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Climate risk management in river-based tilapia cage culture in northern Thailand

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Abstract

Purpose – The purpose of this paper is to analyse how fish farmers manage climate-related risks and explore possible ways to strengthen risk management under current and future climate.

Design/methodology/approach – In total, 662 fish farmers in sites across Northern Thailand were interviewed about risks to the profitability of their fish farms and ways such risks were managed. Nonlinear canonical correlation analysis was used to relate risk factors to management practices at farm and river levels. In total, 68 in-depth interviews with farmers and other stakeholders provided additional information on climate risk management practices.

Findings – Farmers use a combination of adjustments to rearing practices, cropping calendars and financial and social measures to manage those risks, which they perceive as being manageable. Many risks are season, river and place specific; implying that the risk profiles of individual farms can vary substantially. Individual risks are often addressed through multiple practices and strategies; conversely, a particular management practice can have a bearing on several different risks. Farmers recognize that risks must be managed at farm and higher spatial and administrative scales. Social relations and information play critical roles in managing these complex combinations of risks.

Originality/value – This is one of the first papers to report in detail on how inland fish farmers manage climate-related risks. It underlines the need to consider multiple spatial and temporal scales and that farmers do not manage individual climate-related risks in isolation from other risks.

Keywords Water management, Risk management, Adaptation, Aquaculture, Rivers, Climate-related risks

Paper type Research paper

1. Introduction

Climate risk management refers to the inclusion of climate-related information into decisions to reduce losses or increase benefits (Travis, 2014). Relevant experience comes from early warning systems for extreme weather events, through to seasonal forecasts, and efforts to project inter-annual climate variability (Crane *et al.*, 2010; Patt, 2013).

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Individuals, it is recognized, differ in their perceptions, tolerances and attitudes towards climate risks (Menapace *et al.*, 2013; Nielsen *et al.*, 2013). They also have different levels of experience: with past extreme events and long-term observations of change in a particular place. The contexts in which experience and external information is understood and used also vary greatly (Vogel and O'Brien, 2006). Perceived risk can be modified through social relations (Kasperson *et al.*, 2003). Local capacities, resilience and knowledge about how to adapt may also differ (Lebel, 2013; Nelson *et al.*, 2007; Wood *et al.*, 2014).

Moreover, climate risks are not experienced in isolation from other risks (O'Brien and Leichenko, 2000; Smit and Wandel, 2006). The impacts of a drought, for example, are much worse if it coincides with low prices for crops in the market, lack of credit or human diseases (Mubaya *et al.*, 2012). Small-scale farmers may face additional risks from droughts because policies and markets constrain capacities for them to invest in better seeds or technologies (Wilk *et al.*, 2013). In other situations, climate-related risks may be perceived as small relative to other immediate challenges and thus acceptable or requiring no further action (Renn and Klinke, 2012). Thus, effective risk management often requires being able to evaluate multiple risks and having management practices that can deal simultaneously with risks, which should and can be managed.

Learning how to better manage risks under current climate should often be helpful for adapting to a changing climate, but may not be sufficient. Longer-term management of risks associated with climate change must also deal with the significant uncertainties, for instance, about the likelihood of events of a specific magnitude or impacts if that event would occur (Kunreuther *et al.*, 2013). One strategy is to try and build resilience to a range of plausible future perturbations, in particular, if the implied interventions build capacity and are effectively no-regret strategies (Biagini *et al.*, 2014; Troell *et al.*, 2014). Reversibility, flexibility and increasing safety margins are other examples of strategies which may be appropriate in certain situations (Hallegatte, 2009). As climate change becomes more severe however, more transformative responses may be needed (Howden *et al.*, 2007).

In commercial aquaculture, farmers must manage a complex set of risks to profitability of their production system. Salmon farmers in Norway rated the most important sources of risk as future prices, diseases and institutional changes (Bergfjord, 2009). Keeping costs low was seen as the most important risk management tool. Catfish farmers in Vietnam also perceive price and production risks as the most important, but focus their risk management strategies on production factors only (Le and Cheong, 2010). Shrimp farmers in Bangladesh perceive the largest risks being disease, price and availability of quality stock (Ahsan, 2011). In response, however, the only market-related strategy they considered was bypassing middlemen. Mussel farmers in Denmark were worried most about future prices and government regulations (Ahsan and Roth, 2010); their prioritized risk management practices focussed on reducing production costs, cooperative marketing and maintaining good relations with government, actions which correspond well to the risks actually faced.

Climate-related risks have been investigated much less than financial and market-related risks to aquaculture businesses. Flood- and drought-related risks were noted in a detailed study of risk management in catfish farms in Vietnam, but these scored very low when compared with other risks (Le and Cheong, 2010). In a separate study focussed on climate change perceptions, catfish farmers in the lower Mekong

Delta in Vietnam widely reported perceiving climate to have changed and considered it a serious threat to their livelihoods (Minh *et al.*, 2009). Similarly, shrimp farmers also perceived climate to have changed in a variety of ways, causing significant losses (Abery *et al.*, 2009). Mussel farmers in Denmark mention bad weather as an important risk because it interrupts work or makes it unsafe. Extreme weather, like flooding, droughts and storms adversely effects catfish farms in the USA, but to a lesser extent than losses caused by diseases (Hanson *et al.*, 2008). In tilapia culture in the central region of Thailand, risks of disease outbreaks and water pollution events appear to be higher for cage-based than earthen pond production systems; and these risks appear to vary seasonally, being highest in the hot periods towards the end of the dry season (Belton *et al.*, 2009).

This paper investigates in detail, the management of climate-related risks in cage-based tilapia aquaculture in northern Thailand. Fish farmers face a complex set of risks to the profitability of their production system. Floods and low flows, in some years, have particularly large impacts (Lebel *et al.*, 2015). Climate-related risks are perceived as important by farmers, and perceptions are affected by experience of past events, site and individual characteristics (Lebel *et al.*, 2013b). The purpose of this paper is to analyse how fish farmers manage climate-related risks and explore possible ways to strengthen risk management under current and future climate. It is one of the first papers to report in detail on how fish farms in rivers manage climate-related risks.

