

The contribution of a catchment-scale advice network to successful agricultural drought adaptation in Northern Thailand.

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Abstract

The intensification of drought affects agricultural production, leading to economic losses, environmental degradation, and social impacts. To move towards more resilient system configurations requires understanding the processes that shape farmers' adaptation amidst complex institutional contexts. Social networks are an important part of collective action for supporting adaptive capacity and there are continuing calls to strengthen network connectivity for agricultural governance under the impacts of climate change. Through a survey of 176 farmers in northern Thailand, we explore the extent to which the characteristics of information shared in a catchment advice network are associated with adaptations. Statistical analyses reveal the perceived efficacy of communications as well as farmers' relative closeness in the advice network to be positively associated with adaptation to drought. We identify a capacity for local actors to bridge information bottlenecks in the network and opportunities for institutions to enhance their dissemination of information to reach less networked farmers. We find that not all adaptations are perceived as effective against future drought and infer opportunities to support engagement with extension services, encourage the sharing of local knowledge and experience, and devise policy and interventions to strengthen advice networks for more resilient agricultural systems.

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Introduction

Agriculture, a major economic sector and a critical source of livelihood in Southeast Asian countries like Thailand, is vulnerable to climate variability and extremes, including drought [1]. Coupled with climate change, the intensification of drought affects agricultural production and catalyses economic losses [2], environmental degradation [3] and social impacts such as de-agrarianization [4]. Once manifested, these drought impacts signify vulnerability in an agricultural system, particularly where there is not the capacity to absorb the shock or respond to change [5]. From a resilience perspective, research endeavours to understand the elements that enable the system to renew and reorganise and cope with disturbances in the longer term [6]. Thus, efforts to understand the processes that shape farmers' adaptation to climate change [7] in diverse geographic, institutional, and governance contexts [8] can contribute towards the development of more effective adaptation strategies. Using a case study from Thailand, this study aims to investigate the roles of institutions and farmers in sharing advice to support drought resilience.

Various frameworks attempt to draw together the concepts of resilience, vulnerability, and adaptive capacity with respect to socio-ecological systems (e.g. see [9–11], wherein adaptive capacity is a common link and where systems with higher adaptive capacity have a greater chance of moving to a more desirable system state [12]. Adaptation, viewed as a reduction in vulnerability arising from the realization of adaptive capacity [13], can describe reactive responses or the anticipation of and planning for future stresses [12]. Moreover, adaptation can vary in spatial scale, intent, timing or duration [14] and successful implementation involves the coordination of efforts across multiple actors [8]. Public bodies may disseminate information via different communication channels and networks [1] to promote both strategic and on-farm adaptation measures [14]. The sharing of information is further shaped by formal and informal institutional structures and governance arrangements that encompass the capacity for collective responses [8, 15]. Yet whilst evidence shows that access to information and participation in social institutions are associated with households making successful farming changes [16, 17], many farmers remain constrained by a lack of information on what to do in response to drought [18].

Social networks are an important part of collective action for supporting adaptive capacity [19] and they may serve as an indicator of community resilience [9]. Farmers that network more with other farmers and institutional services build social capital [1] and may be more likely to adapt [20–22]. Local farming networks can contribute to information exchange and adaptive responses [1] where farmers often rely on informal, rather than formal (e.g. from a government department), advice networks [23]. Farmers can also generate knowledge through experimentation [23], or by referring to indigenous knowledge [24] which is shared via neighbours and peer groups [1]. Information can enter the social network via prominent individuals (e.g. a

local community leader) [23] or via farmer organisations [25] and advice on adaptation from neighbours, peer groups, and the farming community, rather than from the government, can be more efficacious [1, 26]. Alongside social networks, other factors such as age [27], access to financial resources [28], socioeconomic status [1], and level of education [20] also influence farmers' capacity to adapt.

Within contemporary research and policy, there are calls to strengthen the connectivity of social networks for agricultural governance [27, 28] and for increased farmer inclusion in the development of local adaptation strategies [27, 29, 30]. These concepts can be viewed through an institutional analysis lens and continuing attempts to understand the interplay between governments and the self-governing aspects of natural resource management [15, 31] and the role social networks play in fortifying resilience to drought [32]. Despite innovations in the application of social network analysis (SNA), e.g. [8, 21, 22, 27, 33–35], there is uncertainty in the relationship between a farmer's position in a network and their propensity to make adaptations to counteract drought, particularly in varying climatic or cultural settings. Moreover, little is known about the association between the characteristics of information shared in an agricultural advice network and farmers' evaluations of the success of the adaptations they have undertaken in response to that advice. Thus, further research is needed to help understand the effectiveness of adaptations in different geographical and institutional contexts [7, 8, 36], how to evaluate the characteristics of successful adaptation [11] and then how to best share the knowledge gained with other farmers and institutional actors at local or translocal network scales [16, 22, 26, 36].

In this study, data from a survey of farmers in Northern Thailand are viewed through SNA to investigate how the characteristics of information and the farmers' position in the catchment advice network influence adaptations to drought. To further understand the intersection of SNA research focused on interactions between institutions and farmers [8, 23, 29] with perspectives on constraints to drought management in Thailand [37–39], the study asks: (i) To what extent are the characteristics of information shared in a catchment advice network and the connectivity of farmers within the network associated with farm adaptations? and (ii) to what extent do these factors contribute towards farmers perceiving the adaptations as effective against future droughts? Through answering these questions, we aim to interpret (iii) what the potential contribution of the catchment advice network is for strengthening adaptive capacity and resilience in the context of the case study and more broadly.

Methods

Drought management and the Ping River catchment study area

Recent droughts in Thailand include 2010 (when most provinces were declared disaster areas due to water shortages [40]), 2015-2016 and 2018-2020 [41]. Climate modelling indicates a higher drought risk in the dry season can be expected in the future, alongside a decrease in irrigation water availability and an increase in water demand [36]. Multiple national government ministries and departments are assigned specific roles and responsibilities relating to drought risk and disaster management in Thailand [36]. A selection of prominent departments includes the Royal Irrigation Department (RID, responsible for developing irrigated areas), the Department of Water Resources (DWR, responsible for coordinating water resource management) and the Department of Disaster Prevention and Mitigation (DDPM, responsible for disaster risk management). Additional details of the management structure and roles is provided in **Supplementary Materials – Table 1**. The implementation of national and provincial government drought management activities is facilitated by an administrative hierarchy of provincial governors, district officers, *kamnan* (sub-district headpeople) and village headpeople [43]. Village headpeople are nominated through local elections and their local administrative duties include assisting in implementing government policy, coordination with local government, organising village meetings and communicating government news [44]. The Ping River in northern Thailand (Figure 1) is a major tributary within the Chao Phraya River basin. The Ping catchment traverses five provinces (Chiang Mai, Lamphun, Tak, Kamphaeng Phet and Nakhon Sawan) with varying topography of hills, mountains, valleys, and lowland plains [42].

