

Linkages between Social-learning Networks and Farm Sustainability for Smallholder Shrimp Farmers in Sri Lanka

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Abstract

Shrimp farming has the potential to improve income and diversify livelihoods in rural Sri Lanka. The industry faces challenges including low productivity, disease outbreaks, and unsustainable practices. Shrimp farmers' perceptions about access to knowledge and their knowledge-exchange social networks were examined. A cross-sectional survey of 225 farmers was completed in two separate shrimp farming regions. The questionnaire assessed social learning networks, farm-level sustainability, demographics, and wealth of farmers. Associations between the number of connections in social learning networks (degrees) and the other factors from the questionnaire were examined using Poisson regression analysis. Overall, social learning networks were not highly connected (median farmer degree =2) and network structure varied by geographic location and farmer ethnicity. Higher social learning network degrees were associated with increased wealth and decreased ecological sustainability; however, this varied by ethnicity. Significant differences in networks between geographic areas and ethnicities point to the need for contextually adapted knowledge mobilisation activities.

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Leveraging existing farmer-to-farmer peer networks by providing accurate knowledge through the existing networks, as well as strengthening the farmer-to-expert network, may provide the most relevant and effective route to disseminate information to affect practices to improve farm management and increase the likelihood of improved productivity and income.

Introduction

Shrimp farming in Asia can provide a high value crop that can improve rural incomes and livelihoods. However, shrimp farming has also resulted in environmental degradation, shrimp disease outbreaks, collapses in production and loss of livelihoods (Bene 2005). To date, problems with disease and environmental degradation persist within many countries, particularly on smallholder farms with limited access to resources (Alam et al. 2007; Gregory et al. 2010). This has stimulated research into sustainable production methods that would allow communities to realise positive benefits while minimising negative impacts (Ahmed et al. 2009; Manoj and Namasivayam 2009). Strengthening social learning networks and increasing technical knowledge can improve farmer success (Lebel et al. 2002; Pongthanapanich and Roth 2006; Kumaran et al. 2008).

The Sri Lankan shrimp farming industry is characterised by smallholder farms, high farm density, inadequate biosecurity, and uncoordinated use of common water sources (Munasinghe et al. 2010). Since 1990, environmental degradation and shrimp disease, most notably white spot syndrome virus (WSSV), have severely impacted farmer and community livelihoods in the North Western Province (NWP), the main shrimp farming area of Sri Lanka (Corea et al. 1998; Bergquist 2007). Prior to 2009, lack of civil infrastructure caused by war and a crippling tsunami in 2004 limited actions to improve the situation. Since peace-time, the government has undertaken initiatives to improve shrimp health and farm success, most notably organising shrimp farming areas into management zones based on geographical divisions, creating shrimp farm societies managed by farmer-leaders to coordinate and regulate local shrimp farming activities, and developing a better management practices (BMPs) manual. Despite these efforts, recent investigation into ongoing WSSV outbreaks documented multifactorial causality including poor water quality, poor post-larvae (juvenile shrimp) quality, and lack of farm biosecurity (Munasinghe et al. 2010). In the Eastern province (EP), which has seen recent development of shrimp farming after the end of the civil war, disease problems have yet to be reported. However, since production methods are similar to the NWP and other regions of Asia, it seems likely that shrimp diseases will become a problem in the EP unless sustainable production can be implemented.

Social-learning-networks (SLNs) can be defined as connections between people that change an individual's knowledge or motivation, resulting in behaviour change and alteration of practices (Milbrath 1989; Blackmore 2007; Muro and Jeffrey 2008). Social-learning-networks have been shown to be important for smallholder farmer learning (Conley and Udry 2001; Bandiera and Rasul 2006; Thuo et al. 2013).