2. Materials and methods

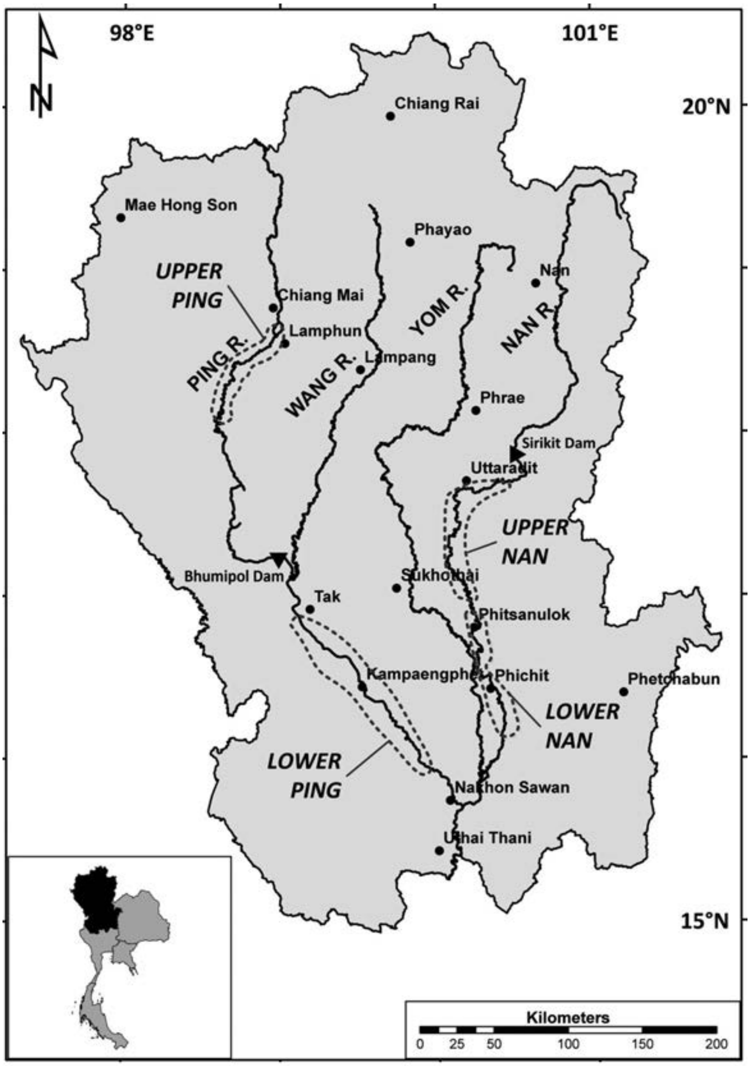
2.1 Study region

This study was carried out in the rivers of northern Thailand; where river-based cage aquaculture is common. Fish are grown in open-top mesh cages suspended on floating platforms. The cages are typically around 4 m × 4 m in areas and 2 m deep (Lebel *et al.*, 2013a). Fish that have been reared in tanks or ponds for two-three months are released into river cages at densities of around 50 fish m^{-3} to be reared for a further three-five months until they reach the market standard size of at least 500 g $fish^{-1}$. Average yields are around 27 kg m^{-3} (Lebel *et al.*, 2013a).

Sites were grouped by provinces into four growing regions (Figure 1) for analysis: upper Ping (Chiang Mai and Lamphun) and lower Ping (Kamphengphet, Tak and Nakon-sawan); upper Nan (Uttaradit) and lower Nan (Phitsanalok and Pichit). The climate of these four regions differs modestly, providing insights into the possible consequences of future climate shifts. The rivers have contrasting flow regimes as a result of dam regulation; which provides another natural experiment for understanding potential flow-related climate changes (Lebel *et al.*, 2015).

2.2 Interviews

A total of 662 fish farmers currently or recently having reared tilapia (red hybrid or black Nile) in cages in the rivers in the northern region of Thailand were interviewed between 9 October 2012 and 21 March 2013. An effort was made to interview all fish farms, drawing on department of fisheries lists, private feed seller advice, and driving along the riverbanks. Approximately half (54 per cent) the respondents were male and two-thirds (65 per cent) had completed only primary school level education. In all cases, the informant was either the owner, investor or caretaker and in most held all three roles. The structured questionnaire covered individual, farm and site level characteristics as



Source: Created by authors

Figure 1. Map of northern Thailand showing fish farming regions considered in this paper

well as more detailed sections about risks to the profitability of their fish farm enterprise and ways such risks could be managed. Questions about types of risks and their management were initially identified through in-depth interviews and then refined following pre-testing of the survey instrument.

Questions to evaluate perceived risks were asked in two related but different ways: "level of concern" and "importance of impacts". For three specific climate risks (hot weather, cold weather, heavy rainfall), we asked questions in both forms and found that it made little difference how the question was asked: rank correlations between scores on two types of questions were always higher than 0.53 and differences in means on two scales was always less than 0.25 units on 0-1 standardized five-point scale. For this reason, they were treated as equivalent in the analyses that follow. Questions about risk management practices covered activities farmers did or intended to do on their fish farm and actions at a higher level; such as at the reach or watershed scale, which are important to the risks they face and which they may sometimes be able to influence.

In-depth interviews around more open-ended questions were carried out with fish farmers (36), fish feed company staff (2), department of fisheries officials (18), officials from other departments (3), local government (4) and university academics (5). Informants were purposively selected to provide a diversity of views on the issues being investigated and thus included men and women, small and larger farms and officials working in sites with different water and fish farming conditions. The interviews were used to help cross-validate findings from the quantitative survey as well as identify less common practices and improve understanding of the reasoning of stakeholders around risk management issues. All interviews were taped, fully transcribed and coded in NVIVO software prior to analysis. The analysis in this paper focuses on statements related to the management of risks. Two facilitated group discussions with approximately 20 farmers each group, were held at a local meeting venue near fish farms in Chiang Mai province in August and October 2014. The discussions focussed on climate-related risks to profits, their management and possible alternative responses given a variable and changing climate. The meetings helped validate and extend insights from the earlier interviews. Discussions were taped, summarize and partially transcribed.

2.3 Data analysis

Average scores for levels of concern for different risk factors were compared among farm sizes and regions using ANOVA, followed by Tukey's HSD. All statements about differences among places or farm size made in the results section were significant at $p < 0.05$; details from ANOVA statistics, however, are only shown in a few instances so as not to disrupt readability. Farm sizes were classified by number of cages into four groups: small ($<= 6$, $n = 187$), medium (7-16, $n = 274$), large (17-40, $n = 154$) and very large (41+, $n = 47$). Small and medium farms could be operated part time by an individual, or more frequently, a couple; whereas larger sizes imply full-time employment or the need for regular external hires. Regions were defined as explained above in Section 2.1.