Questionnaire and respondents

A structured questionnaire (available at [45]) was developed in English, translated into Thai for the fieldwork, and the results were translated back to English for analysis. The questionnaire was designed to collect: (i) farmers' demographic information (e.g. age, gender, annual income, highest level of education), (ii) details of farm characteristics (e.g. crops grown, farm size), (iii) details relating to adaptations that farmers had undertaken during previous droughts, and whether they perceived these drought adaptations as effective, (iv) whether they had received drought advice and acted upon it, (v) characteristics of the information they received (source, frequency, channel, efficacy), and (vi) details of organisations they received drought advice from. The questionnaire contained over 50 questions, the majority with predetermined response categories (e.g. single tick boxes, multiple selection or Likert-type responses scales), however, some open-ended questions were included to elicit qualitative response data, for example, *"Have the household farm undertaken any other adaptation strategies that we have not yet covered? If Yes, Can you describe these other adaptation strategies?"*. Analysis of the survey data was undertaken using SPSS v26.

To complete the SNA and regression models (as described in the next sub-sections), the farmers listed organisations (community, government or private) that had informed their household farm that a drought was coming and/or advised them what to do under drought. They were asked to elaborate on the three

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organisations they were most familiar with, providing details on the content of the information, the channel through which they received the information, the frequency of communications and the perceived efficacy of the communications. Six statements relating to perceived efficacy asked if the communications: had helped farmers prepare for drought, were received in time, were relevant, accurate, comprehensible, and whether the organisation was responsive to farmers concerns. The agree-disagree responses were coded (e.g. 1 = strongly disagree, 5 = strongly agree) and aggregated for analysis. The Cronbach alpha for the six statements was 0.784, considered above acceptable for representing reliability [46].

After ethical approval, and following the concept of rapid rural appraisal [7, 47], farmers were recruited from villages in the four main provinces in the Ping Catchment, to cover a representative spectrum of farming conditions and agricultural areas most affected by recent droughts. The survey took place in January 2020. All respondents gave informed consent and their responses were recorded anonymously. The questionnaire was administered by trained university students and lasted approximately thirty minutes. The interviewers completed the questionnaire for each respondent and made digital recordings to check the recorded responses. The final sample consisted of 176 farmers from twelve districts, three from each of the four provinces (Figure 1. Also see **Supplementary Materials – Table 2**). With an estimated population of farm holdings in the four provinces of 326,000 [48], the sample size ($n = 176$) resulted in a margin of error of approximately 7.5% with a 95% confidence interval (see [49] for formula).

Social Network Analysis

Social networks consist of *nodes* (e.g. farmers and others actors) connected by *ties*, which can describe different types of social relationships [50]. *Centrality* of a particular actor in a social network is used to describe their social influence and their potential for diffusing information [51]. We considered three measures of the centrality of the farmers within the overall catchment advice network and hypothesised that centrality measures would be associated with adaptive behaviours. The centrality measures were: *Degree Centrality* (counting the number of ties a node has, which can indicate exposure to the network and opportunities to influence), *Betweenness Centrality* (how frequently a node lies on the shortest path between two other nodes, which can indicate informal power, gatekeeping, bridging), and *Closeness Centrality* (the distance of a node to all other nodes, which can indicate the time taken to receive advice, or the point of most rapid diffusion) [51, 52]. We used total degree centrality and normalised values for betweenness and closeness centrality in the regression models.

Information channels, as specified by the farmers, were signified as binary data (received information from source = 1, if not = 0). These data were used to create an adjacency matrix in rows (egos) and columns (alters)

for all ties reported by farmers. Guided by literature [37, 43, 53, 54], ties were included between the reported institutions to connect municipal offices, to sub-district offices, to district, province, government department, and government ministry. Additionally, where respondents reported that they had received information from ‘other farmers’ (*Was your household farm informed that a drought was coming and what to do under drought from any other farmers?*), they were connected to a single node for that village designated as ‘other farmers’. Some farmers (n=13) did not provide a response, thus the matrix was defined by n=163 respondents, the organisations they named, interconnecting government departments (e.g. at province and central government levels) and nodes representing ‘other farmers’ where appropriate. The matrix was analysed and visualised using Gephi 0.9.2.

Factors influencing farm adaptations

We used Pearson's chi-squared test (χ^2) for categorical variables and t-tests for continuous variables to explore the interaction of demographic, farm and communication variables (see variables in Table 1, Results section) with the binary categorical variable that contrasted farmers who reported changing something due to receiving information against those that reported not changing something (irrespective of receiving information or advice).

Multiple linear regression was used to investigate factors determining (i) the total number of adaptations undertaken by farmers (model 1), and (ii) the total number of those adaptations perceived as successful (*“Do you think that doing that measure helped the household farm to reduce the impacts of droughts in the future?”*, model 2). We hypothesised that a farmer's relative position in the advice network would help to predict whether they had made more changes on their farms to adapt to drought and whether they perceived those changes as successful. Adaptations reported by the farmers and the number of perceived successful adaptations (see questionnaire available at [45] for more details) were both aggregated as a total count following methods similar to [7, 55, 56].

The independent variables used in the regression model are summarised in Table 2 (Also see **Supplementary Materials – Table 3** for further details and justification of the variables). The socio-demographic and farm characteristic variables referred to similar studies relating to farmer adaptations undertaken in Thailand and South-East Asia so that the model was based on theoretical insights from past research [57] that used regression analysis. We used hierarchical regression with two blocks, such that the first block (model ‘A’) contained the socio-demographic and farm characteristic variables with more established evidence describing their role in predicting farm adaptations in similar contexts. The second block (model ‘B’) contained the variables relating to our research questions that described the characteristics of the information communicated to farmers and the SNA centrality metrics. Studies undertaken in Thailand have used ‘access to the farming

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network' as a binary variable [1] and the number of social group memberships as a continuous variable [58]. We extended these previous analyses by using the SNA metrics. We included the three centrality measures (degree, betweenness and closeness) in the second block of the hierarchical regression and referred to [59] for the inclusion of multiple centrality measures in a regression analysis. The regression models were assessed for multicollinearity using the Variance Inflation Factor (VIF, where all values were less than 10). The results of the Durbin-Watson test were within the acceptable range of between 1.5 and 2.5 (2.245 and 2.098 respectively) indicating the values of the residuals were independent.