Farmer learning through SLNs can be influenced by individual farmer characteristics (Bandiera and Rasul 2006), as well as the structural characteristics of the network (Hoang et al. 2006; Bodin and Crona 2009; Amlaku et al. 2012). In order to use SLNs to promote capacity-enhancing activities for agriculture, it is important to understand the structure of the network as well as characteristics of individual farmers (Mariano et al. 2012), and to identify potential causes of social stratification and the role of socioeconomic status (Hoang et al. 2006; Matuschke and Qaim 2009). This study evolved from ongoing research and extension projects carried out by the co-authors into the root causes and impacts of disease on smallholder shrimp farms in Sri Lanka. We had previously documented that disease outbreaks were linked to unsustainable farming practices, such as failing to clean water exchanged between common water bodies and shrimp ponds, failing to exclude animals that transport pathogens, such as birds and crabs, from ponds, and failing to screen juvenile shrimp (post-larvae) for pathogens prior to stocking ponds (Munasinghe et al., 2010). Observations of co-authors during previous phases of the project led us to hypothesise that inadequate farmer access to knowledge was a major contributor to poor farm sustainability. The goal of this research was to develop evidence-based strategies to increase farmers' uptake of BMPs. To do this, data about 1) farmer and farm attributes, including attributes specific to farm sustainability; 2) farmers' perceptions of access to knowledge; 3) the structure of existing SLNs for shrimp production in the NWP and EP and 4) the relationship between farmer attributes, farm sustainability and SLN attributes were collected. Then these findings were synthesised to create recommendations to guide intervention activities.

Materials and Methods

Data collection (shrimp farmers)

A structured questionnaire was developed to collect information about demographics (including self-identified ethnicity), shrimp farming practices, farmer experience, socioeconomic status, and SLNs for smallholder shrimp farmers in Sri Lanka. Smallholder farms were defined as having five or fewer ponds with the owner as the primary decision maker of the farm. Local interviewers were hired and trained to administer surveys in person with shrimp farm owners (the head of the household). Data were collected confidentially and with informed consent.

The study area included the two major shrimp producing regions of Sri Lanka, the NWP and EP. In the NWP, shrimp farmers were selected from shrimp society membership lists for each District Secretariat (DS) administrative unit. In the EP, all 60 farmers participated in the interviews.

Data collection (shrimp society leaders and technical experts)

Data from shrimp society leaders and industry technical experts were collected by in-person interviews using a structured questionnaire with 25 questions that evaluated what topics experts communicated about, with whom they communicated, and what communication method they used.

All shrimp society leaders and a purposive sample of experts working at companies allied with shrimp farming were invited to participate in the survey.

Network data analysis

Terms used in this study to describe social networks were taken from network science (Hanneman et al. 2005). *Egos* were defined as shrimp farmers, shrimp society leaders, and experts interviewed. *Alters* were defined as someone an ego contacted to seek or share knowledge about shrimp farming. *Degree* was defined as the number of alters with whom an ego reported sharing knowledge.

Each farmer's degree was calculated by triangulating farmer's responses to 1) prompts for expert names using a list of expert titles (e.g. shrimp-feed company representative, shrimp farming expert in government, shrimp farming expert at a hatchery, shrimp farming expert at a university) 2) prompts for names of individuals from whom the farmer accessed knowledge and input-supplies in the previous cycle, and 3) prompts for names of individuals with whom the farmer would theoretically discuss health and production problems on their farms. Farmers' responses were combined with rosters of shrimp industry organisations and knowledge of one coauthor (Kumara), to create network diagrams using a computer software programme for visualisation of network data (Batagelj and Mrvar 2008).

The formal expert network, which was defined as the network that included only experts with post-secondary education in aquaculture, and the peer-identified expert network, which included anyone farmers identified as an expert, including those without formal education or training, were examined. Separate networks for the EP and NWP were examined, and within the NWP networks for the three main ethnic groups in Sri Lanka: Sinhalese, Moors and Tamils were created. In the EP, ethnicity of the majority of farmers was Tamil, so separate analysis was not performed.

Measurement of sustainability of shrimp farming practices

A sustainability index, including four pillars of sustainability (social, economic, ecological and shrimp health) described in Westers 2012, was adapted from the sustainability assessment of farming and environment (SAFE) model (Pope et al. 2004; Van Cauwenbergh et al. 2007; Pretty 2008; Gómez-Limón and Sanchez-Fernandez 2010). Factors assessed in the social pillar include minimising potential for conflict with others, feeling a sense of community, and satisfaction with work and life. Income, expenses, and market activities were included in the economic pillar. The ecological pillar includes environmental factors such as chemical use, water quality, and compliance with ecological BMPs. The shrimp health pillar included disease outbreak histories, farm biosecurity, and compliance with BMPs for shrimp health. A score for each pillar was calculated based on 6-20 variables from the survey.