To assess associations between sets of risks and management practices, a canonical correlation analysis approach was chosen for two reasons. First, because it fitted the problem structure of understanding associations between four sets of variables:

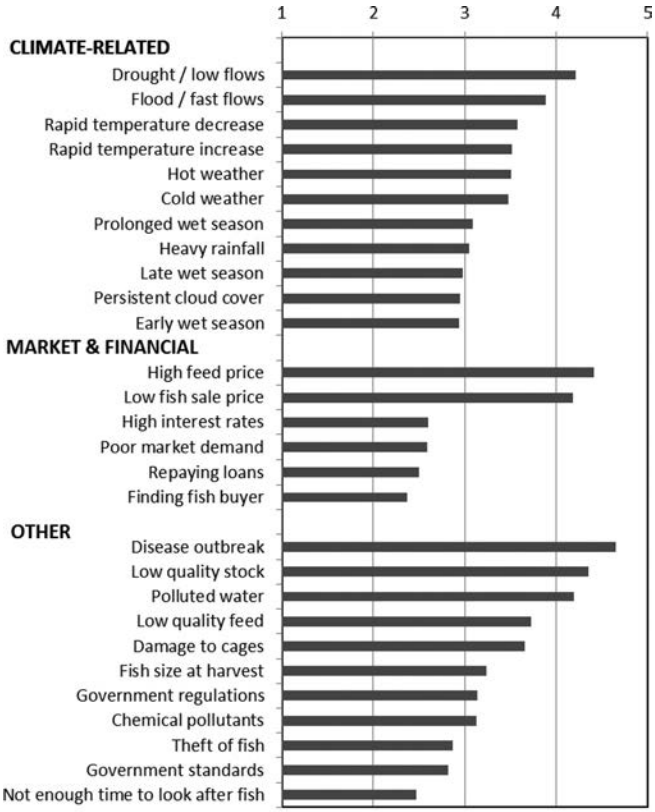
1. climate-related risks;
2. non-climate related risks;
3. farm level risk management practices; and
4. river and watershed level management practices.

Second, because it provided a systematic way to explore complex relations among many variables by reducing that complexity through identification of derived or latent factors. Non-linear canonical correlation analysis was chosen over conventional canonical correlation analysis because all variables were measured on five-point ordinal Likert scales; and because assumptions of interval scale or multivariate normality were unlikely to be upheld. The main product of the analysis is to identify a set of canonical functions that maximizes the correlation between the four sets of variable. The analysis was carried out using the OVERALS procedure in the statistical software SPSS (Meulman and Heiser, 2011).

3. Results

3.1 Sources of risk

Farmers identified disease outbreaks as the overall most worrisome risk to profitability (Figure 2). In discussions with farmers, it should be noted that disease problems were often explained as being triggered by changes in weather, seasons or extreme climate events; which stressed fish, making them more susceptible to diseases. Reductions or abrupt changes in water quality, for instance, associated with polluted run-off following first or heavy rains were also seen as important parts of causal chain to disease outbreaks. Prices of feed and fish as well as quality of stock and feed were other risks of



Note: Average scores of 662 fish farmers on a scale of 1 (unconcerned) to 5 (very concerned)

Figure 2. Level of concern about different types of risks to farm profitability

high concern. Farmers were relatively unconcerned about financial risks such as interest rates or repaying loans and market risks like demand or finding buyers. Among climate-related risks droughts or low flows were ranked highest followed by floods or fast flows.

Level of several risks varied significantly with farm size as follows. Very large farms were less concerned than small- or medium-sized firms about fish size at harvest, government standards or finding buyers, but more concerned about droughts or low flows.

Levels of risks also varied among regions. There were three main patterns. First, farmers in the upper Ping region were more concerned than those in other regions about polluted water, cold weather, persistent cloud cover, late wet season and low fish prices. Second, farmers in the lower regions were less concerned than those in the upper regions about floods/fast flows, repaying loans, interest rates, theft of fish and government regulation. Third, farmers in lower Ping were less concerned than those in other regions about drought.

3.2 Farm-level management of climate-related risks

Farmers gave high importance to a mixture of technical, business and social risk management practices (Figure 3). High-scoring technical practices included choice of stock, quality of feed and cage site selection. Important business practices included keeping money in reserve, and reducing expenses. Three of the top six practices were related to maintaining good social relations: with neighbours, fisheries staff or local government officials. Many other practices also were thought of as being of intermediate importance. Collaboration with other farmers to borrow money, purchase inputs, or sell harvest was among the lowest ranks; underlining the individual enterprise basis of this industry.

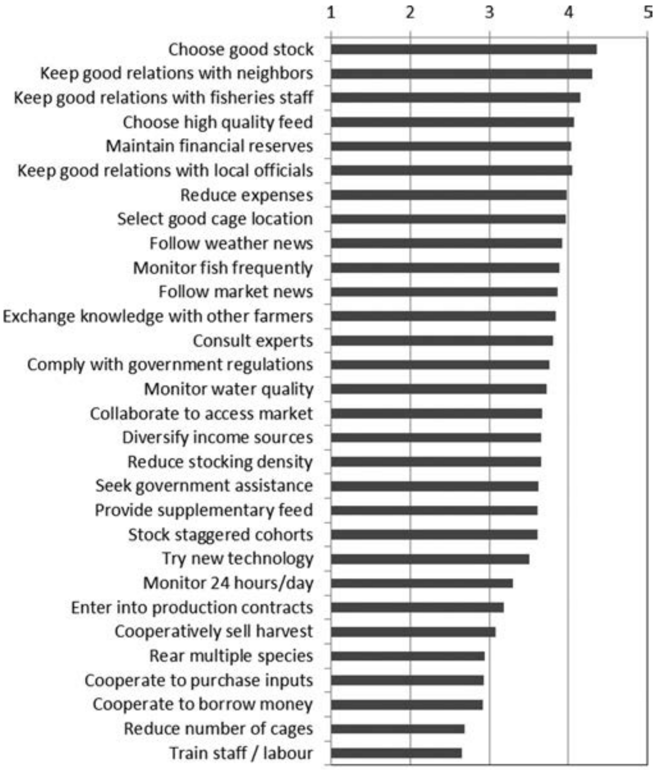
Importance given to different risk management practices in a few instances varied significantly with farm size as follows. Very large farms gave greater importance than smaller farms to maintaining good relations with fisheries department officials and less to diversifying income sources or making harvest sale contracts.

There were also a few regional differences detected. For example, farmers in the upper Ping gave more importance than those in lower Ping region to reducing stocking densities, staggering stocking cohorts, being in contracts, reducing number of cages and monitoring water quality and cages. On the other hand, they gave less importance to maintaining good relations with fisheries or local officials. Farmers in the upper Nan region gave greater importance to rearing multiple species than those in the other regions.

Active management or "taking care" of fish was emphasized by many farmers as key to dealing with change and uncertainty:

> Farmers need to have their own management system because everything seems to change. Nothing is the same. Sooner or later, the flood waters come; this year a lot or less rainfall. Either way you have to take good care.
>
> Moreover, if we take good care – I mean really good care to look after and protect them that will help a lot". And: "It is all about taking care – there is being industrious and being lazy".