Results

Characteristics of the sample and adaptations

Close to half of the respondents identified as female (46.0%) and 53.4% as male. The largest proportion was aged between 40 and 59 years (57.4%), followed by respondents between 60 and 80 years (35.2%), with 7.4% in the younger age group of between 20 and 39 years of age. The majority had completed a highest level of primary school (63.1%), while over a quarter (27.8%) had completed high school. Smaller proportions indicated having no schooling (4.0%) or having attended university (also 4.0%). On average, respondents reported having around 25 years of farming experience (\bar{x} = 24.98, SD = 14.36). Most respondents (58.1%) stated that their household earned between 32,000 and 180,000 Thai Baht (THB) from farming per annum, whilst 17.2% earned less than 32,000 THB. For reference, the average household income in Thailand is around 312,000 THB [60].

Rice was the most grown crops (61.4% of farms) followed by fruit (predominantly longan), long-season crops (mostly cassava), short-season crops and vegetables (see **Supplementary Materials – Figure 1**). Nearly a third of households (31.8%) kept poultry, whilst 12.5% kept larger animals such as pigs and cows. On average, farms had more than two types of production (\bar{x} = 2.31, SD = 1.08), with approximately two family members (\bar{x} = 1.97, SD = 0.95) working on farms of approximately 4.5 hectares in size, on average (\bar{x} = 27.71 rai, SD = 37.79). The majority of respondents owned at least a proportion of the land they farmed (86.9% - 60.8% owned all of the land they farmed) and most had access to off-farm income (72.7%)- outside the main rice growing season, many farmers find work outside of their own farm in either agricultural (e.g. as a day labourer) or non-agricultural (e.g. construction) activities. Most respondents reported that their farm did not have access to water resource infrastructure (68.8%) developed by the RID, which cover approximately 26% of arable land in the North of Thailand [61].

The adaptations that farmers reported undertaking during previous droughts are summarised in Figure 2 (noting that although they may have recalled undertaking such adaptations as a consequence of drought, drought may not have been the only factor contributing to their decision). Nearly all farmers (93%) had undertaken at least one of the adaptations and, on average, farmers had implemented approximate three adaptations ($\bar{x} = 3.34$, $SD = 2.08$). For the adaptation category of water supply, digging or enlarging a pond was the most frequently undertaken (21%) and was also the water supply option perceived as the most effective at reducing the impacts of drought in the future (88% of farmers undertaking the adaptation thought it was effective). Of the farm management practices, forest conservation was the most frequently undertaken adaptation (49%), of which 79% deemed it effective. The next most frequently implemented crop management adaptation was the prioritisation of drought-tolerant crops (29%) of which 65% of the farmers adopting this option considered it an effective measure. Concerning income related adaptations, 36% had taken up off-farm jobs for income diversification, however, only a minority (29%) considered that finding work off-farm could help reduce future drought impacts. A smaller proportion of respondents kept animals (including larger animals, poultry or fish, $n = 70$, 40% of the sample), thus, the 10% of the sample ($n = 17$) who sold animals represented a quarter of farmers with animals. Of those who sold animals, approximately half (53%) considered it as an effective measure.

Adaptations that were viewed as less effective included buying water, not irrigating certain crops, buying feed and culling animals. These types of adaptations could be seen more as coping strategies that did not enhance future adaptive capacity for those farmers. Comparing the mean percentages of adaptations perceived as successful, there was an evident difference between crop adaptations and animal adaptations, where only 30% of animal adaptations were perceived as successful overall, whilst over 60% of the adaptations related to water supply and farm management were viewed as successful, perhaps indicating that producers engaged in animal husbandry might need more adaptation support.

Characteristics of information received

Most farmers reported receiving information from one source ($n = 115$, 65%), with less than a quarter (22%) reporting two sources of drought information. The maximum number of sources was three (3%). The main source of information was the village headperson ($n=86$ responses), noting that eight of these individuals served as both village and sub-district headperson. In terms of administrative level, village ($n=89$) was followed by sub-district government sources ($n=43$), district government sources ($n=42$), then national government sources of information ($n=27$). Few farmers reported communications being received from provincial government sources ($n=5$), some farmers did not respond ($n=13$) and some stated they did not receive information ($n=6$).

The information received contained less than two types of content on average ($\bar{x} = 1.6$, $SD = 0.97$). The main types of information content received were warnings about a drought (90%) and weather forecast information (67%). Less content was related to what to do under drought (20%), river discharge levels (22%), irrigation availability (17%), groundwater levels (5%), or soil moisture (3%). Coinciding with the prominence of the village headperson as the main source of information, the main channel of information was village meetings (66%) followed by online chat groups (15%). Other channels of communication (e.g. television, phone, radio, letter) received few responses. The average frequency of communications was 14 times per year, which varied depending on the source and channel. Internet sources were the most frequently consulted (some almost daily), followed by District and Sub-district Offices ($\bar{x} = 16$ per year). Next, in descending order of average communication frequency was the Department of Agriculture ($\bar{x} = 12$), RID ($\bar{x} = 9$) and village headperson ($\bar{x} = 8$). Communications were received by farmers from other sources infrequently.

Farmers were asked to rate the efficacy of information they had received using six statements. The mean efficacy of each statement was 4.00 or above, equivalent to 'Agree', signifying that the farmers were, on average, satisfied with the information they received, including the timing, relevance, accuracy and comprehensibility. National sources of information were perceived as the most efficacious on average ($\bar{x} = 4.32$), whilst village announcement was the channel associated with higher perceived communication efficacy ($\bar{x} = 4.45$). However, the sample sizes for this source and channel were small and therefore the observed differences were only indicative.

The farmer advice network

The adjacency matrix was visualised and analysed in Gephi with nodes coloured by province and central government (Figure 3). The village nodes are shown around the outside of the figure, connecting inwards to municipal, district and provincial offices (agricultural or administrative), with the central government departments and ministries named by the farmers as sources of information located at the centre of the figure.

In terms of degree centrality, RID had the most ties ($n = 19$), as indicated in Figure 3 by the largest node towards the centre. Thus, RID was the single node (government department) with the most opportunity to have influence in the network (although collectively, village headpersons were the main source of information). Next in terms of degree centrality were the 'other farmer' nodes and several individual village headperson nodes. On average, Chiang Mai villages had the lowest average degree centrality and Tak villages had the highest. The centrally connected Department of Public Administration (connected into the provincial and district administrative offices) and the Department of Agriculture (connected into the provincial and district agricultural offices) had the highest betweenness scores. These were followed by the RID. Thus, these

were the main organisations with power to influence within this network. Farmers on the periphery scored zero for betweenness centrality and were not located between any two nodes. In terms of closeness centrality, again, the two government departments of Public Administration and of Agriculture had the shortest geodesic distances between all other vertices, thus indicating their power to influence and to spread information more easily in the catchment advice network. Some farmers also networked more with other farmers in their local area, thus increasing their degree and betweenness centrality but perhaps reducing their closeness within the catchment network. Many of the villages were well connected to their local administration offices and agricultural offices (sometimes via their village headperson) but not all villages were directly connected to central government sources for receiving advice.

