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PROFILE

Impacts, Perceptions and Management of Climate-Related Risks to Cage Aquaculture in the Reservoirs of Northern Thailand

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Abstract Weather is suspected to influence fish growth and survival, and be a factor in mass mortality events in cage aquaculture in reservoirs. The purpose of this study was to identify the important climate-related risks faced by cage aquaculture farms; evaluate how these risks were currently being managed; and explore how farmers might adapt to the effects of climate change. Fish farmers were interviewed across the northern region of Thailand to get information on impacts, perceptions and practices. Drought or low water levels, heat waves, cold spells and periods with dense cloud cover, each caused significant financial losses. Perceptions of climate-related risks were consistent with experienced impacts. Risks are primarily managed in the short-term with techniques like aeration and reducing feed. In the mid-term farmers adjust stocking calendars, take financial measures and seek new information. Farmers also emphasize the importance of maintaining good relations with other stakeholders and reservoir management. Larger farms placed greater importance on risk management than small farms, even though types and levels of risk perceived were very similar. Most fish farms were managed by men alone, or men and women working together. Gender differences in risk perception were not detected, but women judged a few risk management practices as more important than men. Fish farmers perceived that climate is changing, but their perceptions were not strongly associated with recently having suffered impacts from extreme weather. The findings of this study provide important inputs to improving risk management under current and future climate.

Keywords Drought · Climate-related risks · Perception · Risk management · Reservoir · Cage aquaculture · Thailand

Introduction

To be successful, aquaculture farmers must often manage a combination of market, regulatory, production and climate-related risks. Future prices, for example, were identified as key risks by salmon farmers in Norway (Bergfjord 2009), catfish farmers in Vietnam (Le and Cheong 2010), shrimp farmers in Bangladesh (Ahsan 2011) and mussel farmers in Denmark (Ahsan and Roth 2010). Regulatory risk on the other hand, relate to licensing and zoning of farm locations (Bergfjord 2009), food safety standards, and policies on allocation and management of water. Disease is often the largest production risk and may be exacerbated by poor water quality (Belton et al. 2009). By climate-related risks in this paper, we mean the likelihood and severity of extreme weather or climate events such as heat waves, cold spells and intense rainfall events, as well as other water conditions for which climate is a key driver, like floods and droughts.

How fish farmers evaluate and perceive current and future risks is important, because it can strongly influence what actions they take to manage those risks (Bergfjord 2009; Lebel et al. 2015b). Farmers have been shown to differ in their attitudes towards risk—including to climate-related risks—for a variety of reasons (Nielsen et al. 2013). Recent experience of losses is often found to lead to higher

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perceived risk (Menapace et al. 2013; Ahsan and Brandt 2014). Uncertainties in weather however, may be seen as an unmanageable risk (Barnes et al. 2013); though several studies have shown that farmers are able to make reasonably accurate short-term forecasts (Godoy et al. 2009). Gender differences in risk perception are frequently observed, with women more concerned about climate risks and climate change than men (Sundblad et al. 2007; Safi et al. 2012). Younger and more educated farmers are typically more aware of and concerned with climate change (Roco et al. 2014). The high levels of aversion to risk found in many studies of farmers may be a barrier to the adoption of new practices that could support improved management of climate-related risks, as well as longer-term adaptation to a changing climate (Ghadim et al. 2005; Alpizar et al. 2011).

In the case of aquaculture, climate-related risks have been less studied than other types of risks by comparison, but findings suggest they can still be significant. Catfish farmers in the U.S. for instance, need to deal with flooding, droughts and freezing (Hanson et al. 2008). Shrimp farmers in Bangladesh are severely impacted by floods caused by cyclones, which they perceive as having become more frequent (Shameem et al. 2015). In Denmark, bad weather makes access to mussel rearing sites unsafe, in turn impacting production (Ahsan and Roth 2010). Seasonally varying algal abundance—and thus risks of anoxic conditions—were noted as a possible constraint in otherwise suitable conditions for tilapia cage culture in small reservoirs in Kenya (Kaggwa et al. 2011). Mass mortality of red hybrid tilapia in cages in Kenyir Lake, Malaysia, was attributed to infections by *Streptococcus* bacteria during periods of high water temperatures (Najiah et al. 2012). Low dissolved oxygen levels below 10 m depth in the Batang Ai Dam reservoir, Malaysia, was identified as a significant risk to fish farms if anoxic waters were to move upwards and mix with surface waters (Nyanti et al. 2012). Water quality profiles taken before and after a mass mortality event of fish cultured in cages in Lake Cirata, Indonesia, demonstrated that fish deaths were due to the mixing of anoxic lower waters with surface waters (Effendie et al. 2005). The extent of stratification and the depth of subsequent mixing are likely to be influenced by wind, rainfall and temperature changes (Branco and Torgersen 2009).

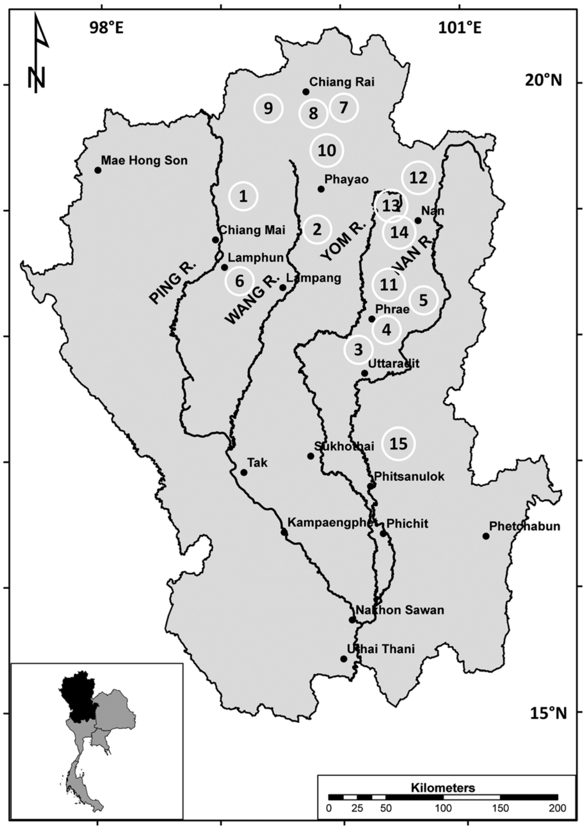
Previous work in Northern Thailand has shown that climate-related risks—in particular, droughts (low flows) and floods (high flows)—are important to cage aquaculture in rivers (Lebel et al. 2015d). Extreme high flow events in the Upper Ping River, such as those that occurred in 2005 and 2011, for example, damaged fish cages, caused mass mortality or allowed fish to escape, resulting in significant losses to income (Lebel et al. 2013; Lebel et al. 2015c). Disease outbreaks are associated with stressful conditions, some of which are climate-related; such as the combination of extreme high temperatures and low water flows that can occur towards the end of the dry season, resulting in low water quality (Chitmanat et al. 2016). In earthen ponds, low water availability is often associated with lower water quality and thus, a key climate-related risk towards the end of the dry season, especially in drought years (Sriyasak et al. 2014). Heat waves, cold spells, heavy rainfall events and periods with dense and prolonged cloud cover, have also been associated with slower growth and reduced survival. High phytoplankton concentrations, on top of thermal stratification and poor turn-over of water in earthen ponds, can expose fish to dangerously low dissolved oxygen concentrations during the early hours of the day (Sriyasak et al. 2015).

Presently, not much is known about the impacts of extreme weather or other climate-related factors on the profitability of cage aquaculture in reservoirs; though we anticipate issues may be a hybrid of river and pond settings. Thus, the purpose of this study was to identify the important climate-related risks faced by cage aquaculture farms in reservoirs, using Northern Thailand as a case study. The study also evaluates how these risks are being managed and assesses how farmers might adapt to the effects of climate change. It is our belief that in strengthening the management of climate-related risks under current climate, fish farmers will be able to better adapt to climate change as it unfolds into the future.