A few farmers have tried switching species as a way to manage climate-related risks. Most shifted to catfish species, which can tolerate low dissolved oxygen levels and are



Note: Average scores of 662 fish farmers on a scale of 1 (unimportant) to 5 (very important)

Figure 3. Level of importance given to different farm level risk management practices

less susceptible to scale damage in higher flows. The channel catfish is popular but has the constraint that it takes 18-24 months to rear; and as production increased, prices have fallen.

Initial choice of site for cages is an important element of risk management (Figure 3). Farmers look for a site where there is good circulation, but the current is not too strong. Farmers note that river bends are favourable as they allow moving cages out of strong currents during flood periods: "strong or fast flows, if we choose a good site, then a lot of risks can be reduced". River depth should be sufficient that water may flow freely under bottom of cages – ideally at least 2.5-3 m. Position relative to dams and weirs are thus important considerations. In practice, farmers may have relatively few options near where they live:

> […] if a site is good, there are few problems. But our chances to select a good site are limited. Water around here is stagnant. We have no choice because available sites are limited.

A few farmers moved to sites at new locations after experiencing difficulties.

Timing of crops is an important decision. Risk-averse farmers in the upper and lower Ping, for instance, avoid having fish in the river during August-September when flows are strongest, and around April when flows are lowest (Lebel *et al.*, 2015). River and site differences however, are substantial: thus, in some places, concerns are higher for floods than low flows and in others the opposite. In interviews, farmers and fisheries officials explained that some farmers are willing to grow fish at the time when risks from weather and climate are relatively high because these are also the times when market supplies compared to demand are low and prices for fish are high. Others, however, emphasize the lack of alternatives.

Our survey provided some specific evidence about climate risk management practices that were specifically undertaken in the last year to reduce risks from floods and low flows. A substantial fraction of farmers had in the past year changed stocking dates (41 per cent), moved cage sites away from high velocity areas (41 per cent) or temporarily stopped rearing (30 per cent), as a way to reduce risks from floods or high flows. Other much rarer practices reported included making baffles to reduce flow velocities, reducing number of cages, and lowering stocking densities. In preparation for the dry season, many farmers changed stocking dates (37 per cent), prepared aerators (51 per cent) and water pumps (56 per cent), moved cages into deeper water (79 per cent) or temporarily stopped rearing (22 per cent), as a way to reduce risks from drought or low flows.

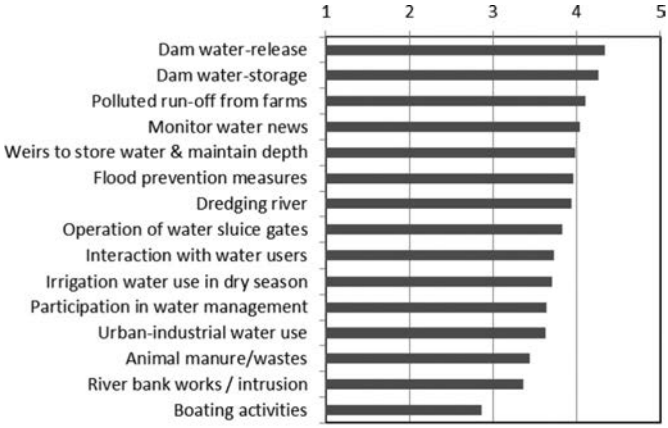
Many risks are beyond farmers' control, so they focus on those which they can do something about. "Rearing fish in cages in the rivers involves many risks. We cannot control many of them, just a few". Farmers know from experience, for example, that "during the cold season they should adapt by reducing stocking densities". In addition, when "rivers flood or are turbid, stocking density is reduced". Under conditions of low flows and dissolved oxygen concentrations, reducing densities is also recognized as a useful management strategy. Adjusting rearing densities was one of the most common specific practices mentioned by farmers to deal with climate-related risks in in-depth interviews.

3.3 River basin management

At the river reach and basin level, farmers identified the storage and release of water from dams as the most important risk management practice (Figure 4). These were more important in the upper and lower Nan than in the upper Ping region. Operation of weirs and sluice gate, on the other hand, were more important in the upper Ping than other regions. Very large farms gave greater importance to dam water release and storage than small farms. Average levels of importance given to river basin level risks (Figure 4) were comparable to those for individual farms (Figure 3).

Interactions among water users, irrigation water use, urban-industrial water use and participation in water management were all considered more important in the upper Ping than in the lower Ping. Management of run-off from farms, orchards and livestock rearing was also emphasized more in the upper Ping than in other regions. Piggeries were identified as a particularly important source of pollution by farmers and experts in in-depth interviews. Concerns with boating were relatively low everywhere (Figure 4).

Farmers recognize that many risks influencing their farms profitability lay beyond their direct control, in the sense of actions they can take to protect their own set of cages. In lieu of such challenges, farmers give substantial weight to both watershed and river management as ways to manage risks to fish farms. The operations of dams, weirs and sluice gates all have significant implications for fish farms. For the most part the



Note: Average scores of 662 fish farmers on a scale of 1 (unimportant) to 5 (very important)

Figure 4. Level of importance given to different river reach or basin-level risk management practices

Irrigation Department, however, does not see fish cage culture as either part of the river ecosystem or an agricultural activity.

In the past, farmers in Uttaradit along the Nan River could send formal requests to Sirikit Dam operators to request water releases when water levels were low. Irrigation Department officials considered such requests on a case-by-case basis. Following the 2011 floods in Bangkok and surrounding regions, a new Water and Flood Management Committee was created and that centralized body has taken over more of the operating decisions. Now when farmers request releases directly from the dam, the local officials cannot make a decision themselves but must ask for permission from the national-level committee. The process is very long. Farmers in Uttaradit province have protested against the new procedures at district office, requesting releases from Sirikit Dam – the tactic worked and water was released to restore levels to about 3 m.

Small, local check dams or weirs are under community or local irrigation office control. These are particularly important in the upper Ping sites studied, as they help maintain depths during periods of low flows where fish are grown. Exchange of information within communities about water management is important to risk management, for instance, about the schedule for opening and closing water gates. The high level of importance given to maintaining good relations (Figure 3) while important for individual farm-oriented practices is also useful to addressing reach and watershed level management issues.

River channels are dredged for different purposes. The Department of Navigation and Harbours has projects to dredge the channel to reduce flood risks as well as maintain navigability during low flows. Riverbanks are also modified. While this work is underway, there may be increased risks from high water turbidity; but at other periods, the interventions may be beneficial. Dredging is sometimes also done by farmers or local governments to increase channel depth for fish farms during periods of critical low flows. This type of management practice requires collaboration among farmers working in the same area.