Adaptation in response to drought advice

Many of the farmers who were informed a drought was coming (91%) and received information on what to do (65%) made changes on their farms (Figure 4). We explored interactions with the binary categorical variable that contrasted the farmers who reported changing something due to receiving information (51%) against those that reported not changing something (irrespective of receiving information or advice, 49%, see Table 1). There were significant interactions with highest level of education (more likely to make changes when highest level of education was equivalent to high school or above,) but not with other demographic characteristics of the farmers such as age, gender or income. Having changed something did not interact with variables capturing different farm characteristics, including whether the farm had access to Government irrigation zone infrastructure, whether the household owned the farm, the number of production types, and farm size. Farms with short-season field crops (e.g. corn) were significantly more likely to change something on the farm as a result of receiving advice but not farms with other crops or with animals. Geographically, the proportion of farmers making changes based on the advice they received differed significantly by village but not by Province.

Characteristics of the information received interacted with the propensity to make changes on the farm. Respondents were more likely to have reported making changes if they received information from a government source (any government level including central, provincial and district offices) and when the information was perceived as more efficacious. Another significant interaction was with the average number of different types of information received, however, the frequency and the number of channels for receiving information were not significant. Two SNA centrality metrics were significantly higher for the farmers that adapted, degree centrality and closeness centrality.

Factors predicting adaptations

The results of the regression models are summarised in Table 2 for the two dependent variables (1. total adaptations, 2. total perceived successful adaptations) and for the two-step hierarchical analyses. The R^2 values for the final models were 0.309 (total adaptations) and 0.298 (total successful adaptations). Both were significant at $p < 0.05$, indicating that the independent variables significantly predicted the dependent variable. In terms of the hierarchical analysis, for both dependent variables the second step of the analysis (that included the predictors describing the characteristics of the information and the SNA metrics) significantly increased the R^2 , thus illustrating the added predictiveness of these variables. As the significance of the model ANOVA increased in both cases, we surmised that the model became better at predicting the outcome through adding the communication variables.

The variables significantly predicting the 'total number of adaptations' were: age (model 1A), number of production types (1A and 1B), and closeness centrality (model 1B). Thus, accounting for the different results across the two steps of the hierarchical model, generally, farmers aged between 20 and 59, who were more central in the advice network and farms with more production types were more likely to undertake more adaptations. For the second dependent variable, total perceived successful adaptations, the two significant independent variables were total production types (model 2A) and information efficacy (model 2B). Centrality measures were not significant in model 2. Thus, more diverse farm production and receiving information perceived as more efficacious were predictive of the number of perceived successful adaptations.

Discussion

Relationships between an advice network and adaptation

Nearly all farmers had implemented at least one adaptation during previous droughts and, on average, had adopted three. Our results showed that the number of adaptations undertaken during past droughts by farmers was associated with having more farm production types and the farmers' age. However, limitations to our data meant more nuanced relationships between the adaptations (including the sequence of implementation) and characteristics of discrete drought events (e.g. severity, duration, timing of onset) could not be uncovered. As other evidence suggests, farmers that have diversified production [4] and younger farmers [27], can be more inclined to take on adaptive management or innovative technology. Generally, farmers who received information on what they should do in response to drought made changes on their farms and were more likely to do so if they had higher levels of education. This result fits with the extant body of evidence supporting the importance of education in facilitating adaptations (e.g. [7, 20]) but also foregrounds that most sampled farmers had no more than a primary school level of education - potentially constraining adaptive capacity. The farmers that were more central in the catchment advice network

(specifically those closer to sources of information and more able to spread information) were more likely to have made more adaptations on their farms – although not all were perceived as successful. The positive implication is the benefit to being closer to other actors in the network with the potential to access information, ideas, and resources. However, the benefits of network centrality may introduce elements of inequality if those on the periphery miss out [34, 35].

Several characteristics of communications were associated with the adaptations undertaken by our respondents during previous droughts. Communications received directly from government sources (inclusive of central, provincial and district government offices) and a higher average number of different types of information were both associated with a propensity for adaptation. Our finding on the role of government information (although also noting potential unequal effectiveness between departmental communications) is somewhat in contrast to other studies that have found local sources of information to be more influential on farmers adaptation decisions [1, 26]. Whilst advice sharing in rural Thailand may be a more local phenomenon, with many adoption decisions being influenced by local peers or the subjective norms of the farming community [1, 26], we can also highlight the influence of the inter-connected advice network, the intermediary roles of actors such as village headpeople (in cascading government policy to their local areas), and farmers' desire for clear government guidance on what to do, how, and when. Thus, on this point, we contribute to the debate on the relative roles of local versus institutional advice and support a role for both in an integrative, reflexive advice (and support) network. Generalising, our findings support recommendations for promoting higher frequency and higher quality communications from institutions to farmers, perhaps under a broader ambition of shifting towards more dialogue-based interactions [62, 63] whilst also making the most of local networks and key information brokers [26]. Further qualitative research is recommended to explore the qualities of communications in more depth, including how different qualities might help to enable or constrain adaptation to droughts with distinct characteristics and in farming communities with different characteristics (e.g. those growing different crops or with unique demographics).

For the second dependent variable in the regression analysis, 'total number of perceived successful adaptations', the efficacy of communications was the only variable significantly predicting success (in terms of helping the household farm reduce the impacts of drought in the future). Other research has discussed how many farmers tend to apply short-term, reactive measures in response to drought rather than more longer-term strategic adaptations [36] that anticipate and plan for future stresses [12]. Our results help to expose the contrast between the total number of adaptations and their perceived longer-term success, which, commensurate with [7], helps to illustrate how implementing more changes does not necessarily mean being better adapted (or more resilient). Farmers have cited the lack of information on what to do in response to drought as an obstacle to successful adaptation [18] and participation in social institutions is associated with

households making successful farming changes [16, 17]. Farmers are likely to need further support, commensurate with their level of education, so that the changes they are making can be more effective, and more effectively translate strategic advice to the farm-level [64], particularly for responding to droughts of varying severity, duration and occurring at critical times in the crop cycle. Alongside increasing the perceived quality of advice, the success of adaptations could be aided through extension support (particularly in providing technical assistance, [26, 65]), through engaging farmers in the development of local adaptation strategies [1, 23, 24], and through facilitating opportunities to exchange knowledge and learn [29, 30].