Methods

Study Area and Climate

This study was carried out in 15 reservoirs distributed across 9 provinces in Northern Thailand (Fig. 1). The climate of Northern Thailand is highly seasonal and can be illustrated by mean values for Chiang Mai. Temperatures are highest in April (36.5 °C) and lowest in January (14.9 °C). Most rain falls between May and October (1225 mm), whereas from December to March (52 mm) there is very little rain. Peak flows in the river usually occur towards end of the wet season, like September. Historically, peak flows of the Ping River at Nawarat Bridge in Chiang Mai city have not increased since 1921; but minimum wet season and annual flows show a downward trend (Lim et al. 2012). Over the same time period there was no significant change in annual rainfall, suggesting that changes in flow are due to other factors, such as the expansion of irrigation areas. In the last four decades however, annual rainfall has significantly declined (Sharma and Babel 2013), suggesting more recent climate variability and change. Projections of future climate and hydrology for Northern Thailand vary



	Reservoir	Farms	Cages
1	Maengad	14	153
2	Kewlom	2	179
3	Sirikit	16	252
4	Maethang	27	619
5	Maetik	5	96
6	Bannongyoung	1	2
7	Houykang	2	21
8	Maetak	2	35
9	Tadkwan	1	14
10	Nonglengsai	15	151
11	Namhaeng	1	40
12	Nongnamkrok	6	26
13	Nongthadonchai	1	14
14	Nongnatho	3	22
15	Kaenghai	1	35
	TOTAL	97	1659

Fig. 1 Map of the study region in Northern Thailand showing approximate locations of reservoirs in which fish farms were surveyed

depending on the climate models and emissions scenarios used (Lacombe et al. 2012). Two recent studies, for instance, suggest decreasing trends in precipitation for the wettest (Aug-Oct) period (Singhrattna and Babel 2011), and a decrease in annual stream flow of 13–19 % (Sharma and Babel 2013); whereas another analysis with 9 climate models project wetter conditions on average (Kotsuke et al. 2014; Watanabe et al. 2014).

Data Collection and Analysis

Survey interviews were collected between 2 March and 24 April 2015 from 97 fish farms with cages in 15 reservoirs (Fig. 1). This constituted almost the entire population of fish farms operating in the major reservoirs at the time of this study. These interviews were preceded by several visits to fish farms on Mae Ngad Reservoir beginning in November 2014.

The survey questions covered: background information on the informant and their household, including other income sources; rearing practices, including stocking densities, stocking calendar and fish species cultured; business management practices, including contracts, loans and standards; details of most recent crop harvested, including information on losses due to climate-related factors and net profits; perceptions of climate-related, market, financial and regulatory risks, measured on a 5-point level of concern or level of importance of impacts scale; importance of a range of risk management practices at farm and reservoir or collective level, also on a 5-point level of importance scale; and understanding of and levels of concern about climate change.

For analysis of the survey, farms were grouped into 3 classes: 23 small (1–4 cages), 56 medium (5–20 cages), and 18 large (21 or more cages). The large class included three farms with over 100 cages. In some analysis the medium and large classes were combined and dubbed the 'larger' class. The responses of the three large farms were inspected, and care taken to ensure they did not distort summary estimates. Thirty-eight reservoirs were classified as small (<30 million m^3) and 59 as large ($\geq$30 million m^3). Comparisons across farm sizes, reservoir sizes and gender of mean levels of concern with various risks and the perceived importance of management practices, were performed using analysis of variance (ANOVA). For comparing financial losses attributed to different extreme weather events, the non-parametric Friedman Test was used as variable distributions were highly skewed.

In-depth interviews were conducted with 28 fish farmers between October 2015 and April 2016. The interviews covered characteristics of the farm, rearing and business practices, experience with climate risks and common risk management practices. Interviews typically lasted about 30 minutes. To get another perspective and validate our information, 3 experts from the Department of Fisheries (DOF) were also interviewed using a similar set of questions given to farmers. All interviews were taped and transcribed, then coded using the NVIVO software for further analysis.

Fish Farmers

Three quarters of the subjects interviewed were male; most were older than 40, and over one-third had more than a primary level education (Table 1). Most fish farming households had other income sources, and these were evenly spread among categories. Just over a third also had fish ponds in addition to fish cages.

Three-quarters (76 %) of fish farmers interviewed had 5 or more years of experience with cage aquaculture in reservoirs; the mean being 9.9 years. There was no difference in years of experience between men and women, or between small and larger farms. Women rarely managed or took care of fish farms on their own; usually it either involved men or was done by men only (Table 1). One reason for this was that some tasks required physical strength: “It is a little tricky, especially when we have to take cages or fish out, then we must have somebody to come and help.” Working in a reservoir, “it is dangerous for a woman to do alone, as sometimes it can be very windy, and you have to have good skills with a boat, and know how to swim well. If you don’t know how to use a boat, then you shouldn’t farm fish, it can be dangerous.” Another reason was that women did not normally stay alone overnight on the rafts, because “it is not safe for a woman to be alone, there is no electricity, no mobile signal, you are just with the water.”

Table 1 Characteristics of the individuals and households surveyed ($n = 97$)

Individual characteristics	%
Gender	
Female	26
Male	74
Education	
No formal	6
Primary	53
Secondary	25
Higher	16
Age group	
<30	5
30–39	12
40–49	25
50–59	41
60+	17
Assets	
Own pickup or car	74
Own land	62
Monthly income (baht)	
<10,000	15
10,000–20,000	35
20,000–30,000	24
30,000+	25
Other income sources	
Rice paddies	39
Orchards	35
Fish ponds	36
Trading	42
Civil servant	9
Laborer	34
Other	8
Feeding fish	
Men only	53
Women only	10
Business decisions	
Men only	53
Women only	10
Installing or moving cages	
Men only	65
Women only	2

Farming Practices

Most farmers farm fish year round (92 %). Five of eight that stopped for more than a month did so because of poor water quality. None stopped because of insufficient water depths, low market prices, or lack of fry. Fish were usually fed twice (42 %) or thrice (34 %) per day, while some were only fed once per day (18 %). In just over half of farms (56 %) someone watched over the cages all day long. Fry came mostly from private hatcheries (58 %), government hatcheries (57 %), or were wild caught (39 %); three fish farms had their own on-site nursery.

Just over half (55 %) of farmers reared more than one type of fish, with the most common being: red tilapia (67 %), Nile tilapia (58 %), and channel catfish (55 %). Table 2 compares stocking practices and yields for the last harvested crop for four species. Walking catfish were stocked at relatively higher densities, and Channel catfish at lower densities. Median feed conversion ratios were similar among species. The choice of species to be reared was primarily related to market demand, past experience, and the availability of fish fry in different locations. Most farmers held the view that “if you want to make money quickly, then Nile or red tilapia is usually the best.”

Table 2 Comparison of stocking practices, yields and FCR for last harvested crop of four commonly cultivated species (Mean ± SEM by farm or Median)

Species	Farms	Cages	Stocking density fish m^{-3}	Yield density kg m^{-3}	Median FCR kg feed kg $fish^{-1}$
Hybrid red tilapia	29	174	30.4 ± 8.6	10.4 ± 2.9	1.75
Nile tilapia	18	35	23.5 ± 4.1	9.7 ± 1.2	1.60
Channel catfish	33	96	10.2 ± 2.1	9.8 ± 2.4	1.78
Walking catfish	6	32	53.7 ± 17	7.2 ± 4.0	1.67

Just under half (42 %) of farms had some form of agreement with a company, including: using their fry (25 %), using their feed (40 %), using their medicine (29 %), or selling fish back to the company (32 %). About a quarter (27 %) had a signed written agreement. "Being in a contract reduces market risks," one farmer explained, "We don't have to look for a market ourselves, and in the contract, a standard selling price per kilogram is guaranteed." Having feed delivered to the farm was seen as convenient, though expensive. Small farms (22 %) were less likely to have an agreement with companies than medium (50 %) or large (44 %) farms. After taking into account farm size, farms with agreements and those without made similar profits from their last crop (ANOVA, F = 0.3, $P > 0.5$). Most (90 %) fish farms made a profit from their last harvested crop.