3.4 Early warning, event preparation and compensation

Farmers were slightly more likely to receive flood early warnings in the upper Ping (78 per cent) and lower Nan (79 per cent) than in the lower Ping (57 per cent) and upper Nan (68 per cent) regions. Farmers received warning information from multiple sources, the most common being: TV (88 per cent), community broadcasts (85 per cent), radio (72 per cent), other farmers (71 per cent) and fisheries officials (62 per cent). Two-thirds of farmers indicated they had high trust in the warnings and only 4 per cent had little or no trust. Early warning triggered additional preparations. Farmers moved cages towards banks (91 per cent) and into slower flowing areas (83 per cent) and tied up cages more firmly (96 per cent). Virtually all increased their monitoring activities (97 per cent). Over a third (35 per cent) harvested fish earlier than they initially had planned. In 7 per cent of cases, farmers moved fish from cages to a pond. About a third of fish cage farmers in upper Nan (31 per cent), lower Nan (29 per cent) and lower Ping (33 per cent) regions also had fish ponds; ponds were used both for nursing prior to stocking and for rearing fish to maturity. Fish ponds were less common in the upper Ping (15 per cent).

Seeking compensation was one of the few post-event strategies this study (with its focus on ex-ante risk reduction) explored. Farmers in the upper Ping (20 per cent) were less likely to have received assistance after floods than those in the upper Nan (70 per cent), lower Ping (62 per cent) and lower Nan (40 per cent) regions. Assistance was usually in the form of cash (88 per cent) and more rarely as fish stock (22 per cent) or feed (12 per cent). Farmers estimated the average value of this assistance at 19,450 Baht; representing a quarter to one-third of the average value of reported losses (Lebel *et al.*, 2015). The most common source of assistance was the Department of Fisheries (DOF) (85 per cent), followed by local government or sub-district administrative organizations (19 per cent). According to regulation of the DOF, only farmers who have registered their fish farms with the DOF and did not stock their fish during the flood and drought warning period can get assistance. Officials from the DOF issue warnings: that farmers should not rear fish in lowflow risk period in the dry season (March-April) as well as flood risk period in the wet season (August-September). It was not entirely clear if this "no eligibility" periods were strictly enforced or varied according to differences in local flow regimes. Financial assistance, according to interviews with a DOF official, was provided at a rate of around 270 baht per square metre.

3.5 Risks and management practices

Associations between four sets of variables describing different climate-related risks ($n = 11$), non-climate risks ($n = 17$), farm-level risk management ($n = 32$), and reach or basin level risk management practices ($n = 15$) were studied using nonlinear canonical correlations analysis (Table I). A model with six dimensions was chosen after also considering models with four or five which proved much more difficult to interpret because of unusual variable combinations. Eigenvalues for each dimension were: 0.68, 0.60, 0.52, 0.48, 0.47 and 0.44. The overall fit, estimated from the sum of six eigenvalues was 2.8/6 or 47 per cent which is reasonable given the type of data involved; but also underlines that a lot of variation remains unexplained.

The results of the analysis are summarized by identifying the most significant correlations (or loadings) between original variables and the canonical functions and then offering interpretations for these combinations of co-varying variables or the

Set	Dimension 1	2	3	4	5	6
Climate-related risks						
Flood/fast flows	**0.40**	−0.22	*−0.11*	0.**28**	*0.15*	*−0.15*
Drought/low flows	**0.46**	*0.12*	0.23	*0.03*	**0.39**	**−0.28**
Hot weather	**0.37**	*−0.01*	**0.29**	0.23	*−0.14*	*−0.01*
Cold weather	**0.36**	**0.30**	*−0.06*	*0.02*	*−0.14*	*0.01*
Heavy rainfall	**0.42**	**−0.38**	*−0.18*	*0.02*	*−0.16*	*−0.09*
Cloud cover	**0.38**	*0.07*	**0.25**	*0.15*	−0.20	*0.05*
Rapid temperature decrease	**0.51**	*0.08*	*−0.18*	*−0.01*	*0.15*	**0.42**
Rapid temperature increase	**0.31**	**0.38**	*−0.10*	*0.07*	*−0.14*	*−0.02*
Early wet season	**0.46**	−0.20	**−0.29**	*−0.05*	**−0.25**	*0.12*
Late wet season	**0.39**	**0.40**	*−0.07*	*−0.19*	*−0.13*	*−0.01*
Prolonged wet season	**0.48**	−0.24	*0.00*	*−0.12*	*−0.15*	*−0.03*
Non-climate-related risks						
Low-quality stock	**0.32**	*−0.06*	*−0.18*	0.**27**	0.23	*−0.15*
Low-quality feed	0.26	0.23	*−0.10*	*0.15*	*−0.02*	*−0.08*
Disease outbreak	0.26	*−0.07*	*−0.01*	*0.16*	**0.26**	*−0.12*
Not enough time to look after fish	0.26	*−0.17*	*−0.04*	*−0.18*	*−0.19*	**−0.33**
Theft of fish	**0.42**	*−0.11*	*0.06*	*−0.14*	*−0.01*	*−0.06*
High feed price	0.22	*−0.10*	*0.10*	0.20	*0.00*	*−0.04*
Chemical use	0.29	*−0.07*	**0.29**	*0.19*	**−0.32**	*0.00*
Cages damaged	**0.39**	*−0.19*	0.22	*−0.11*	*−0.13*	*0.06*
Low fish price	0.28	*−0.03*	*−0.14*	0.20	*−0.06*	*0.19*
Small size at harvest	0.28	*−0.11*	*−0.04*	*0.15*	**−0.34**	*−0.14*
Finding fish buyer	**0.37**	**−0.29**	−0.22	*−0.01*	*−0.17*	*−0.17*
Low market demand	**0.48**	*0.04*	*−0.08*	−0.23	*−0.20*	*−0.07*
Wastewater	**0.39**	*0.03*	**0.51**	*0.09*	*0.09*	*−0.15*
High interest rates	**0.43**	*−0.08*	*0.12*	*−0.14*	*−0.02*	*−0.19*
Repaying loans	**0.41**	*0.16*	*0.14*	*0.10*	−0.24	*−0.16*
Government standards on practices	**0.47**	**−0.34**	*−0.02*	*−0.06*	*−0.16*	*0.19*
Government regulations on river use	**0.50**	**0.33**	*−0.02*	*−0.18*	*−0.08*	*0.08*
Farm-level risk management practices						
Choose good stock	*0.12*	**0.39**	*−0.17*	**0.27**	*−0.02*	*−0.12*
Reduce stocking density	0.26	*0.17*	*0.04*	**0.28**	*−0.14*	*−0.09*
Choose high-quality feed	**0.37**	0.21	*−0.18*	*0.10*	*−0.01*	*0.01*
Monitoring fish frequently	*0.13*	*−0.13*	*−0.20*	*0.15*	*−0.09*	*−0.08*
Monitor water quality	**0.37**	*−0.02*	**0.29**	*0.18*	*0.02*	*0.03*
Reduce number of cages	**0.33**	**−0.27**	*−0.07*	*0.06*	*−0.13*	*−0.05*
Select good cage location	**0.32**	*−0.16*	*−0.04*	*0.06*	*0.18*	*−0.00*
Train staff/labour	*0.11*	**0.30**	−0.22	*0.20*	*0.06*	*−0.01*
Monitoring 24 hours per day	**0.30**	*−0.12*	*−0.06*	*0.18*	*−0.09*	*−0.17*
Provide supplementary feed	*0.17*	*0.12*	0.24	*0.03*	−0.24	*0.02*
Consult experts	**0.36**	*0.02*	*−0.11*	*0.18*	*0.14*	*−0.10*
Reduce expenses	**0.46**	*−0.08*	*0.03*	*0.10*	**0.33**	*0.16*
Maintain financial reserves	0.28	−0.22	*−0.11*	*0.06*	0.24	*0.18*
Follow market news	**0.36**	−0.20	**−0.26**	*0.03*	*0.04*	*0.07*