Each variable was normalised using min-max normalisation to assign a score of zero for the least sustainable option and one for the most sustainable option. The individual variable scores were summed to create a pillar score. The overall sustainability score (herein referred to as the SAFE score) was calculated from the sum of the pillar scores, divided by the number of pillars (four), and multiplied by 100 to obtain scores between 0 and 100 (OECD 2008; Gómez-Limón and Sanchez-Fernandez 2010).

Measurement of wealth for smallholder shrimp farmers

A wealth index for each household was developed as a composite proxy for socioeconomic status (SES). A principal component analysis with a polychoric correlation matrix of a number of variables of interest to extract factors was used (Filmer and Pritchett 2001; Kolenikov and Angeles 2009). No rotation was used as only one factor with an eigenvalue greater than 1.0 was extracted. The four asset variables in the final index were number of shrimp ponds, number of hired workers, sum of assets, and main household fuel source.

Statistical analysis

All data were entered into Microsoft® Access (Microsoft Corp., Richmond, WA, USA) and two separate independent researchers verified data entry. Listwise deletion of observations was used for missing data of variables of interest due to the exploratory nature of the study.

Descriptive statistics were generated for the outcome and variables of interest using appropriate measures of central tendency depending on the type and distribution of data. Contingency tables were used to further delineate differences between ethnic groups and variables of interest. Comparisons between geographical regions and different ethnic groups utilised χ^2 test of goodness of fit or Fisher's exact test (for small numbers), and the Kruskal Wallis test as appropriate for the type of data.

Poisson regression was used to examine the associations between farmer degree and the following predictors of interest: age, education, ethnicity, divisional secretariat (geographical location), wealth index score, and individual sustainability pillar scores or the overall SAFE score. Selection of predictors was based on literature review and context of the study. Each variable was analysed separately in unconditional analysis using simple Poisson regression with SLN degree as the outcome. A cut-off of $p < 0.20$ was used to determine predictors appropriate for use in the multivariable Poisson model. Simultaneous entry of variables was used in the initial step, followed by manual stepwise removal of those variables with $p < 0.10$, based on assessment of the Wald test. Variables were kept in the final model if $p < 0.05$. The Wald test was used to evaluate the significance of different levels of categorical variables. First order interaction terms of significant main effect variables were assessed for statistical significance at $p < 0.05$.

If interaction terms were significant, continuous predictors were centered on the mean to facilitate interpretation of the coefficients. To further interpret the role of effect modification in the models, data were stratified by the appropriate variables. Analysis was completed in Stata Statistical Software: Release 13 (StataCorp. 2013. College Station, TX: StataCorp LP).

Results

A total of 165 farms were surveyed in the NWP and 60 in the EP. In both the NWP and EP, the most common method farmers used to seek knowledge about shrimp farming was in-person discussion (73%), followed by mobile phone calling (16%), land phone calling (8%) and mobile phone text messaging (3%). The majority of farmers in both provinces expressed interest in attending training courses (NWP 85%, 95% CI:75-92, EP 84%, 95% CI:76-97).

Comparison of experience, self-perceived knowledge and access to knowledge in different ethnic groups

Within the NWP, there were significant differences between the three ethnic groups in experience, self-perceived knowledge, and access to knowledge. The median years of experience for Sinhalese farmers was 12 (q1 = 7, q3 = 16), for Tamil farmers was 11 years (q1 = 7.5, q3 = 15), and for Moor farmers the median years was 8 (q1 = 5, q3 = 13) ($\chi^2 = 9.31$, df = 2, $p = 0.0095$). Nearly half of Sinhalese farmers rated their self-knowledge as between good to excellent (48%, N = 87), while 94% (N = 37) of Tamil farmers and 100% (N = 30) of Moor farmers rated their knowledge between good to excellent ($\chi^2 = 78.52$, df = 6, $p < 0.001$). For access to training, 61% of Sinhalese farmers felt they knew where to access training, while 55% of Tamil farmers felt the same, and 30% of Moor farmers felt they knew where to access training ($\chi^2 = 8.41$, df = 2, $p = 0.015$).