About half (49 %) of the farms had taken out a loan to rear fish. The majority of loans were with the Bank of Agriculture and Agricultural Cooperatives (70 %), or the Village Fund (40 %). Relatives (9 %), commercial banks (6 %), and other local cooperatives (6 %) were rarer sources. The median amount borrowed was 100,000 Baht (ca. 30 Baht/USD), at a median interest rate of 7 % per annum. About a fifth (21 %) of those taking a loan had experienced problems with repaying debts.

Just over half (54 %) of all farms had Good Aquaculture Practices (GAP) certification. Larger farms were much more likely than small farms to keep written records of: stocking rates (70 vs 20 %), feed used (58 vs 26 %), yields (62 vs 26 %), and income (66 vs 30 %). Larger farms (32 %) were also more likely to monitor water quality—typically DO, pH, and temperature—than small farms (9 %). From in-depth interviews, it was apparent that some farmers also received information from water quality monitoring done by third parties, such as researchers or reservoir managers.

Results

Climate-Related Impacts

At the time of interviews, the vast majority of farms last harvested a crop between December 2014 and April 2015. This meant potential exposure to four extreme climate conditions during the typical 4–6 months rearing period as shown in Fig. 2. The likelihood of experiencing different types of impacts was comparable across conditions, but with cold spells most likely to reduce feeding and growth. There were no differences in likelihood of impacts on small and larger farms, or between farms located in small versus large reservoirs. Fish farmers estimated the financial impacts of these events on their last harvested fish crop by taking into consideration the expected value at harvest of the fish that died (Table 3). For those farms which were impacted, the median total financial loss and median loss per cage attributed to different extremes were not significantly different (Friedman Test, $P > 0.1$). Assuming it takes 5 months to rear fish, this represents median losses of 11–16 % of total household income for each event type and 32 % for all types combined (Table 3).

Several farmers noted that dry season (2014–15) was the driest they had ever experienced. Heat waves on their own were not seen as a problem by most respondents. Fish, it was observed, tended to swim down into deeper waters when temperatures were very high. The combination of low water levels and high temperatures was particularly challenging: "There is little water, and it is very hot. The fish are stressed. Two farms lost crops. I used propeller mixers and moved cages away from shoreline and over to deeper waters." Another farmer observed that he would consider stopping fish farming for a while if the water levels next year were lower than this year. In some locations, more severe drought would not necessarily prevent fish farms from operating, as farmers believed that minimum water levels would still be adequate for fish production, but acknowledged that "less water means rearing less fish, and more problems with diseases."

Impacts from dense and prolonged cloud cover was also frequently observed by about half of the farmers. These events are locally referred to as '*fah-bit*'—literally meaning 'closed skies.' As one farmer explained, in these weather conditions "oxygen levels in the water drops, so must reduce feeding and provide aeration." Others raised the bottom of cages so fish could stay near the surface where oxygen concentration was highest. Under these conditions you could "lose all the fish in a cage, so there is no going

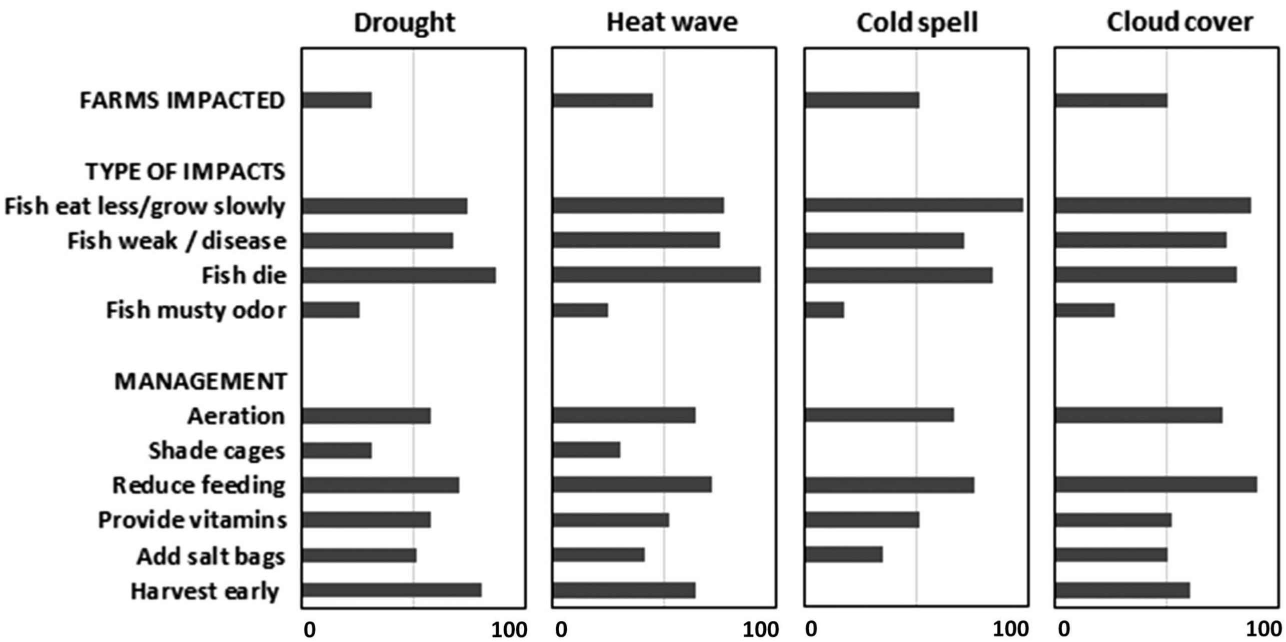


Fig. 2 Percentage of farms for which last crop was impacted by four types of climate-related conditions and the actions taken to reduce impacts

Table 3 Financial value of losses attributed to four different extreme weather conditions by fish farmers for the last set of cages harvested

Variable	Drought	Heat wave	Cold spell	Dense cloud	All events
Proportion of farms with losses in last harvested crop	0.32	0.45	0.51	0.50	0.81
If impacted:					
Median total loss	20,000	11,500	15,000	8000	28,000
Median loss per cage	4167	3333	5000	2583	6667
Median total loss : Household Income	0.16	0.14	0.16	0.11	0.32

home; it is important to stay on the rafts and monitor the conditions." Experts and some farmers understood phytoplankton to be both a source and consumer of oxygen. On the other hand, in sites with very clear waters and low phytoplankton levels, dense cloud cover episodes appeared to have much less or no effect.

Most respondents (84 %) said heavy rain had no significant impacts. Others noted that when there is heavy rainfall or strong winds, water in the reservoirs can become turbid. Under these circumstances, fish eat less, so farmers must reduce feeding. Heavy rainfall brings pollutants and sediments into the reservoir, especially "when the first rains of the season flow into the reservoir. There are always problems, fish cannot adjust."