(*continued*)

Table I. Summary of nonlinear canonical correlation analysis between risks and risk management practices

Table I.

Set	Dimension 1	2	3	4	5	6
Follow weather news	0.24	*−0.08*	*−0.13*	*0.13*	*0.09*	**0.31**
Diversify income sources	**0.38**	*−0.14*	0.25	*0.05*	*−0.07*	*0.14*
Seek government assistance	**0.33**	−0.24	*−0.20*	*0.02*	*−0.08*	*0.07*
Keep good relations with neighbours	**0.32**	**0.31**	−0.20	*0.12*	*0.10*	*0.12*
Collaborate to access market	**0.39**	−0.20	*−0.05*	**−0.27**	*−0.09*	*−0.08*
Collaborate to borrow money	**0.46**	*0.05*	*−0.08*	*−0.19*	*−0.17*	*−0.18*
Comply with government regulations	**0.41**	**0.29**	*−0.11*	**−0.28**	*−0.01*	*0.09*
Cooperate to purchase inputs	**0.36**	*−0.18*	*−0.16*	*−0.12*	*0.05*	*0.00*
Cooperatively sell harvest	**0.41**	*0.04*	*−0.07*	*−0.11*	*0.06*	*−0.05*
Exchange knowledge with other farmers	0.24	*0.04*	*0.05*	**0.28**	*−0.06*	**0.31**
Keep good relations with local officials	0.27	**0.39**	**−0.28**	*0.13*	*−0.17*	*0.08*
Keep good relations with fisheries staff	0.28	**0.26**	**−0.28**	*0.07*	*0.01*	*−0.03*
Try new technology	**0.32**	**0.30**	−0.20	0.20	*−0.11*	*−0.06*
Reduce investment costs	**0.41**	0.21	*0.01*	**.25**	*0.12*	*0.08*
Work aside from fish farming	**0.40**	*0.15*	*0.14*	*−0.11*	*−0.02*	*0.13*
Enter into production contracts	**0.42**	*−0.03*	0.22	*−0.04*	*−0.07*	0.22
Stock staggered cohorts	0.24	**0.32**	*−0.14*	*−0.17*	*−0.13*	*0.11*
Rear multiple species	**0.33**	**0.26**	*−0.07*	−0.25	*0.01*	*−0.14*
Reach and river basin risk management practices						
Dam water release	0.28	*−0.01*	*−0.16*	*0.19*	*0.18*	**−0.32**
Dam water storage	0.27	**0.34**	−0.23	*0.12*	*0.11*	**−0.32**
Weirs to store water and maintain depth	**0.32**	**0.37**	*0.05*	**.26**	*−0.14*	*−0.07*
Irrigation water use in dry season	**0.40**	−0.21	*0.04*	−0.22	*−0.06*	*0.07*
Urban and industrial water use	**0.32**	**0.47**	*0.03*	*−0.16*	*−0.03*	*−0.04*
Flood prevention measures	**0.54**	*0.03*	**−0.26**	**0.27**	*−0.08*	*0.01*
Dredging river	**0.45**	*0.06*	*0.08*	*0.14*	**0.32**	*0.01*
River bank works	**0.48**	**0.35**	*−0.17*	*−0.15*	*−0.11*	*0.06*
Boating activities	0.29	*−0.04*	*0.20*	*0.03*	*−0.19*	*−0.03*
Control polluted run-off from farms	**0.47**	*−0.02*	**0.39**	*−0.14*	*0.08*	*−0.20*
Animal manure/wastes	**0.49**	−0.28	*0.11*	−0.21	*−0.08*	*−0.06*
Operation of water sluice gates	**0.44**	**0.31**	**0.27**	*0.04*	*−0.04*	*0.10*
Participate in water management	**0.51**	−0.22	*0.04*	0.21	*0.10*	*0.19*
Interact with water user groups	**0.51**	*−0.11*	**0.31**	*0.02*	*0.14*	0.21
Follow water news	**0.52**	*0.10*	*−0.12*	*−0.09*	*0.20*	*0.13*

Notes: Values are the loadings or correlations between original variables in the four variable sets and the six canonical functions (C1-C6); loadings > 0.3 on first dimension and > 0.25 on all other dimensions are shown in bold. The four sets of variables analyzed are headed by a descriptive label in italics

canonical functions. Six latent dimensions in the dataset were identified based on interpretations of the canonical functions, namely:

(1) overall concern with risks;

(2) final stages of winter;

(3) beginning of the wet season;

(4) floods or high flows;

(5) drought or low flows; and

(6) start of winter.

These interpretations will now be explained in more detail function-by-function.

Canonical Function 1 describes overall concern with risks and attention given to risk management practices: all variables show correlations in the same direction (Table I). All of the climate-related risk loadings were high; many of the non-climate-related risks and management practices were also high. The implication is that some fish farmers worry more about risks and take steps to deal with those risks, whereas others are less concerned and therefore do less to manage risks. This could reflect differences in actual risks among sites as well as differences in individual attitudes towards risk.

The second canonical function describes risks associated with the final stages of winter: climate conditions with cold weather, rapid temperature increases and no heavy rainfall or late start to wet season. Stocking management practices were associated with these climate risks, including choosing good stock, stocking staggered cohorts and rearing multiple species. Farmers also tended to try new technology. Management of risks at the basin level included dam water storage, weirs to store water, water gate operations, urban-industrial water use and river bank works. A non-climate risk was government regulations on river user. In response, farmers comply with regulations and maintain good relations with neighbours, local officials and fisheries staff. They also train staff. Risks from government practice standards and finding a fish buyer were associated with reducing number of cages.