Description of the farmer SLN degree and network structure

Input supply (e.g. feed suppliers) networks were significantly more concentrated in the EP than NWP ($p < 0.001$). In the NWP, median farmer input-supply degree was 3 (n = 98, q1 = 2 –q3 = 3), indicating that most farmers interacted with three different alters to buy inputs and sell shrimp, while in the EP it was 1 (n = 56, q1 = 1, q3 = 1), indicating that most farmers bought from and sold to one source.

Social-learning-networks were similar in appearance in the NWP and EP (Figs. 1, 2). In the NWP, 75% (124/165) of farmers were part of the major network component, while in the EP, 80% (41/60) of farmers were part of the major network component. Median farmer SLN degree was similar in the NWP and EPs (median degree = 2, NWP q1 = 1, q3 = 4 and EP q1 = 1, q3 = 3). In the NWP, 116 individuals were named as experts; the majority of these experts were other farmers (n = 69, 58%) or informally trained technicians (n=34, 29%) while others were formally trained experts in government (7) and industry (6). Eleven farmers had ties to the network only through other farmers, and lacked ties to any formally trained expert.

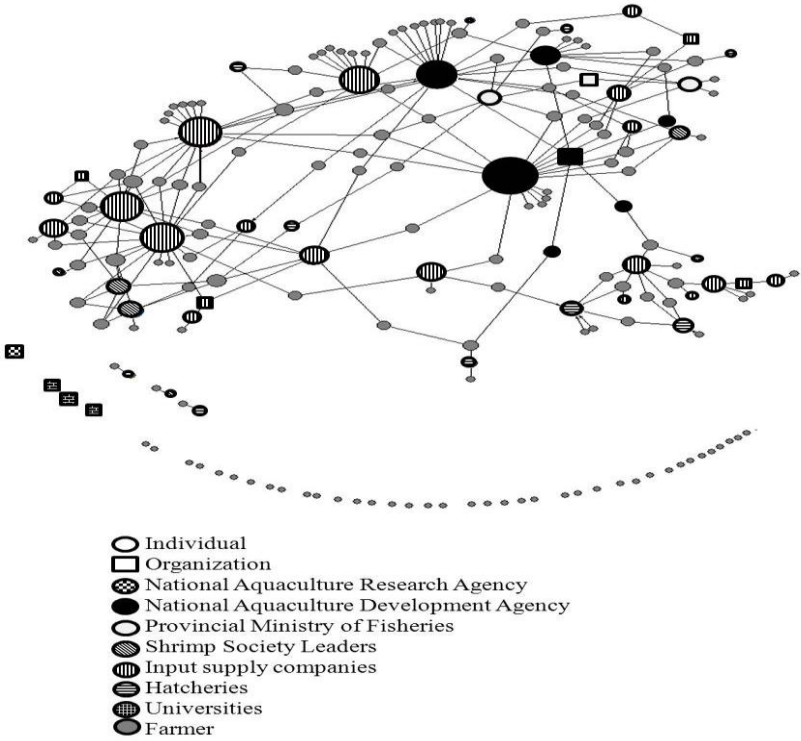


Fig. 1. Network created from egocentric ties reported by 165 shrimp farmers in the North Western Province of Sri Lanka to formally trained experts in shrimp farming. Node size is proportional to actor degree.