In reservoirs with significant thermal stratification, water turnover events can expose fish to low concentrations of dissolved oxygen or hydrogen sulfides ('smelly gases'), which farmers observe by seeing fish float to the surface. According to reports by fish farmers and officials, and confirmed by measurements (Whangchai 2015), these events occur when sufficient cool and denser water on the surface sinks, driving warmer water that has been trapped below upwards. Under these conditions, farmers stressed the importance of aerators to help oxygenate the water. One farmer elaborated on the seasonal dimension: "Water turnover occurs at the start of the cool season, when the seasons change, there is some wind. Oxygen levels in the water are low. That is a dangerous time." In Mae Ngad reservoir, a turnover event was observed and measured around November 2014, following the first cold spell of the dry season. Several farms suffered mass mortality events, while others were able to minimize losses by using aerators or harvesting fish early (Whangchai 2015). In reservoirs that are shallow or with strong thru-flow, this phenomenon does not pose as big a problem because thermal stratification is small.

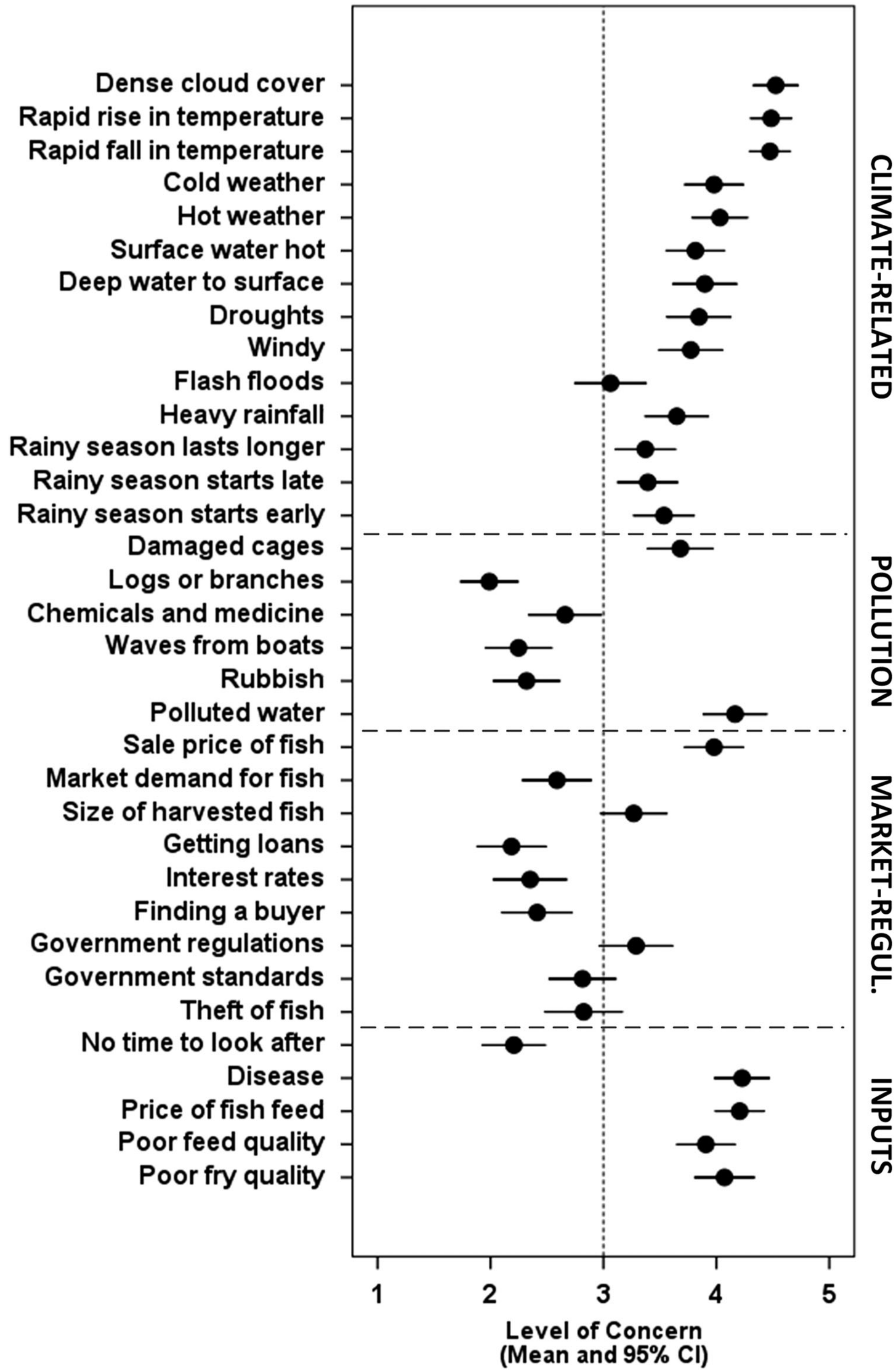
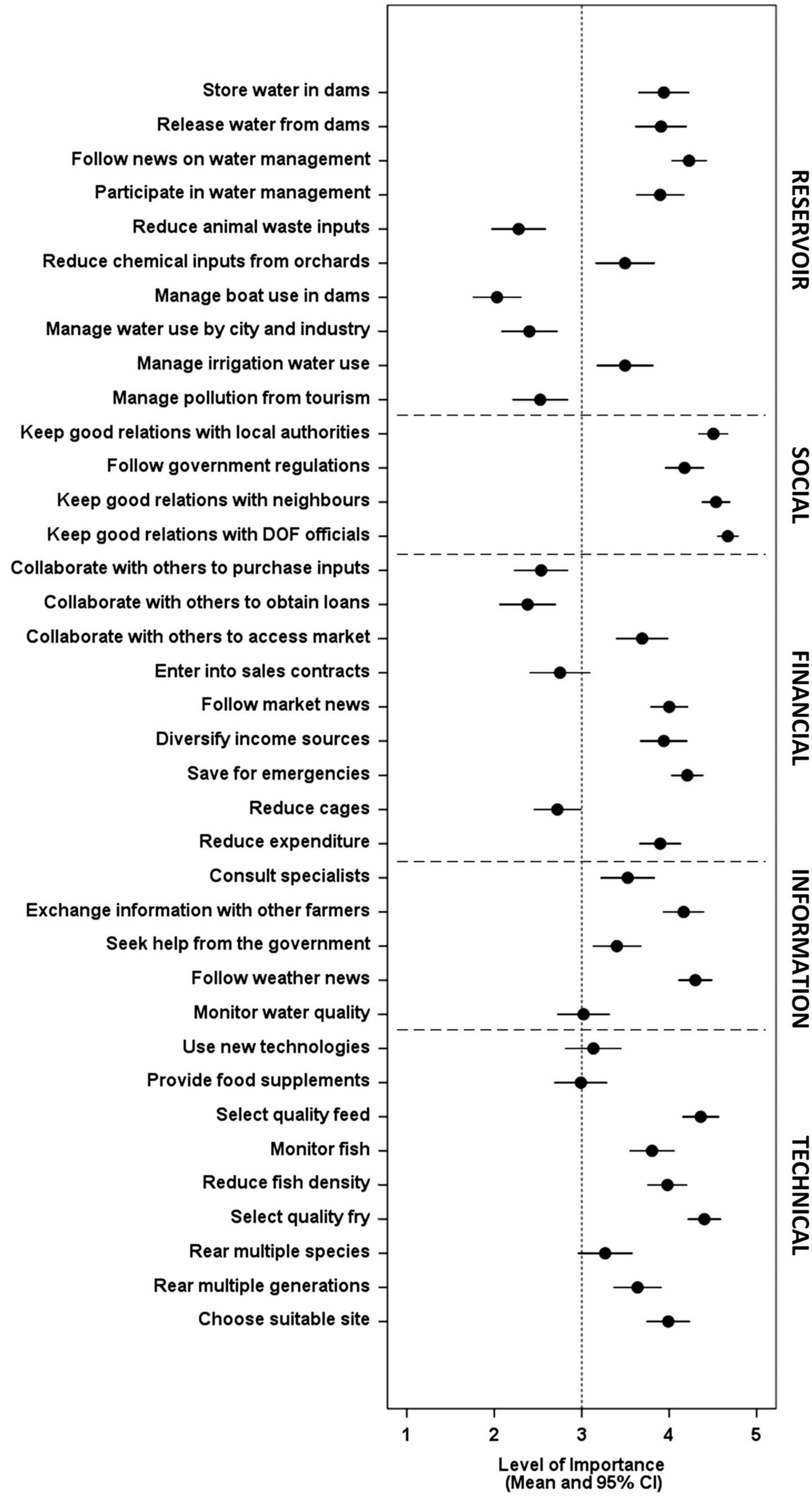