Limited connections in some villages indicated that structural holes in the advice network could be improved through bridging organisations [52]. Thomas [43] suggests local administrations in Thailand can act as coordinators with government agencies and that *tambon* (subdistrict) administrations should be a focus for improved local management. The prominence of the village headperson as the main source of information for many farmers has implications for their bridging role in the network but may also introduce potential information biases. For example, information entering the advice network via prominent local individuals or organisations can arrive in modified forms that could influence behaviour [23, 25]. By supporting network bridging organisations, and through strengthening the interconnecting ties in the advice network [66], sought after advice (developed through interdepartmental coordination) could be more effectively disseminated [25, 63] beyond institutional bottlenecks [67] to span cited administrative gaps in Thailand's water resource governance [36, 38, 39]. Through bridging actors, locally derived knowledge or experience may be transferred to other networks at different scales (e.g. translocal, national) or with other types of production [26].

Along with advancing the use of SNA metrics as a measure of access to farming networks in statistical analysis of farmer adaptations in Thailand (e.g. [1, 58]), a contribution of this study is in further highlighting methodological benefits to using SNA as a diagnostic tool to identify network weaknesses, prominent actors, and bridging organisations that can help address administrative gaps associated with implementing adaptation strategies and drought mitigation measures in Thailand [36–39] – and also elsewhere. Beyond the focus of this study, SNA diagnostics are recommended at multiple scales (e.g. local, translocal) and multiple time points to monitor changing dynamics. Where previous authors have documented a need to strengthen the connectivity of social networks for agricultural governance [27, 28], our research adds to the understanding of the network qualities in terms of transmitting efficacious advice to stimulate adaptive capacity through facilitating more successful adaptations. These observations lead to policy implications summarised in the next section and add to proposed indicators for conceptual resilience frameworks (e.g. [9]) and resilience assessment (e.g. [68]) through highlighting the importance of evaluating social network

characteristics of structure but also agency when interpreting adaptive capacity – on an ongoing, periodic basis.

Implications for policy

The findings have several policy implications centred on improving communications in the advice network (and extending to other geographic areas of the country and other types of agricultural production) to support more effective adaptive practices. Dissemination of best-practice advice could be aided through a river basin-level knowledge centre that offered a range of advice in national and ethnic languages [43]. Additionally, the development of best practice advice should draw on local knowledge and encourage experience sharing and social learning through strengthening local farmer advice networks [1, 37, 38] – previously identified ‘higher adapters’ such as those with more production types and younger farmers with higher levels of formal education would be well placed to help network and share knowledge with other farmers, with the possibility to leverage their knowledge and enthusiasm to support participation in field trials and on-farm demonstrations [1]. There are opportunities to explore multi-level administrative partnership models [43] and for capacity building of the lower level (e.g. sub-district) administrative organizations to act as the bridge between local people and governmental agencies [66]. Under the remit of the Department of Agriculture, regional agricultural extension offices may be well-placed to bridge information dissemination across administrative scales and policy areas [8]. Examples of positively perceived extension support already exist in many countries including Thailand, for example, an ‘Alternative Agriculture Network’ engages in seed sharing and organises an annual farmers’ fair [66], and local ‘soil doctors’ share their knowledge through model farms practising sustainable land management [4].

The positive perception of communications from government sources suggests there are benefits to enhancing their reach throughout the network for our case study. More generally, institutions involved in communicating drought advice should consider experimenting with the design of messages to improve their efficacy and facilitate more rapid dissemination through innovative mobile phone and internet-based communication channels that can also reach farmers in more isolated locations [25, 63]. A small proportion of farmers in our study were actively using social media for sharing advice and online and in-person forums could be promoted so that farmers have opportunities to network and deliberate in more ways [16]. We have already noted the unequal access to information in the advice network (and also potentially unequal reach and influence of departmental communications). Thus, the design of information campaigns should aim to find ways to reach the less connected farmers on the periphery of the advice network (for example, older farmers not using social media), ideally through interdepartmentally coordinated communications. Farmers may find it difficult to know what changes they should make and formalising the judgement of the success of an adaptation [11] could support the development of an evidence base documenting what works which can then

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be shared through interconnected advice networks and be used to inform the appropriate scale and timing of policy interventions. Furthermore, institutions, supported through research, could enhance monitoring and evaluation of communicative systems [28] and clarify policy guidance on adaptation [63] to improve links between proposed government management measures and the adaptations undertaken by farmers [37]. Alongside knowledge support, financial support can help farmers implement adaptations more successfully [58], thus policy should consider how financial resources can be targeted to support agricultural resilience through leveraging SNA diagnostics to help target vulnerabilities at different scales and in responses to drought with heterogeneous characteristics.

Limitations

The network represented the farmers' self-reported advice network and was limited to the respondents (a non-probability sample, which, for example, was possibly over-representative of older, wealthier farmers) and the method (e.g. farmers may not have recalled who they received information from in the past nor the characteristics of past droughts and the motivations behind their adaptive responses). There were further limitations to the SNA analysis, for example, the network was indicative and did not describe every relationship (e.g. the network did not include the perspectives of institutional representatives) nor different types of communication occurring over time (the network represented a cross-sectional 'snapshot'), or at different geographic network scales [11], and, as such, any attempts to generalise the findings are made cautiously.

Conclusions

To move towards a more resilient agricultural system requires an understanding of the processes that shape successful adaptation amidst complex institutional contexts. Social networks are an important part of collective action for supporting adaptive capacity and there are continuing calls to strengthen the connectivity of social networks for agricultural governance under the impacts of climate change. Through our case study in Thailand, we observe that farmers are making changes on their farms, however, they are less certain about the longer-term benefits of the actions they take and many changes they make might be more reasonably viewed as shorter-term coping strategies. Our analysis revealed several variables interacting with farmers propensity to adapt. These included more diversified farms, younger farmers, farmers with higher levels of education, the characteristics and qualities of the information they received, and farmers' centrality in a localised advice network.

The presence of a network infers the potential to draw together heterogeneous knowledge bases that span farmer and institutional perspectives. As a relatively no-regret policy intervention, strengthening the catchment advice network could help reduce current drought vulnerabilities while mainstreaming adaptation in the long run. We identify a capacity for local actors to bridge bottlenecks in the advice network as well as opportunities for institutions to enhance their dissemination of information to reach less networked farmers on the periphery and to interconnect with other related networks (e.g. other catchments or other types of agricultural production). We found that not all adaptations were perceived as effective against future drought and, therefore, there are opportunities to support farmers adaptive capacity through improving the qualities of advice they are given, for example, through building on existing extension provisions and leveraging local advice networks to encourage the sharing of knowledge and experience, and social learning. Thus, through understanding the qualities and dynamics of social networks, policy initiatives and interventions can be devised to support agricultural systems that can become more resilient to drought and other climate change-driven phenomena threatening rural livelihoods and agricultural economies.