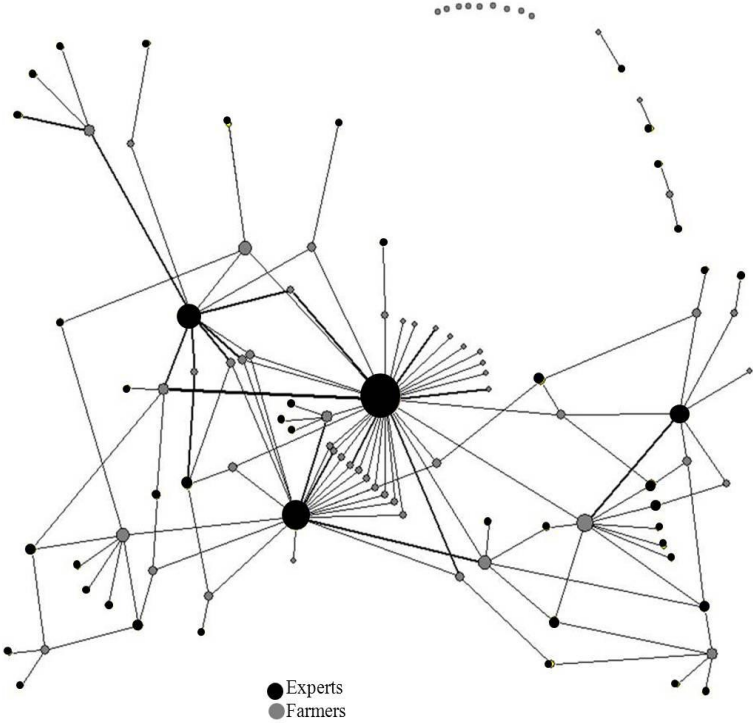


Fig. 2. Network created from egocentric ties reported by 165 shrimp farmers in the Eastern Province of Sri Lanka to experts in shrimp farming. Node size is proportional to actor degree.

In the EP, farmers named 49 individuals as experts, nine of whom were also named by farmers in the NWP. The most popular expert was named by 35 farmers; however similar to the NWP, most experts were named by just one farmer. The two most connected experts in the network were identified as an employee of a supply company and an employee of the national government department that oversees aquaculture in Sri Lanka (the National Aquatic Development Association [NAQDA]), respectively.

In the NWP, farmer SLNs differed by ethnicity. The median network degree was 1 for Sinhalese ($q1 = 1$, $q3 = 2$), 4 for Tamils ($q1 = 1$, $q3 = 5$), and 5 for Moors ($q1 = 4$, $q3 = 5$). These differences were statistically significant ($H = 60.5$, $df = 2$, $N = 162$, $p = 0.001$). In addition, 27% of Sinhalese farmers were isolated from the major network component, while only 16% of Moors and 5% of Tamils were isolated ($\text{Chi square } p=0.02$). Networks for the three ethnicities in the NWP appeared quite different visually, with the Sinhalese network more highly connected to experts at NAQDA, while the Moor and Tamil networks were more highly connected to other farmers (Fig. 3). The Moor and Tamil farmer-to-farmer network were connected together, sharing 10 ties, while the Sinhalese farmer-to-farmer network was relatively separate, sharing only 2 ties with the networks for the other ethnicities (Fig. 4). Farmers of all ethnicities were connected to technical experts at input supply companies in a uniform manner.

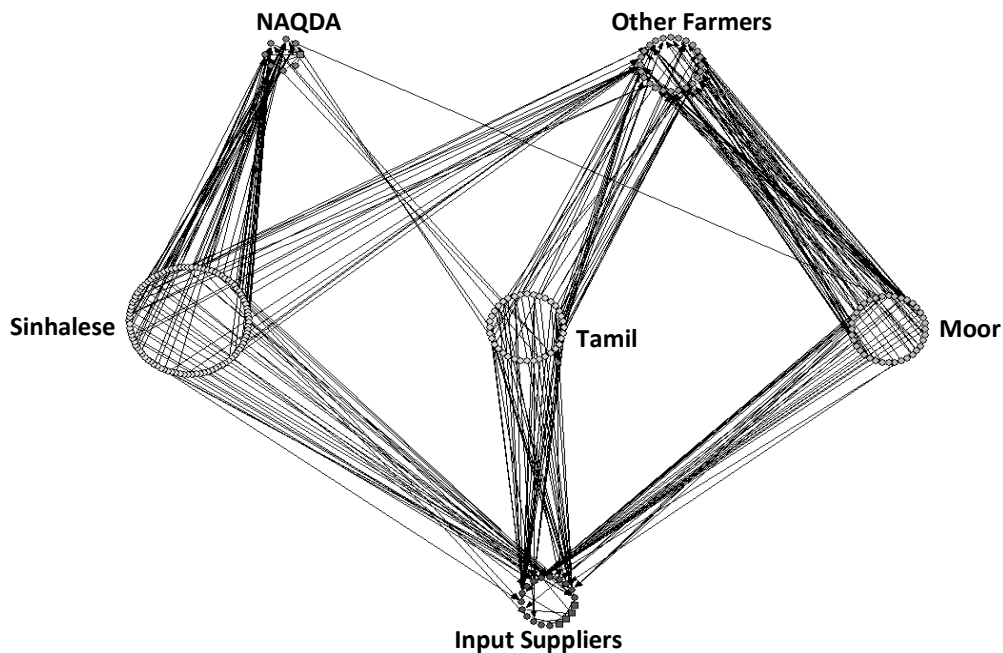


Fig. 3. Network diagram for the North Western Province of Sri Lanka showing ties between farmers of different ethnicity and three key sources of knowledge; the government National Aquatic Development Association (NAQDA), other farmers and input supply companies.