Fig. 3 Mean level of concern about factors influencing the profitability of fish farms based on individual responses ($n = 97$), scored as: 5 (very concerned) through 3 (somewhat concerned) to 1 (not concerned at all)

Perceptions of Risks

Fish cage farmers were significantly concerned about several climate-related, financial or market, disease and input quality risks (Fig. 3). Periods with extreme high or low temperatures and droughts ranked highly; so did conditions with heavy rainfall, strong winds, and when deep waters (low in DO) rose to the surface. Rapid rise and fall in temperature, as well as periods with prolonged cloud cover, were also significant concerns. The risk perceptions of respondents with small and larger farms were very similar, with two notable exceptions: rapid rise in temperature and

Fig. 4 Mean level of importance of various risk management practices based on individual responses ($n = 97$), scored as: 5 (most important) through 3 (intermediate) to 1 (not important)



late start to rainy season, for which both were perceived by larger farms as higher risks than small farms. The risk perceptions of men and women were similar for all risks.

Overall, weather or climate was considered a relevant factor in disease risk by almost all fish farmers (97 %). Most fish farmers felt that the weather and seasonal differences were important to risks of different diseases: "Seasonal changes are really important, whenever temperatures are very high, fish cannot adjust, they become stressed and susceptible to diseases like *Streptococcus*. During cold spells, infections are common. Fish also have difficulties when the temperature changes sharply between night and day." There was no clear pattern of agreement on which periods of the year had the highest risks of disease however. Among fish farmers surveyed, the majority perceived that risks of disease were associated with or caused partly by: low DO levels (89 %), warm water conditions (74 %), heavy rainfall (74 %), and droughts (60 %).

Fish farmers were also concerned about water pollution from activities on land; such as chemicals used in orchards upstream and the risk of runoff pollution it poses. They were less worried about pollution from activities in the reservoir however; such as rubbish or chemicals they used, or impacts from tourist boats and rafts (Fig. 3). In terms of financial risks, fish farmers showed low concerns with loans and finding buyers, but were very concerned with the selling price of fish. Concerns with government standards and regulations were moderately high; because reservoirs as public water bodies typically requires special permission to be used for aquaculture purposes.

Fish farmers were very concerned with the quality of key production inputs; namely fish fry and feed. The dilemma is that for good growth, "need feed between 30–32 % protein, but the price of such feed is high." Farmers also depended on experience, reusing a brand and formulation which resulted in a satisfactory profit. There was no association between levels of concern with fish fry quality and the types of sources used.

Having recently experienced negative impacts from drought, heat waves, cold spells or prolonged cloud cover, were all positively and significantly associated with the level of concern with the corresponding climate risk (χ^2 tests of linear association, all $P < 0.05$). Be that as it may, having experienced negative impacts from diseases in the past two years (64 %) was not associated with level of concern with disease risks.

Risk Management

Selecting good feed and fish fry were considered very important technical practices to manage risks to profits (Fig. 4), consistent with the high perceived risks associated with low quality feed and fish fry (Fig. 3). Quality and availability of fish fry varies seasonally (see also Uppanunchai et al. 2015). Apart from quality of fish fry, farmers appreciated the fact that some hatcheries gave extra fish fry or replaced some that died. Ultimately, selection of fish fry sources was an issue of trust based on past performances. Fish farmers also paid attention to seasonal differences in risks; adjusting the amount of fish they reared and thus the level of investment risk. "For example, in the cool season," one farmer reflected, "we have to reduce the amount of fish we stock. When new water comes again, you reduce the amount of fish or sell harvest early. We avoid the times with the highest risks and the most problems."

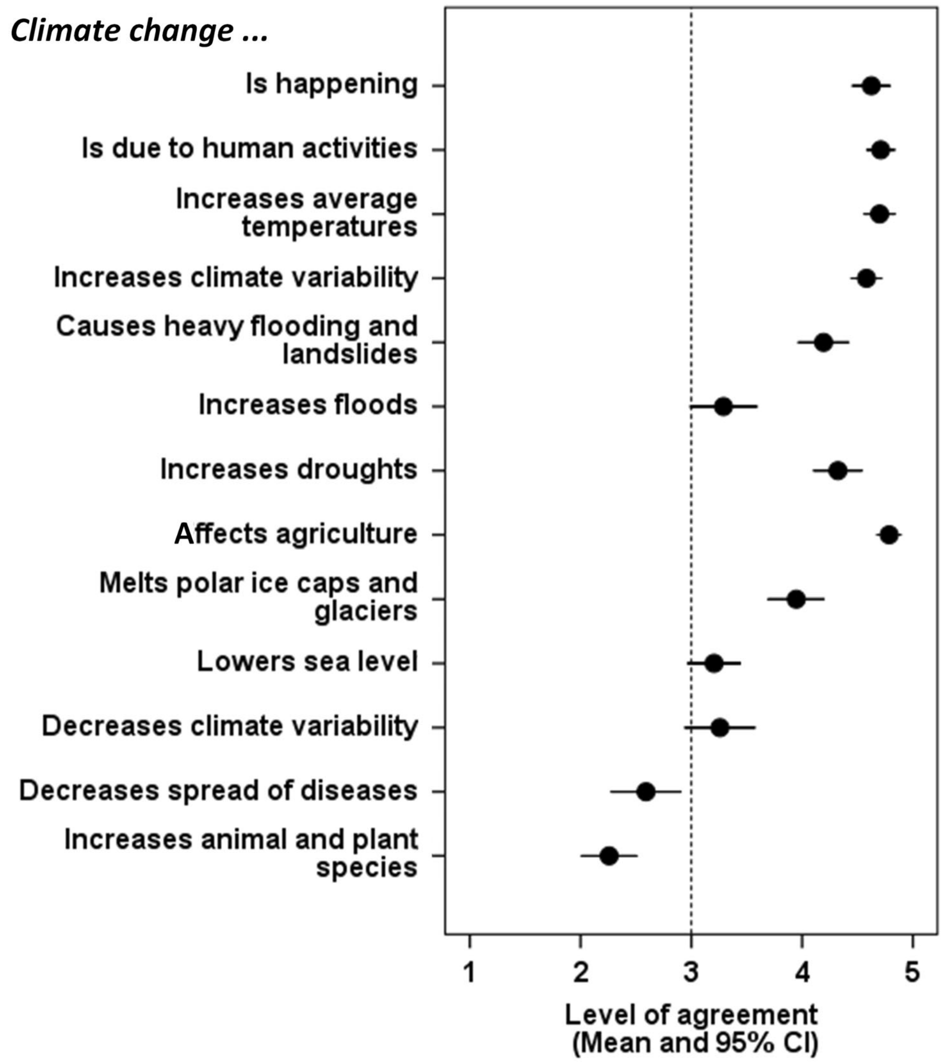
Keeping up with weather (79 %), water management (79 %), and market news (66 %) was often considered to be important or very important for managing risks; with women on average giving higher importance to all three information-related practices than men (ANOVA, all $P < 0.05$).

Financial strategies like maintaining adequate savings, reducing costs, and diversifying income sources were recognized as equally important (Fig. 4) by men and women (ANOVA, all $P > 0.1$). Cooperating with others to obtain loans or inputs were not rated as important however; which is consistent with the low level of concern with obtaining loans or high interest rates (Fig. 3). In follow-up interviews, farmers also mentioned the need for financial assistance when they were affected by a disaster. Indeed, official recognition of extreme events made a difference: "If we have a problem but a drought or natural disaster [flood] is not declared, then there is no support, none at all, even if there is a big impact."