Additional Information

Ethics

The study gained ethical approval through the Cranfield University Research Ethics System (CURES) CURES/9419/2019.

Data Accessibility

The dataset and questionnaire for this study can be found in the Cranfield Online Research Data (CORD) <https://doi.org/10.17862/cranfield.rd.16553136>

Authors' Contributions

DR, CS and IH acquired the funding. CS, DR, IH and GS developed the questionnaire and conceived the original scope of the article. LP, SV and CE coordinated the fieldwork and translations from English to Thai and back to English. CS and DG developed the statistical analysis. DG drafted the manuscript. All authors reviewed, edited and approved the manuscript.

Competing Interests

The authors declare that they have no competing interests.

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Table 1 Interactions with the binary categorical variable that contrasted the farmers who reported changing something due to receiving information against those that reported not changing something

Variable category	Variable	Test statistic
Farmer	Highest level of education is high school or above	$\chi^2 (1) = 7.780^{**}$
	Age	$\chi^2 (2) = 2.091$
	Gender	$\chi^2 (1) = 0.064$
	Annual income	$\chi^2 (6) = 3.091$
	Access to off-farm income	$\chi^2 (1) = 0.063$
Farm	Access to Government irrigation zone infrastructure	$\chi^2 (1) = 0.008$
	Household owns farm	$\chi^2 (1) = 0.001$
	Number of types of production	$t = -0.333$
	Size of farm (rai)	$t = -0.463$
	Number of family members working on the farm	$t = -0.963$
	Grows short-season field crops (e.g. corn)	$\chi^2 (1) = 5.004^*$
	Grows rice	$\chi^2 (1) = 1.304$
	Grows long-season field crops	$\chi^2 (1) = 0.155$
	Grows fruit	$\chi^2 (1) = 1.301$
	Farm has large animals	$\chi^2 (1) = 0.036$
	Farm has poultry	$\chi^2 (1) = 0.155$
	Village	$\chi^2 (11) = 23.765^*$
Province	$\chi^2 (3) = 5.656$	
Information	Received from Government source (any level of government)	$\chi^2 (1) = 6.629^{**}$
	Received from village headperson	$\chi^2 (1) = 0.229$
	Received from other farmers	$\chi^2 (1) = 0.748$
	Average number of different types of information received	$t = -2.001^*$
	Frequency of information	$t = -1.647$
	Number of information channels	$t = 0.678$
	Perceived efficacy of information	$t = -2.341^*$
Advice network	Degree centrality	$t = -2.636^{**}$
	Closeness centrality	$t = -2.164^*$
	Betweenness centrality	$t = -0.689$

*significant at $p = 0.05$, **significant at $p = 0.01$

Table 2 Hierarchical Linear regressions results on the predictors of (i) the total number of farm adaptations and (ii) the total number of perceived successful adaptations (n = 176)

Variable category	Variable	1. Total number of adaptations						2. Total number of perceived successful adaptations					
		Model A			Model B			Model A			Model B		
		B'	t	p	B'	t	p	B'	t	p	B'	t	p
Farmer (Block 1)	(Constant†)	0.682	0.784	0.434	-4.783	-1.864	0.065	0.637	0.945	0.347	-4.054	-2.069	0.041*
	Gender	0.024	0.281	0.779	-0.005	-0.062	0.951	0.167	1.892	0.061	0.110	1.243	0.216
	Education	0.002	0.021	0.983	-0.093	-0.949	0.345	-0.037	-0.382	0.703	-0.125	-1.27	0.207
	income (med)	0.048	0.528	0.598	0.050	0.545	0.587	-0.035	-0.374	0.709	-0.011	-0.123	0.902
	income (high)	0.074	0.666	0.507	0.044	0.399	0.690	0.186	1.637	0.104	0.165	1.496	0.137
	age (20-39)	0.234	2.314	0.022*	0.113	1.044	0.299	-0.048	-0.462	0.645	-0.118	-1.085	0.280
	age (40-59)	0.276	2.873	0.005**	0.141	1.366	0.175	0.131	1.332	0.185	0.042	0.407	0.685
Farm (Block 1)	Number of production types	0.311	3.698	0.001***	0.211	2.463	0.015*	0.215	2.498	0.014*	0.142	1.648	0.102
	Farm size	-0.022	-0.225	0.823	-0.001	-0.009	0.993	-0.097	-0.978	0.330	-0.092	-0.953	0.342
	Farming experience	0.153	1.666	0.098	-0.011	-0.112	0.911	0.097	1.034	0.303	-0.037	-0.383	0.703
	Land ownership	-0.095	-1.156	0.25	-0.035	-0.393	0.695	-0.108	-1.281	0.202	-0.021	-0.235	0.815
	Family farm workers	0.050	0.598	0.551	0.061	0.74	0.461	0.046	0.535	0.594	0.066	0.793	0.430
Information (Block 2)	Number of types of information				0.093	0.904	0.368				0.153	1.476	0.143
	Number of communication channels				0.146	1.756	0.082				0.043	0.517	0.606
	Frequency of communications				0.118	1.384	0.169				0.120	1.407	0.162
	Efficacy of communications				0.060	0.616	0.539				0.236	2.411	0.017*
	Information from Other farmers				-0.127	-0.971	0.334				-0.035	-0.267	0.790
	Information from Government				-0.301	-1.764	0.080				0.054	0.311	0.756
	Information from Village headperson				-0.165	-1.067	0.288				0.074	0.477	0.634
Advice network (Block 2)	Degree Centrality				0.306	1.811	0.073				0.014	0.084	0.933
	Betweenness Centrality				-0.040	-0.386	0.700				-0.036	-0.344	0.731
	Closeness Centrality				0.273	2.199	0.030*				0.111	0.889	0.376
R ²		0.193		0.309			0.153			0.298			
Model ANOVA		F (11) = 2.758, p = 0.003			F (21) = 2.496, p = 0.001			F (11) = 2.088, p = 0.026			F (21) = 2.365, p = 0.002		
Δ R ²					0.117						0.145		
Change ANOVA					F (10) = 1.974, p = 0.042						F (10) = 2.414, p = 0.012		

B' = standardised coefficient, *significant at p = 0.05, **significant at p = 0.01, ***significant at p = 0.001. †Coefficient is unstandardised for the Constant