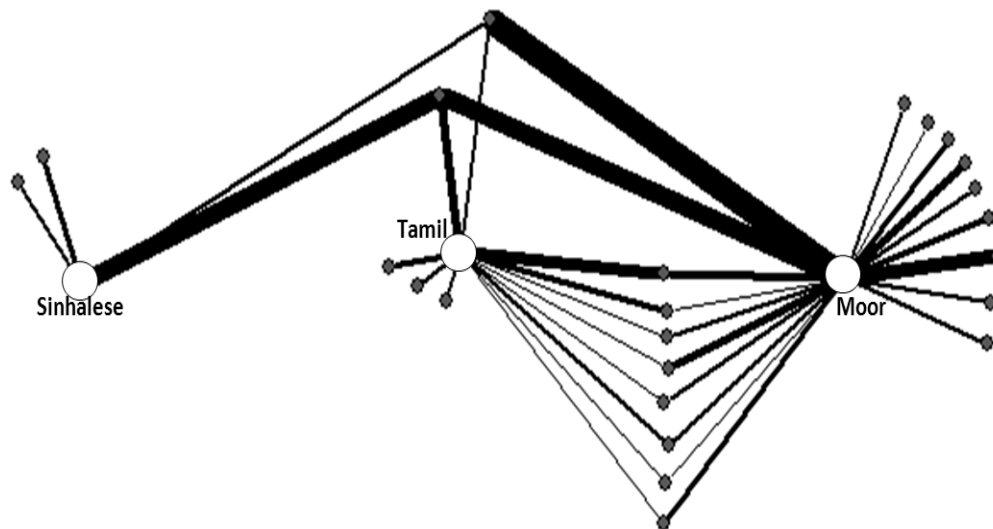


Fig. 4. Network diagram for the North Western Province of Sri Lanka showing ties to farmer-experts by farmers of different ethnicities. Grey dots represent individual farmer-experts. Tie strength is proportional to line width.

In the EP, where the two ethnicities are Tamil and Moor, there was no difference in SLN degree between Tamils (median = 2, q1 = 1, q3 = 3) and Moors (median = 2, q1 = 2, q3 = 3) ($H = 1.92$, $df = 1$, $N = 51$, $p = 0.1661$).

Sustainability measurement

In the NWP, the mean overall shrimp farm SAFE score was 59.7 (95% CI: 58.5 – 60.9) with a range of 35.2 to 78.6 where higher scores indicate greater sustainability with a maximum score of 100 (Westers 2012). In the EP, the mean overall shrimp farm SAFE score was 54.3 (95% CI: 52.3 – 56.4) with a range of 39.5 to 75.4 (Westers 2012). Descriptive statistics for the sustainability pillar scores are presented in Table 1.

Table 1. Descriptive statistics of the pillars of sustainability of smallholder shrimp farms in Sri Lanka.

Sustainability Pillar	Mean	SD	Lower Range	First quartile	Median	Third quartile	High Range
Social	69.9	15.4	31.8	59.1	72.2	81.8	100.0
Environment	62.8	12.9	30.0	55.6	66.7	75.0	88.9
Ecological	51.3	11.5	14.7	44.7	52.0	60.3	73.9
Shrimp health	54.7	10.4	28.6	46.4	57.1	60.7	75.0

Wealth index

In the NWP, the median wealth index for Sinhalese was 0.64 (N = 87, q1 = 0.32, q3 = 1.37), while for Tamils it was 2.64 (N = 38, q1 = 1.38, q3 = 4.56), and for Moors it was 3.91 (N = 35, q1 = 2.66, q3 = 4.56). The difference in the wealth index between different ethnicities was statistically significant (H = 78.59, df = 2, $p = 0.001$). In the EP, for Tamils, median wealth was 5.80 (N = 26, q1 = 4.22, q3 = 7.71), and for Moors the median wealth was 5.07 (N = 25, q1 = 3.28, q3 = 6.02). This was not statistically significant (H = 2.10, df = 2, $p = 0.1475$).