In terms of technical information and financial practices, respondents with larger farms tended to give higher importance than those of small farms in matters such as: quality of fry and feed, monitoring water and fish all day, site selection, consulting specialists, reducing costs, and rearing multiple generations and species (ANOVA, All $P < 0.05$). Women (68 %) were more likely than men (46 %) to rate rearing multiple species as important or very important.

Fish farmers attempted to manage the risks from four highlighted climate-related conditions with significant impacts, using a couple of general techniques like aeration and reducing feeding (Fig. 3), as well as more phenomenon-specific actions like delaying the morning feed during cold spells. While the majority of farmers used aeration to reduce the risks of low oxygen levels (Fig. 2), details of individual practices were highly variable. Some farmers followed a regular schedule, for instance, aerating every morning or after every feeding time; whereas others only did so when conditions appeared to warrant it: "I use it when there's not much water, or water levels are changing quickly. I don't use it all the time, not when fish have no problems." Another farmer noted that he would leave the aerator on day

Fig. 5 Mean level of agreement with statements about the existence and impacts of climate change based on individual responses (n=97), scored as: 5 (fully agree) through 3 (uncertain) to 1 (completely disagree)



and night during periods of prolonged cloud cover. Meanwhile, some farmers used automatic systems to turn aeration machines on and off at fixed times during the day and/or night.

Maintaining good relations with local authorities (88 %) and fisheries officials (93 %) was rated as important or very important by most farmers (Fig. 4): “They have technical knowledge, when all we have is our practical experiences.” Although some interaction was essential for gaining permission to use public waters, farmers did not expect fisheries officers or other officials to help them. Thus, the level of engagement with officials varied among reservoirs; from very little interaction with any officials, to complex interactions with forestry, irrigation and fisheries officials as in Mae Ngad reservoir, where: “They would tell us that when fish died, the dead fish should not be thrown into the reservoir, but buried on land. They don’t want water quality to be affected, as the reservoir is an important tourism site. They also set rules on how many cages each farm can have.” Fish farmers also recognized that officials had limited budget and time, and thus, for the most part they were on their own; especially when it came to dealing with market-related risks.

Overall, farmers maintained good relations with other fish farmers, and considered connections helpful in terms of marketing fish: “Help each other, exchange experience, share quality fingerlings when we have a lot. Sometimes there is not enough fish for the market, or not enough customers, so we share our connections.”

Apart from actions farmers could undertake themselves, they also recognized various reservoir and watershed management practices as important (Fig. 4). Highly ranked were being aware of and engaging in water management activities. Nevertheless, fish farmers were clear that their farming interests were not the priority of the authorities. “You should not forget,” one farmer noted, “that the objective of the Irrigation Department is to build reservoirs for storing and managing water for agricultural uses, not for farming fish.” Water polluted with chemicals used in orchards was seen as another important but a difficult risk to manage. Consistent with levels of perceived risks (Fig. 3), management of boat use, pollution from house rafts or animal waste inputs, were seen as less important (Fig. 4).

Climate Change Perceptions

Almost all fish farmers (96 %) had heard of ‘climate change’ or ‘global warming’. When asked how concerned they were about climate change on a 5-point scale, two-thirds (66 %) said they were very concerned, and a further 16 % were quite concerned. There was no difference in level of concern between men and women, or between small and large farms.

Overall, fish farmers believed that climate change was already happening, was a result of human activities and that it would affect agriculture (Fig. 5). In in-depth interviews, several farmers interpreted the hot and dry conditions of the last two years as evidence that climate change was already having an impact. However, some farmers thought moderately warmer conditions would not be a problem for fish, and might even be beneficial if more light meant more oxygen was produced. One farmer explained that global warming “effects are indirect; for example, changes in seasons, storms, higher temperatures, or unusual rainfall.”

For the most part, fish farmers agreed with true statements about the impacts of climate change, and disagreed with those that were false (Fig. 5). In the case of sea-level rise—not directly relevant to these inland locations—farmers were less certain about the impacts of climate change. Many farmers were also uncertain about whether climate variability and flooding would increase or decrease. A climate change knowledge score was obtained by summing scores for the 13 impact statements after putting a negative sign in front of all false statements. There was no difference in the mean knowledge score for men and women. Respondents from larger farms however, scored significantly higher than those from small farms (ANOVA, $F = 4.0$, $P < 0.05$).

Having recently experienced negative impacts from drought was not associated with a higher level of agreement that droughts would increase under climate change ($\chi^2 = 0.6$, $df = 1$, $P > 0.4$). Likewise, there was no significant association between recent impacts from heat waves and greater expectations of increased temperatures. Under climate change, the expectation was that the weather or seasons would no longer be normal.

Table 4 Mean level of agreement with statements of small and larger fish farms about broad strategies for adaptation to climate change based on individual responses ($n = 97$), scored as: 5 (fully agree) through 3 (uncertain) to 1 (completely disagree)

Adaptation strategy	Small	Larger
Diversify income sources	4.48	4.24
Reduce investment costs	3.65	*4.34
Try new farming methods	3.26	*4.05
Make sure that there is enough money to live on	4.04	*4.54
Need to plan	4.57	*4.78
Need to know more about future climate	4.30	*4.76
Need to know more about the risks	4.57	4.66
Adapt to current climate variability	3.48	*4.26

* Significant differences indicated with an asterisk (ANOVA, $P < 0.05$)

When presented with strategies often proposed as important to adapt to climate change, most farmers were in high agreement; in particular, on the need for information and to plan ahead (Table 4). The lowest scoring option was trying new farming methods. For all strategies apart from diversification and knowing more about risks, respondents with larger farms agreed significantly more with strategy statements than those with small farms (ANOVA, all $P < 0.05$). Some strategies like reducing investment costs and diversifying income sources (Table 4) were also seen as important for dealing with current climate risks (Fig. 4).

As an entry point to consider impacts and responses to climate change, in 11 interviews farmers raised or discussed the possibility of droughts becoming more serious in the future. Most took either the 2014–15 or 2015–16 dry seasons as their starting point for comparison. In 2 cases farmers were not overly concerned because the reservoirs they cultured fish in were very deep, and even in the driest years water was still more than adequate. In the other 9 cases farmers expected significant impacts, including increased risks from low water quality and diseases. By far the most common adaptive response ($n = 6$) was to reduce the amount of fish stocked: fewer cages or low fish densities. Two farmers did not indicate what they would do, and one said they would stop rearing fish completely for the season.

Discussion

This study found that drought, heat waves, cold spells and prolonged periods with dense cloud cover, caused significant financial losses in cage aquaculture farms in the reservoirs of Northern Thailand (Table 3). These impacts were reflected in risk perceptions as measured by levels of concern (Fig. 3). Moreover, several individual climate-related risks assessed in this study were seen by fish farmers as comparable in importance to risks from the market and variation in quality of key inputs such as fish feed and fry. This is similar to findings for cage culture in rivers in Northern Thailand (Lebel et al. 2015d). As others have reported, having recently experienced negative impacts from an extreme weather event was associated with a higher perceived risk (Ahsan and Brandt 2014; Shameem et al. 2015). Understanding farmers' perceptions of climate-related and other risks is important, because these perceptions are likely to influence how new information is evaluated and decisions on the adoption of risk reduction practiced.

Fish farmers manage climate-related and other risks with a mixture of short and longer-term actions. Examples of widely used short-term practices in this study included: the provision of supplementary aeration, temporarily reducing feeding, and the provision of vitamins or feed supplements. These measures are perceived to be important to the management of multiple stress-causing risks, such as: droughts (low water), sharp temperature changes, heat waves, cold spells, and prolonged cloud cover episodes. Nevertheless, while they are widely practiced that does not necessarily mean they are cost-effective.