The third canonical function describes a specific set of conditions which can arise at the beginning of the wet season when flows are low but temperatures are high and when wet season is not early. Under the former conditions, there are risks of poor water quality from wastewater and chemical use. This is an example of interacting climatic and non-climatic risks. The favoured responses to these risks are to monitor water quality, control polluted run-off from farms, adjust operations of sluice gates and interact with water user groups. In contrast, low values on this function were associated with an early wet season risk, following market news, keeping good relations and flood prevention measures.

The fourth canonical function corresponds to flood or high-flow conditions. This was associated with non-climatic risk of low-quality stock. The associated risk management practices included:

- choose good stock;
- reduce stocking density;
- exchange knowledge with other farmers;
- reduce investment costs;
- manage weirs to maintain depth; and
- flood prevention measures.

The fifth canonical function relates to periods with drought or low-flow conditions, especially when the wet season is not early. Disease outbreaks were associated with risks of low flows, while risks from chemical use and small size at harvest coincided with an early wet season. The risk management practices were to reduce expenses and dredge the river.

The sixth canonical function captures the start of winter when temperatures decrease, but low-flow conditions do not yet occur. It is a period when many farmers are worried they will not have enough time to look after fish, as it is key period for other agricultural activities such as harvest of the main rice crop. Risks associated with temperature drops are managed by following weather news and exchanging knowledge with other farmers. The low-flow conditions are best managed through dam water storage and release.

One clear higher-level pattern was that the last five functions were associated with peak climate and flow-related risks at different times of the year:

(1) final stages of winter (February-March);
(2) beginning of wet season (April-May);
(3) flood or high flows or main wet (June-October);
(4) start of winter (November); and
(5) drought or low flows (December-February).

These findings from the canonical correlation analysis are consistent with information from in-depth interviews, group discussions and field observations.

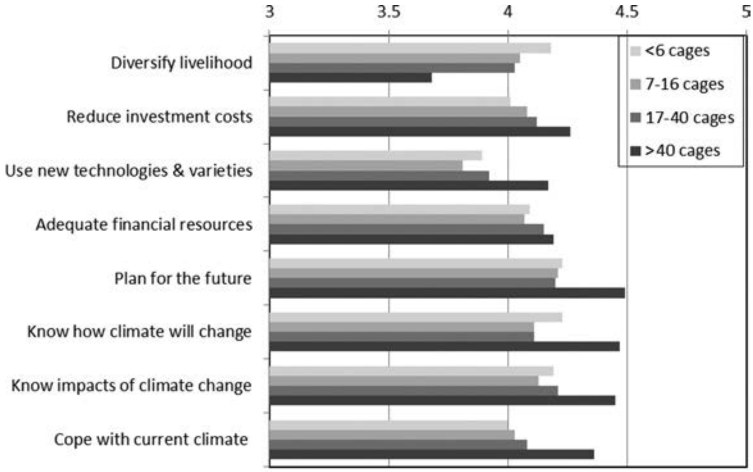
The analysis of loadings also identified several other important patterns. First, climate-related risks are inter-related and sometimes associated with non-climatic risks. Second, some risk management practices are associated with several climate-related risks, for example choosing good stock and maintaining good relations. Third, most climate-related risks are associated with multiple risk management practices. Fourth, risk management practices at farm and basin level are often combined.

3.6 Risk management and adaptation

Many farmers perceive that climate and seasons have changed and have become more uncertain (Lebel *et al.*, 2013b). In discussing existing and potential future responses, farmers view adjusting culture periods, technologies such as aerators and flow baffles and new water infrastructure as important ways to build resilience and adapt. Climate change, like normal variability, represent risks, they argue, that must be addressed, as they are important and cannot be avoided: “In the future the world will become hotter. Hence, fish farmers will have to adapt to the changed environment”.

Fish farmers were asked in the quantitative survey whether they agreed with various ways to adapt to a changing climate. Farmers showed relatively uniformly high levels of agreement with a set of eight statements about adapting fish farming to climate change (Figure 5). There were no differences among regions. Very large farms agreed more strongly than smaller farms on need to plan for the future, know future climate, know impacts of climate change and cope with current climate. They tended to be less likely to agree on the need to diversify livelihoods, whereas small farms emphasized this strategy more.

To explore the association between climate risk management practices and adaptation attitudes, three aggregate variables with average score were created for farm-level practices ($n = 32$ variables, Figure 3), river-level practices ($n = 15$, Figure 4) and adaptation attitudes ($n = 8$, Figure 5). Adaptation attitude scores were then regressed against the farm- and river-level risk management practice variables with a few other selected predictors. Region was included in the model as a possible



Note: Average scores of 662 fish farmers on a scale of 1 (disagree completely) to 5 (fully agree)

Figure 5. Level of agreement with various statements about adapting fish farming to climate change of different sized farms.

confounding variable given risks vary geographically; farm size was considered, but dropped because it was not significant. Measures of knowledge of impacts and causes were also included because they are important to how climate change-related risks are perceived (Lebel *et al.*, 2013b). All variables were significant in the final model. A high attention to farm- and river-level risk management practices was strongly positively associated with agreeing on multiple adaptation strategies (ANOVA; df = 6, 599; $F = 44.8, p < 0.001$).

4. Discussion

At the individual farm level, farmers gave high importance to a mixture of technical, business and social risk management practices. Climate- and weather-related risks are managed alongside other risks. An important finding of this study was that individual risks are addressed by multiple practices and particular practices contribute to management of multiple risks. Supporting evidence come from the patterns of association revealed in non-linear multivariate canonical correlation. Qualitative data provided some additional support when farmers explained how they managed multiple risks at the same time. Good technical practices like using good quality stock and frequent monitoring are understood by farmers as making their farms more resilient to a wide range of perturbations, including climate-related ones. This study also found that building and maintaining social relations were an important part of managing risks; suggesting the importance of social resilience. Farmers also recognize that risks interact: the effect of climate on profitability depends on things like interest rates and market prices for harvested fish. Reducing risks may need to take into account more than one source of risk.

At the river or watershed level, farmers identified the storage and release of water from dams, weirs and sluice gates as important risk management practice but which vary in importance among sites depending on proximity and influence of infrastructure on flow regimes. Watershed management was seen as important to controlling risks from polluted run-off again with site-specific differences reflecting patterns of industrialization and agriculture. Interviewees suggested that pollution episodes can be related to climate, for instance, floods or heavy rainfall events early in wet season. Regional differences in particular risks and risk management practices were also identified. Thus, an important insight from this study for aquaculture policy is that climate-related risks need to be managed at multiple scales: farm, reach and river or basin level.

Farmers focus on managing those risks that can be managed. The persistence of fish farmers in the face of occasional losses improves understanding of how farmers think about acceptable risk, in particular, for those sources of risk for which they have only modest or no control. Compensation for loss and damages arising from extreme events represents an important type of post-event risk management that complements the many ex-ante strategies explored in more detail in this study. One reason that farmers give a high priority to maintaining good relations with officials is that they hope that it will improve access to assistance. It should be noted, however, that some forms of compensation depend on registration; the formal procedures of which have recently changed to become much more stringent.