Table 2. Final multivariable Poisson regression model of farmer network degree with sustainability and socioeconomic factors for shrimp farming households in the NWP of Sri Lanka.

Predictor	β	SE	P	95% CI	
				Lower	Upper
Ethnicity ^a			<0.001		
Sinhalese ^a					
Tamil	1.856	0.788	0.019	0.311	3.402
Moors	1.145	0.615	0.063	-0.061	2.351
Ecological pillar	-0.006	0.008	0.390	-0.021	0.008
Wealth ^b	0.181	0.087	0.037	0.011	0.351
Interaction			0.0023		
Tamil x wealth	0.010	0.101	0.924	-0.188	0.207
Moors x wealth	-0.245	0.104	0.019	-0.449	-0.041
Interaction			0.0245		
Tamil x ecological	-0.023	0.012	0.052	-0.047	0.000
Moors x ecological	0.007	0.010	0.462	-0.012	0.026
Constant	0.547	0.453	0.227	-0.341	1.434

Model likelihood ratio $\chi^2 = 125.40$, df = 8, $p = < 0.001$

Pseudo $R^2 = 0.2085$

^a Reference category

^b Centered variables

Results from the analysis of degree in the social learning network with associations of interest

For the NWP, model diagnostics indicated the data fit the Poisson distribution. The final regression analysis model had significant predictors of ethnicity, wealth, the ecological pillar, and the two-way interactions between ethnicity and wealth and ethnicity and the ecological pillar (Table 2). The trend of wealth for the Sinhalese and Tamils was similar when controlling for the effect of the ecological variable. For a one-unit increase in the wealth index, the log of expected SLN degree increased by 0.18 and 0.19, for Sinhalese and Tamils respectively (i.e. increased wealth associated with higher SLN degree). For the Moors, wealth was not a significant predictor of SLN degree. As an individual variable, the ecological pillar did not differ by ethnicity (H = 3.02, df = 2, N = 163, $p = 0.2213$). The significance of the ecological pillar was only evident among Tamils.

With a one-unit increase in the ecological pillar among this group, the difference in the log of expected SLN degree would decrease by 0.03 units, when controlling for wealth (i.e. increased ecological sustainability was associated with lower SL network degree. For the EP, multiple Poisson regression failed to produce any model with more than one variable. Two separate univariable models were assessed as the final models for this analysis (Table 3); these included the overall SAFE score and the social pillar. The effect of the overall farm SAFE score with SLN degree indicated a one unit increase in the overall SAFE score corresponding to an expected increase in the log SLN degree of 0.026. For a one unit increase in the social pillar, the difference in the log of expected SLN degree would be expected to increase by 0.013. Therefore, SLN degree would be expected to increase as sustainability increases. For both models, goodness of fit (deviance and Pearson) was non-significant, indicating the data fit the Poisson distribution.

Table 3. Unconditional Poisson regression analysis results of significant sustainability pillars associated with social learning network degree in shrimp farming households of the Eastern Province of Sri Lanka.

Predictors	n	β	SE	<i>p</i>	95% C.I.	
					Lower	Upper
Overall SAFE	55	0.026	0.010	0.013*	0.005	0.046
Social pillar	55	0.013	0.006	0.024*	0.002	0.024

Discussion

This research has shown that for smallholder shrimp farmers in Sri Lanka, social learning networks differed based on geographical location and ethnicity. Within the NWP, Sinhalese farmers had lower wealth and smaller social network degree than Tamil or Moor farmers. About one fifth of farmers in both provinces were not connected to the major SLN component of their shrimp farming network, leaving these farmers isolated from the knowledge being disseminated through the network.

The ethnic groups in the NWP had different network structures. Sinhalese farmers had much smaller networks compared to the Tamils and Moors, but were well connected to government shrimp farming experts. Tamil and Moor farmers were poorly connected to experts in government, but highly connected to farmer peers. Language may, in part, explain why the Moor and Tamil networks were more similar because both Moor and Tamil farmers speak Tamil, while Sinhalese farmers speak primarily Sinhala. Homophily – the tendency for people to associate or connect with other people who are similar to them with respect to socioeconomic status, values, and other characteristics – may also be at play here. Homophily within social networks has been reported in many network studies (McPherson et al. 2001; Sligo et al. 2005).