Indeed, farmers were concerned about the cost of aeration; studies on optimizing use would therefore help improve practices (Kumar et al. 2013). The practice of temporarily reducing stocking densities during periods of stress by re-locating fish is only available to farms with spare cages. Further studies regarding the costs and benefits of this practice is needed. Early harvest to cut losses in response to severe conditions was seen as another important measure to deal with risks of mortality events, as has been observed in river-based cage culture (Lebel et al. 2015b). Intermediate-term strategies focussed on quality of inputs, management improvements and adjustments to the stocking calendar. The latter is particularly important for managing climate-related risks; for example, by avoiding having fish in cages during times of the year when there is very high risk of low water levels or extreme weather events. Rearing multiple species was not seen as an important risk management tool, even though over half of the farms reared more than one species. Longer-term strategies often went beyond technical measures, such as: diversification of income sources, or maintaining good social relations with other fish farmers and officials.

At the reservoir scale, management of water storage and the surrounding watershed are both recognized as important by fish farmers to the risks they face. These risks are not direct climate risks, but they are often climate-related; for example, when reservoir operations reflect seasonal and inter-annual variability in climate, or the risks of pollutants in run-off increasing greatly with extreme rainfall events. From interviews it appears that fish farmers often struggle to reduce risks at this scale as it requires collective action. At the same time, fish farmers do not perceive their own activities—such as feed and chemical use, or disposal of dead fish (Chitmanat et al. 2016)—as an important risk to water quality or fish farming, when in reality they could be (David et al. 2015). The key policy implication is that fish farmers need to become more involved in water management. By the same token, the Department of Fisheries (DOF) should help ensure inclusion of fish farmer representatives in watershed dialogues and committees.

Respondents with small and larger fish farms had very similar perceptions of a range of climate-related risks. They differed however, in the importance they placed on the various risk management practices, and overall readiness to adapt to climate change. When they differed, larger farms invariably placed greater importance on risk management practices than smaller farms. This suggests that larger farms have greater capacity or confidence in managing such risks. Consistent with this was the greater attention paid to record keeping and monitoring of water quality by larger farms. In addition, larger farms were more likely to have contracts with companies, which may help reduce market-related risks because they have a guaranteed buyer. Some business practices of larger farms could be modified to help small farms better manage their resources and risks. Fish farming cooperatives and clubs already exist in many areas, and would be a suitable venue for the sharing of these skills and experiences. The extension services of the DOF could also target small fish farms.

In this study of reservoir cage culture, gender differences in risk perception were not detected; but women judged a few risk management practices—monitoring weather, market and water management news—as more important than men. One reason for the greater attention to formal information sources by women may be because they have more limited access or depend less on personal networks, at least when it comes to aquaculture activities. In contrast to these findings, a study in river-based cage aquaculture also in Northern Thailand found clear evidence that women were more concerned than men about climate-related risks (Lebel et al. 2015d). It should also be noted that fewer women were involved in the reservoir-based culture system studied here than was found in previous studies of both river-based aquaculture (Lebel et al. 2009) and earthen pond aquaculture (Kusakabe 2003). One explanation might be that reservoir-based cage culture takes place further away from home, and women's mobility is constrained by household chores and social norms in rural Thailand (Sullivan 2006; Lebel et al. 2015a). Even when women were involved in reservoir farms, it was usually alongside their partners.

Expanding the participation of women in reservoir fish farming would be possible by providing skills training related to swimming, using boats, or in record-keeping and financial management (Kenney 2006; Lebel et al. 2009); however, dealing with risks of personal safety and security may be more difficult to address.

Fish farmers perceive that climate is changing, and they expect it to continue to do so in the future. In this study we did not explore perceptions of change in detail, but it was clear from responses that farmers are concerned about multiple climate-related risks; expectations about the future however, were not closely associated with the most recently suffered impact. Concerns with climate change may not translate immediately into taking adaptive actions. In some studies, farmers report a high willingness to adapt (Galdies et al. 2016); whereas in others, resistance to change or constraints can be significant (Alpizar et al. 2011). Of particular significance, farmers in the current study did not emphasize seeking out new farming methods or technologies as adaptation strategies. This may reflect in part, the high level of standardization in culturing practices reinforced by almost half of the farms being in contract farming arrangements; or alternatively, the high cost of such technologies and the uncertainty of return on investment may be a deterrent. Either way, many of the existing risk management practices recorded appeared to be useful for dealing with climate variability, including not just technical fixes, but also financial measures related to use of savings, reducing expenditure and diversification of income sources, as well as paying attention to news and information services.

This is one of the first studies to report how fish-cage farmers in reservoirs perceive and manage climate-related risks. The findings, while of primary relevance to the challenges of managing fish farms under current climate, also provide some initial insights into the longer-term adaptation needs for cage aquaculture in reservoirs. First, the responses to questions on adaptation strategies suggest that fish farmers want to know more about future risks and climate. Information about seasonally varying risks and uncertainties about future climate are available, and can be shared with farmers through effective communication. Second, fish farmers recognize the need for planning ahead; in particular, while making stocking decisions, even though there are uncertainties with respect to weather and markets. Improving skills with tools like scenario planning and making available seasonal forecasts of reservoir conditions, would further help in the management of risks. Experience with such tools should also be helpful for building capacities to adapt in the longer-term (Hobday et al. 2016). Third, risk management practices at the farm level need to be integrated more closely with reservoir and watershed management. This requires greater cooperation between water managers and fish farms. Last, as water quality issues interact with climate—for instance, during droughts, when waste products from fish farming may become more concentrated—it is important that fish farming practices minimize feed waste, and that production densities do not exceed the assimilative capacities of the reservoir's ecosystem.

Government agencies involved in fish cage farming in reservoirs can support the adoption of improved climate risk management practices in a couple of ways. First, by working together with farmers and researchers to validate under what conditions particular risk management practices—such as reducing densities or supplementary aeration—are cost-effective. Second, by providing more targeted assistance to small farms; including helping them develop peer-networks and associations through which they can engage suppliers and learn about innovative practices. Third, by collaborating with private firms involved in contract farming arrangements with fish farmers to develop better risk sharing mechanisms that could help deal with extreme weather events.

Conclusions

Important climate-related risks faced by cage aquaculture farms in reservoirs include: sharp changes and extreme temperatures, prolonged periods with dense cloud cover, and droughts. These climate-related risks are managed alongside a portfolio of other pollution, market and input risks to profits. Risk management at the farm and reservoir level is pursued through a mixture of technical, information, financial and social practices. Specific climate risks like drought, heat waves, and dense cloud cover are often addressed by using aeration, temporarily reduce feeding, provide feed supplements, and in desperate cases, early harvests. Understanding farmers' perceptions of risk is critical to efforts to communicate new information about changing risks, because perceptions influence intentions and actions. Fish farmers perceive that climate is changing, and acknowledge the relevance of broad strategies for adaptation to a changing climate like planning ahead, learning about risks, and diversifying income sources. Existing climate risk management practices and related actions that support sustainable aquaculture, appear to be helpful for dealing with risks under future climates, but may not be sufficient. For successful adaptation, aquaculture stakeholders will also need to give greater attention to watershed management, especially in a drying climate or one in which risks of drought and water shortages increases for other reasons, such as changes in land-use or large increases in water demand by other sectors.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interests.