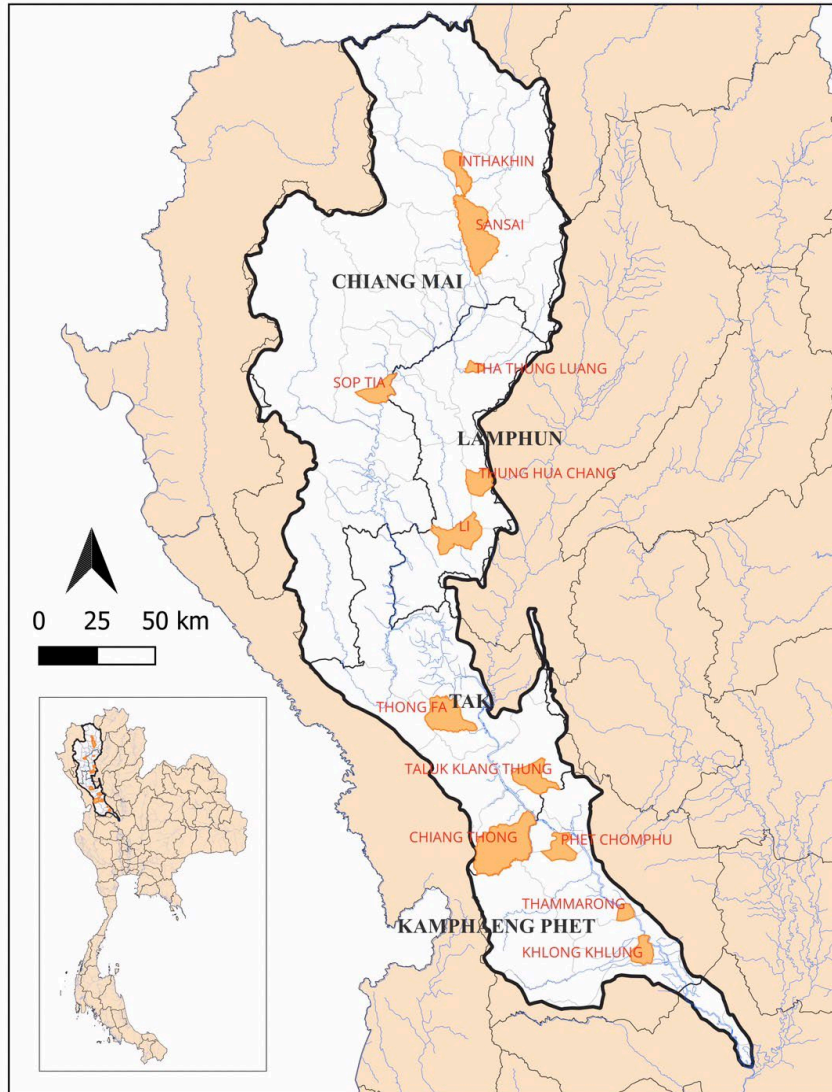


Figure 1 Location of Ping Catchment and study areas

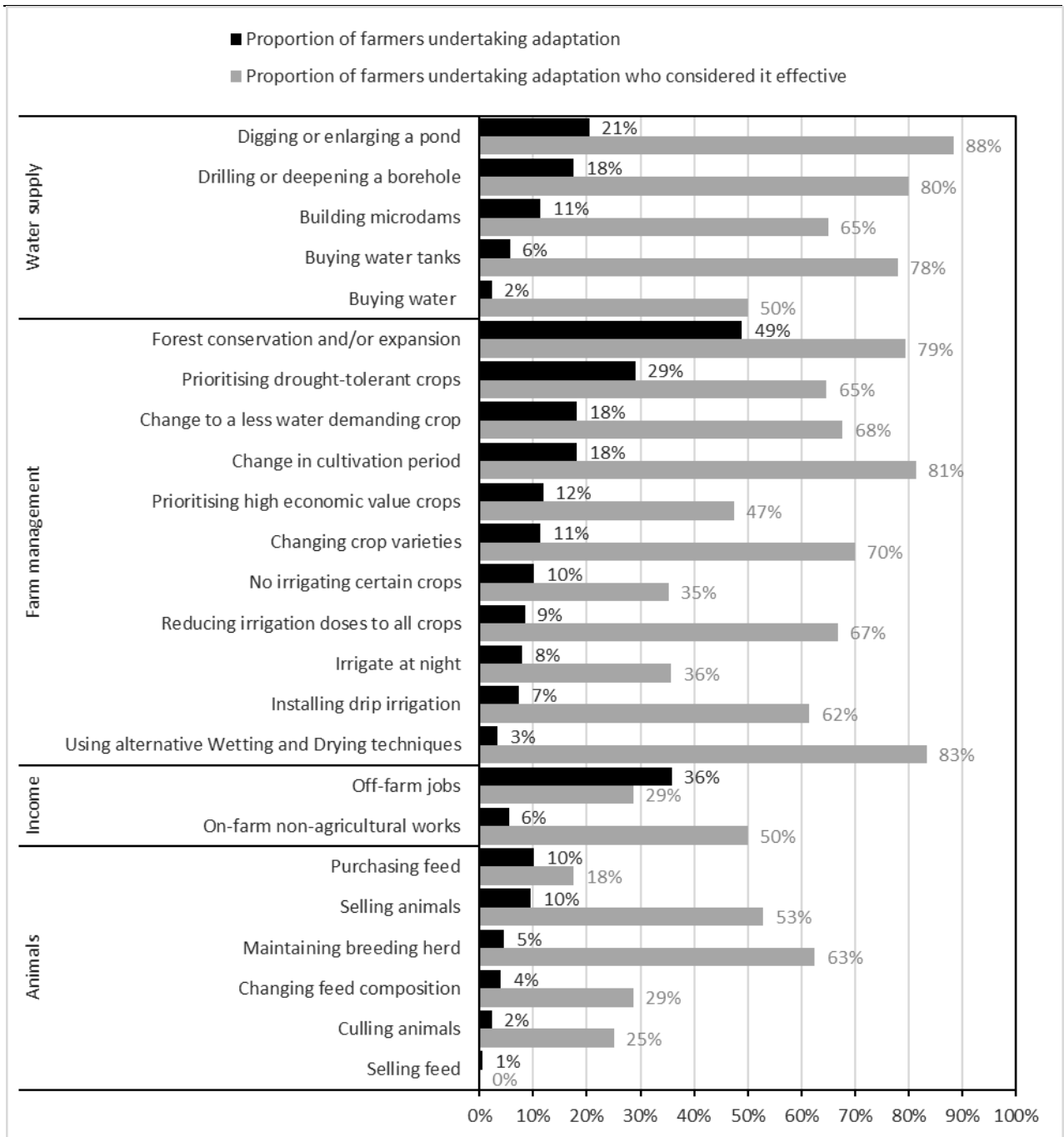


Figure 2 Adaptations undertaken by farmers during drought and the proportion of those adaptations perceived as effective against future droughts