Most farmers in our study rated their knowledge about shrimp farming as high and nearly all farmers felt they knew where to access information. However, the people whom most farmers accessed for knowledge lacked training in BMPs for shrimp farming. This indicates an important gap between farmers' perceptions about access to knowledge and their actual access to trained experts. NWP farmers rated their self-assessed knowledge as lower compared to farmers in the EP, despite having more years of experience and self-reported better access to training. The struggles NWP farmers have experienced with poor production and WSSV (Munasinghe et al. 2010) may have influenced the lower rating of their own knowledge. Only half of the farmers in the NWP and one quarter in the EP responded that they had access to training courses. In the EP, this perception was likely influenced by the smaller industry in the region, less infrastructure post-civil war, and geographical isolation from the more densely populated NWP.

A resounding proportion of farmers in both provinces were interested in formal training courses if they were available. However, having small individual networks may preclude smallholder farmers from being informed of such courses, and smallholder farmers may feel uncomfortable in these formal settings due to hierarchical relationships with government extension workers or academia (Hofstede 2001; Hoang et al. 2006). The regression analysis demonstrated that the measure of sustainable practices was significantly associated with SLN degree. How shrimp farmers managed their farms was associated with how well connected they were to people with shrimp farming knowledge. In the NWP, wealth and ethnicity were significant predictors of SLN degrees, with the effect of wealth on degrees dependent on ethnicity.

By itself, wealth also varied by ethnicity with a significantly higher wealth index among Tamils and Moors. For Tamil farmers, increased wealth translated to a greater number of network degrees. Higher wealth may relate to being more influential and therefore having a greater number of ties to other people. This has implications for farmers adopting new technologies and practices, since access to credit and wealth has been associated with greater adoption of innovations (Bandiera and Rasul 2006; Matuschke and Qaim 2009; Mariano et al. 2012) and greater access to extension services (Hoang et al. 2006).

The differential effect of wealth and ethnicity within the network generates implications for practice, policy, and methodology. A "one size fits all" intervention applied to all shrimp farmers will likely not succeed without acknowledging the dynamic relationship between social, economic, environmental, and cultural factors. Limitations of this study include the focus of the study on shrimp farming SLNs of farmers; individuals have multiple social networks (e.g. financial, land, labour, kinship), which may also provide informal knowledge that farmers did not identify. This study did not explore the quality of farmers' interactions and other factors related to power relations, and this would be an important next step in determining the effectiveness of these social ties in terms of trust and respect, which are key to an effective uptake of information (Oreszczyn et al. 2010).

In addition, unobserved individual characteristics, such as self-motivation and ability, are difficult to quantify but are important factors in social learning and adaptation of practices (Munshi 2004; Muro and Jeffrey 2008; Matuschke and Qaim 2009). Qualitative interviews with farmers and more in-depth questions regarding knowledge obtained and the quality and influence of relationships would help shed light in these areas. These interviews could in part focus on farmers who represented more isolated nodes in the network.

Conclusion

To our knowledge, this research presents results from the first use of network theory to understand reasons for poor uptake of BMPs on smallholder shrimp farms and suggest methods to improve farm sustainability. From the evidence collected in this study, three strategies might be considered to increase farmers' uptake of BMPs to improve farm success and limit the impact of WSSV; 1) encourage the flow of accurate knowledge through existing farmer-to-peer networks; 2) strengthen farmer-to-expert networks; and 3) purposefully engage farmers who are isolated from existing networks. To improve the flow of accurate knowledge through existing farmer-to-farmer peer networks, farmers that are key nodes in the network would need to receive up-to-date knowledge about shrimp farming BMPs. Techniques could include targeted training of shrimp society leaders and other important nodes in the peer network. Strengthening the farmer-to-expert network would enable more farmers to identify and communicate with formally trained experts when facing a novel or challenging problem on their farms. Strengthening ties between NAQDA and Moor and Tamil farmers might be particularly beneficial. Engaging the high proportion of farmers who represent isolated nodes in the network might be helped by using broad outreach techniques such as radio and SMS messaging, as well as traditional extension methods using farm visits and on-farm needs assessments. In order to elicit the greatest possible benefit to different shrimp farmers in Sri Lanka, any proposed activity must be sensitive to differences in socioeconomic status and ethnicity.

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