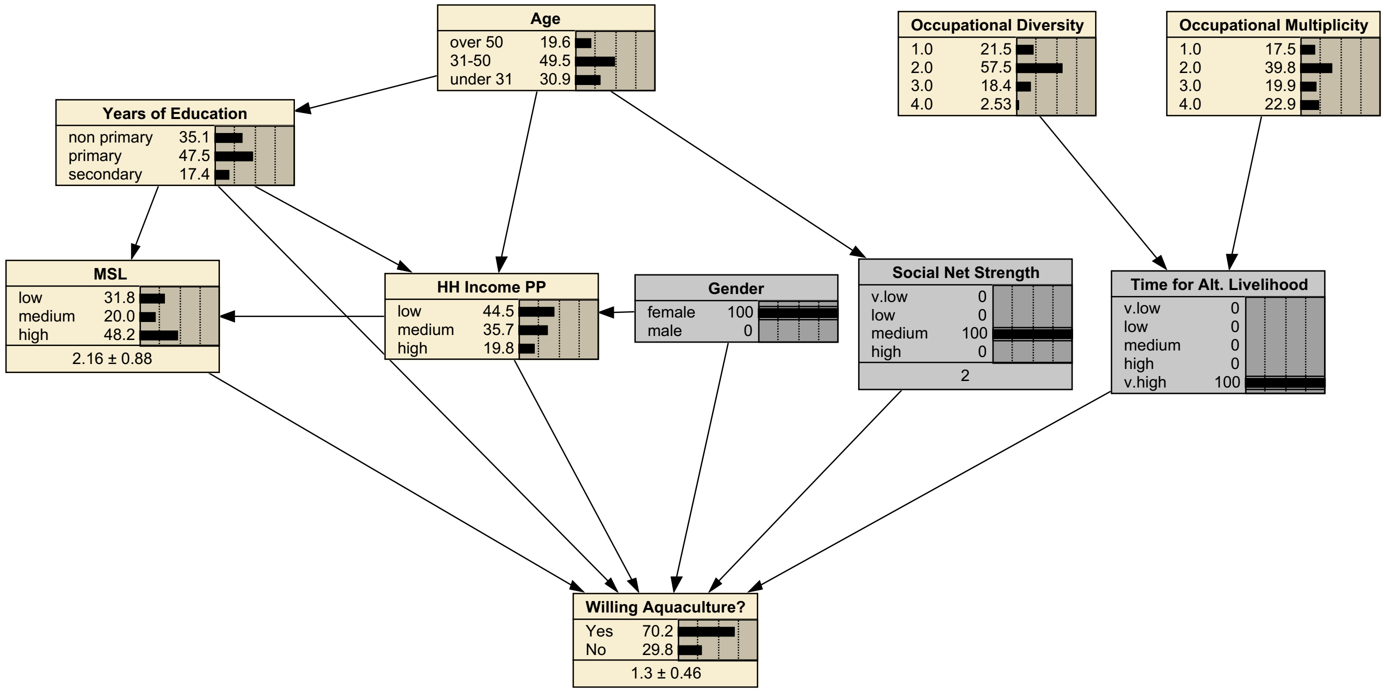

Fig. 5. Graphic representation of manipulation of final (*beta*) Bayesian Belief Network model showing decision nodes and links affecting 'willingness to participate in aquaculture'. The node for gender has been manipulated to select females. Adjusting the value of the node social network strength to "medium" and time available for an alternative livelihood to "very high" (25 + hours per week) increases 'willingness to participate in aquaculture' from 49.8% to 70.2%.

(Figs. 3 and 4). In the case of female respondents, policy-makers can predict that stepwise increases in social network strength and time available for an alternative livelihood will also increase willingness of respondents to become involved in aquaculture, providing insights in to how best aquaculture activities could be implemented in practice (Fig. 5).

The decision support model presented does not specifically take into account factors which may influence willingness such as prior knowledge or experience of sea cucumber aquaculture or recognised value of sea cucumbers based on prior fishery experience (Ogundari and Ojo, 2009; Eriksson et al., 2012b). In the current study however, prior extension, training or past experience of sea cucumber aquaculture was extremely unlikely among respondents. However in future studies with more established aquaculture species in Tanzania, these factors would need to be considered. Equally, the fact that sea cucumbers are present, albeit in low numbers at all sites studies and considered a high-value species by most fishers and gleaners in Tanzania, is likely to have positively influenced interest in aquaculture involvement overall (Eriksson et al., 2012a; Mgaya et al., 2007).

The model presented here is limited in its scope for addressing primarily social and socio-economic data, centred on a single willingness response variable. Future developments of the BBN model will benefit from the integration of natural science data such as estimated sea cucumber stocks as an initial source for broodstock and other factors indicating marine ecosystem health, an important factor for assessing longer term viability of marine aquaculture. The purpose of initially focussing on a single 'willingness' variable is to assess the value of the BBN modelling approach to provide meaningful and practical advice on the relationships between socio-economic factors and livelihood choice.

Future extension requires a truly interdisciplinary model to support overall advice on marine governance structures required to support marine policies targeting poverty alleviation measures can be further developed. This requires reproducible methods for valuation and integration of data from social science, economics and natural sciences into a dynamic decision-making model (Levontin et al., 2011). Such a model would extend the outputs presented herein and allow policy-makers to capture trade-offs within policy and allow changes to the valuation of additional factors that affect livelihood uptake to be considered, such as marine health, economic success and overall ecosystem value.

5. Conclusions

This paper has discussed how BBN models can be applied as an assessment tool to understand social and economic drivers for aquaculture development. The methods herein begin to address a major gap in current marine policy science by providing a method to analyse socio-economic variables in a way policy-makers can easily use to assess whether introducing a particular sector like aquaculture can have a positive impact on reducing poverty in vulnerable communities.

The first conclusion is that perceptions and expectations of coastal communities must be included in informed policy-making for introducing aquaculture development. Secondly, on the basis of the rudimentary manipulations herein, policy-makers aiming to drive aquaculture uptake must form policy to address long-term ultimate drivers such as level of education, as well as direct factors such as increasing time availability. Additionally, extension workers targeting low-income individuals or women to involve in aquaculture training can effectively target those with more than 25 h available for an alternative livelihood, with medium to high social network strength and those with a minimum primary level of education. Thirdly, the resulting BBN model presented herein provides, for the first time, a graphic tool which predicts the effect of adjustments to socio-economic factors on community member's willingness to be involved in aquaculture. It allows accurate prediction of willingness to adopt a livelihood among specific groups and provides succinct estimates of the outcome of changes to policy for those groups. If the model is extended and combined with natural sciences data and information from other disciplines like engineering to capture technological constraints influenced by availability of local resources, the model can support more effective implementation of aquaculture development. This will aid policy-makers to successfully implement and extend aquaculture in developing nations and will aid aquaculture in realising its full potential in providing food security and alleviating poverty.

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