In this study, some expert and government stakeholders believe that the objective should be to minimize risks from extreme flows and climate by avoiding rearing fish at high risk times. This is incomplete reasoning, as farmers' are quick to point out, as this may also be times when prices are highest. Up to a threshold level, risks may be acceptable; risk management and adaptation is needed when those levels are likely to be exceeded (Jones, 2001). Risk management should not be equated to risk avoidance or elimination.

Previous studies on the management of risks in aquaculture have rarely considered climate-related risks in much detail. This is likely to change given increasing concerns with climate change and its influence on water resources. The findings of this study strongly suggest that even in the absence of climate change, climate-related risks are an important set of considerations to aquaculture and, in particular, flow-related disturbances for culture systems in rivers.

Our cross-sectional study of climate risk management practices had some limitations. Responses to our questionnaire, for instance, were sometimes ambiguous about whether a particular practice was already being undertaken or the practice was something a farmer would like or intended to do under particular circumstances, but had not yet done. This was especially the case when talking about larger-scale and longer-term responses. More detailed follow-up with farmers is needed to understand how decisions are made about risk management practices on different time and space scales and which strategies are in fact pursued. This study intentionally focussed on ex-ante risk management; in practice, coping strategies after events occur are also important for recovery and longer-term engagement in aquaculture. These and other post-event strategies like weather-indexed insurance (Peterson, 2012; Shaik *et al.*, 2008) also deserve further study, as these some may complement, or even undermine, ex-ante risk management practices (Abdelhak *et al.*, 2012).

Despite these limitations, this study shows that understanding of climate risk management practices under current climate provides some important insights for developing longer-term strategies to adapt to a changing climate in the aquaculture sector.

First, our findings underline the need to think of strategies at multiple scales: spatially, from farm through reach or local community to the whole of watershed or river basin; and temporarily, from within season, among season and inter-annual phenomena (Table II). There is a need to go beyond the conventional focus on early warning, site selection, farming techniques and avoiding risky times. Greater attention needs to be given to the aquaculture stake in river basin management. Maintaining reasonable water quality and flow conditions and thus viable freshwater ecosystems is very much in the interests of aquaculture farms sensitive to flow and quality. Building resilience of aquaculture through more sustainable farm-level practices and improving river ecosystem health would have multiple benefits for adaptation to climate change. This is a multi-scale response.

Second, our findings emphasize the value of simultaneously considering multiple risks and thus the need for supporting information systems. Fish farmers do not manage climate-related risks in isolation from supply, financial or institutional risks. Information is important to making good risk decisions, for example, about stocking calendar, given patterns in fish prices and likelihoods of climatic and flow risks. Different kinds of risks need to be evaluated jointly. At the moment, there is very little decision support available for farmers apart from their social networks. As others have found in central Thailand (Belton *et al.*, 2009), disease outbreaks are a key concern in northern Thailand. Improving disease management is important to management of climate-related risks, because increased susceptibility to disease is triggered by or part of a causal chain to impacts for most climate-related risks. Trustworthy information could help farmers make better stocking calendar decisions. Early warning systems with respect to floods, for instance, are already partly in place in the different regions and make a valuable contribution to reducing losses. Much less effort so far has been given to slower-onset risks such as anticipating the severity of the dry season and thus low-flow conditions.

Third, our findings underline the relevance of a climate risk management approach. Farmers strongly agreed that reducing risks under current climate was an important strategy for dealing with climate change (Figure 5). The information system skills needed to deal with a variable climate are an important foundation from which to deal more explicitly with challenges created by a changing and uncertain climate. Fish farmers have a reasonably good, but broad understanding of climate change (Lebel *et al.*, 2013b). It is noteworthy that fish farmers already place a high priority on monitoring activities, following-up information sources and social relations. These are important pre-requisites for learning about change. Fish farmers also emphasize the need to know how climate will change and what impacts it will have (Figure 5); but it was less clear that the high levels of uncertainty around future climate change are fully appreciated. More engagement with farmers and other stakeholders is needed to communicate these uncertainties; to draw on existing appreciation of climate variability on annual to decadal scales and to address the challenges which arise for practice and policy with more severe climate change (Howden *et al.*, 2007).

The findings of this study also have broader implications for scholarship and practice beyond the aquaculture sector. For scholarship, the findings suggest that social sources of resilience, such as those accessed through social relations, are important to

Table II. Time and space scales of risk management practices relevant to adaptation

Risk management scales	Short Hours-days	Intermediate Weeks-months (crop)	Long Years (multi-crop)
Farm level			
Technical	Move cages towards banks	Adjust stocking date/density	Move/rent new site
Financial	–	On schedule loan payments	Diversify – specialize
Social	Share warning information	Share rearing knowledge	Improve relations
River level	Flow and early warning information systems	Collectively lobby infrastructure operators	Engage in water and basin management activities
		Seasonal water allocation decisions	Operating rules and procedures for infrastructure
National or sector level	Financial support/relief decisions	Emergency compensation	Variety improvement/new species trials
			Infrastructure development/wetland and river restoration
			New insurance schemes

managing physical and ecological as well as social or institutional risks. They also suggest the need for greater attention to scale issues, especially temporal ones, when considering the process of adaptation. Adaptation to climate-related risks will often need to be multi-scale rather than purely local or national. In terms of practice, the findings suggest paying greater attention to managing multiple risks simultaneously and therefore actions which have multiple risk management benefits. The findings also support the increasing attention given to understanding existing risk management practices and their performance under recent climate variability to gain insights on opportunities and constraints for adapting to even more uncertain or directional changes in climate.

5. Conclusion

This is one of the first papers to report in detail on how inland fish farmers manage climate-related risks. It shows that they use a combination of adjustments to rearing practices, cropping calendars and financial and social measures to manage those risks which they perceive as being manageable. Some other risks are tolerated or understood to require longer-term and indirect actions to influence water and watershed management at higher spatial levels. Many risks are both season and river or place specific meaning that the risk profiles of individual farms can vary substantially. Farmers must manage both climate-related and non-climatic risks, and take additional care when these interact to exacerbate risks to livelihoods and profits. A key finding of this study is that individual risks are often addressed through multiple practices and strategies and that a particular practice can have a bearing on several different risks. Social relations and information play critical roles in managing these complex combinations of risks underlining the potential importance of collective action, best practices and decision support tools for strengthening risk management. More broadly, the findings of this study imply that adaptation will often need to consider multiple spatial and temporal scales as well as the fact that farmers do not manage individual climate-related risk in isolation from other risks.

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