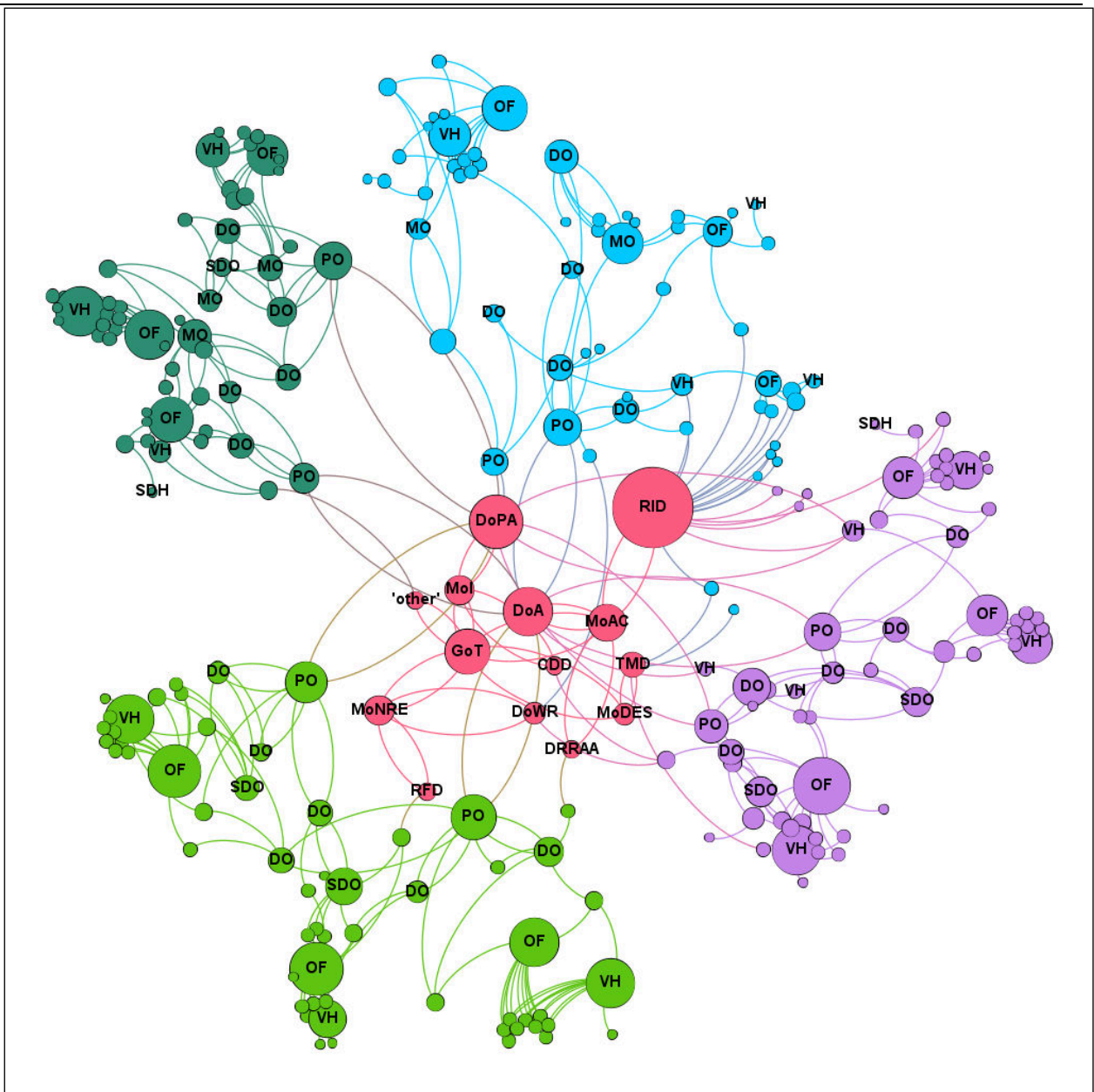


Figure 3 Catchment advice network (Gephi) with node size by Degree Centrality. Dark Green = Lamphun, Blue = Chiang Mai, Purple = Kamphaeng Phet, Green = Tak, Pink = Central Government Departments and Offices. OF = 'other farmers', VH = village headperson, SDH = Sub-district headperson, MO = municipal office, SDO = sub-district office, DO = district office, PO = provincial office. GoT = Government of Thailand. See Supplementary Table 1 for Government office and department abbreviations.

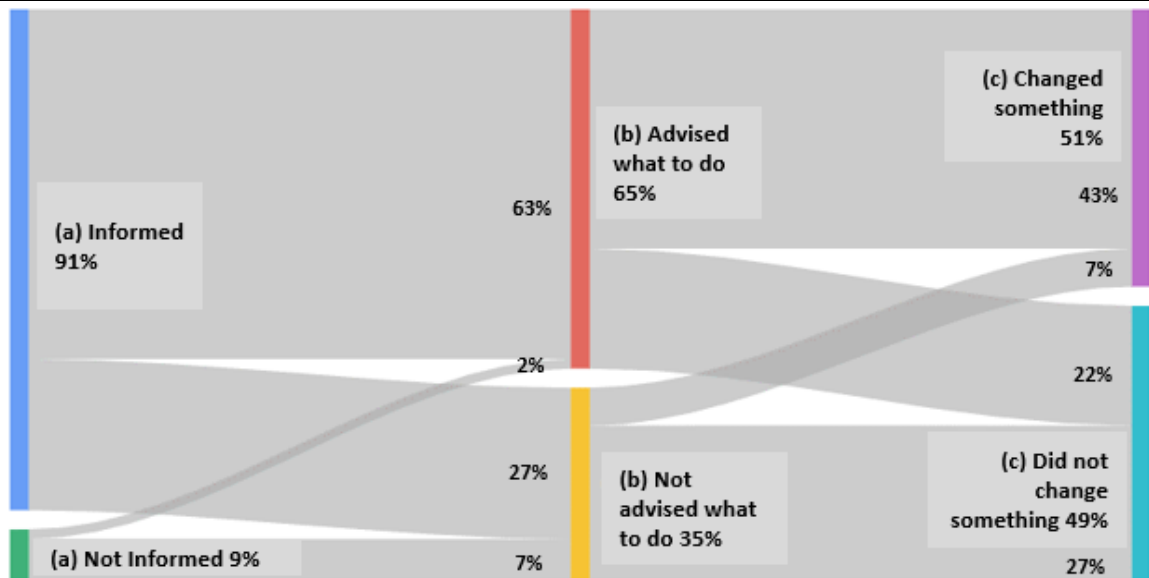


Figure 4 The proportion of farmers (a) informed of drought, (b) advised what to do, and (c) changed something as a result of the advice they received.