References

Ahsan D, Brandt US (2014) Climate change and coastal aquaculture farmers' risk perceptions: experiences from Bangladesh and Denmark. J Environ Plann Man 58:1649–1665

Ahsan D, Roth E (2010) Farmers' perceived risks and risk management strategies in an emerging mussel aquaculture industry in Denmark. Mar Resour Econ 25:309–323

Ahsan DA (2011) Farmers' motivations, risk perceptions and risk management strategies in a developing economy: Bangladesh experience. J Risk Res 14:325–349

Alpizar F, Carlsson F, Naranjo MA (2011) The effect of ambiguous risk, and coordination on farmers' adaptation to climate change—A framed field experiment. Ecol Econ 70:2317–2326

Barnes AP, McCalman H, Buckingham S et al. (2013) Farmer decision-making and risk perceptions towards outwintering cattle. J Environ Manag 129:9–17

Belton B, Little D, Grady K (2009) Is Responsible Aquaculture Sustainable Aquaculture? WWF and the Eco-Certification of Tilapia. Soc Nat Resour 22:840–855

Bergfjord OJ (2009) Risk perception and risk management in Norwegian aquaculture. J Risk Res 12:91–104

Branco BF, Torgersen T (2009) Predicting the onset of thermal stratification in shallow inland waterbodies. Aquat Sci 71:65–79

Chitmanat C, Lebel P, Whangchai N et al. (2016) Tilapia diseases and management in river-based cage aquaculture in northern Thailand. J Appl Aquacult 28:9–16

David GS, Carvalho ED, Lemos D et al. (2015) Ecological carrying capacity for intensive tilapia (Oreochromis niloticus) cage aquaculture in a large hydroelectrical reservoir in Southeastern Brazil. Aquacultural Engineering 66:30–40

Effendie I, Nirmala K, Hasan Saputra U et al. (2005) Water quality fluctuations under floating net cages for fish culture in Lake Cirata and its impact on fish survival. Fish Sci 71:972–977

Galdies C, Said A, Camilleri L et al. (2016) Climate change trends in Malta and related beliefs, concerns and attitudes toward adaptation among Gozitan farmers. Eur J Agron 74:18–28

Ghadim AKA, Pannell DJ, Burton MP (2005) Risk, uncertainty, and learning in adoption of a crop innovation. Agr Econ 33:1–9

Godoy R, Reyes-García V, Vadez V et al. (2009) Does the future affect the present? The effects of future weather on the current collection of planted crops and wildlife in a native Amazonian Society of Bolivia. Hum Ecol 37:613–628

Hanson TR, Shaik S, Coble KH et al. (2008) Identifying risk factors affecting weather- and disease-related losses in the U.S. farm-raised catfish industry. Agr Resour Econ Rev 37:27–40

Hobday AJ, Spillman CM, Paige Eveson J et al. (2016) Seasonal forecasting for decision support in marine fisheries and aquaculture. Fish Oceanogr 25:45–56

Kaggwa MN, Liti DM, Schagerl M (2011) Small tropical reservoirs and fish cage culture: a pilot study conducted in Machakos district, Kenya. Aquacul Int 19:839–853

Kenney CT (2006) The power of the purse: allocative systems and inequality in couple households. Gend Soc 20:354–381

Kotsuke S, Tanaka K, Watanabe S (2014) Projected hydrological changes and their consistency under future climate in the Chao Phraya River Basin using multi-model and multi-scenario of CMIP5 dataset. Hydrol Res Lett 8:27–32

Kumar A, Moulick S, Mal BC (2013) Selection of aerators for intensive aquacultural pond. Aquacult Eng 56:71–78

Kusakabe K (2003) Women's involvement in small-scale aquaculture in Northeast Thailand. Dev Pract 13:333–345

Lacombe G, Hoanh C, Smakhtin V (2012) Multi-year variability or unidirectional trends? Mapping long-term precipitation and temperature changes in continental Southeast Asia using PRECIS regional climate model. Clim Chang 113:285–299

Le TC, Cheong F (2010) Perceptions of risk and risk management in Vietnamese catfish farming: an empirical study. Aquacult Econ Manage 14:282–314

Lebel L, Lebel P, Sriyasak P et al. (2015a) Gender relations and water management in different eco-cultural contexts in Northern Thailand. Int J Agr Resour, Gov Ecol 11:228–246

Lebel P, Chaibu P, Lebel L (2009) Women farm fish: gender and commercial fish cage culture on the Upper Ping River, northern Thailand. Gend, Technol Dev 13:199–224

Lebel P, Whangchai N, Chitmanat C et al. (2015b) Climate risk management in river-based Tilapia cage culture in northern Thailand. Int J Clim Chang Str Manag 7:476–498

Lebel P, Whangchai N, Chitmanat C et al. (2015c) Risk of impacts from extreme weather and climate in river-based Tilapia cage culture in Northern Thailand. Int J Glob Warm 8:534–554

Lebel P, Whangchai N, Chitmanat C et al. (2013) River-based cage aquaculture of Tilapia in northern Thailand: Sustainability of rearing and business practices. Nat Resour 4:410–421

Lebel P, Whangchai N, Chitmanat C et al. (2015d) Perceptions of climate-related risks and awareness of climate change of fish cage farmers in northern Thailand. Risk Manag 17:1–22

Lim H, Boochabun K, Ziegler AD (2012) Modifiers and amplifiers of high and low flows on the Ping River in Northern Thailand (1921–2009): The roles of climatic events and anthropogenic activity. Water Resour Manag 26:4203–4224

Menapace L, Colson G, Raffaelli R (2013) Risk aversion, subjective beliefs, and farmer risk management strategies. Am J Agr Econ 95:384–389

Najiah M, Aqilah NI, Lee KL et al. (2012) Massive mortality associated with Streptococcus agalactiae infection in cage-cultured red hybrid tilapia Oreochromis niloticus in Como River, Kenyir Lake, Malaysia. J Biol Sci 12:438–442

Nielsen T, Keil A, Zeller M (2013) Assessing farmers' risk preferences and their determinants in a marginal upland area of Vietnam: A comparison of multiple elicitation techniques. Agr Econ 44:255–273

Nyanti L, Hiii KM, Norhadi I et al. (2012) Impacts of aquaculture at different depths and distances from cage culture sites in batang Ai hydroelectric dam reservoir, Sarawak, Malaysia. World Appl Sci J 19:451–456

Roco L, Engler A, Bravo-Ureta B et al. (2014) Farm level adaptation decisions to face climatic change and variability: Evidence from Central Chile. Environ Sci Policy 44:86–96

Safi A, Smith W, Liu Z (2012) Rural Nevada and climate change: vulnerability, beliefs, and risk perception. Risk Anal 32:1041–1059

Shameem MIM, Momtaz S, Kiem AS (2015) Local perceptions of and adaptation to climate variability and change: the case of shrimp farming communities in the coastal region of Bangladesh. Clim Chang 133:253–266

Sharma D, Babel M (2013) Application of downscaled precipitation for hydrological climate-change impact assessment in the upper Ping River basin of Thailand. Clim Dynam 41:2589–2602

Singhrattna N, Babel M (2011) Changes in summer monsoon rainfall in the Upper Chao Phraya River Basin, Thailand. Clim Res 49:155–168

Sriyasak P, Chitmanat C, Whangchai N et al. (2015) Effect of water destratification on dissolved oxygen and ammonia in Tilapia ponds in northern Thailand. Int Aquat Res 7:287-299

Sriyasak P, Whangchai N, Chitmanat C et al. (2014) Impacts of climate and season on water quality in aquaculture ponds. Khon Kaen University Research Journal 19:743–751

Sullivan L (2006) The impacts of aquaculture development in relation to gender in northeastern Thailand. In: Choo PS, Hall S & Williams M (eds) Global symposium on gender and fisheries: Seventh Asian fisheries forum, 1-2 december 2004, Penang, Malaysia, WorldFish Center, Penang, pp 29–42

Sundblad E-L, Biel A, Gärling T (2007) Cognitive and affective risk judgements related to climate change. J Environ Psychol 27:97–106

Uppanunchai A, Apirumanekul C, Lebel L (2015) Planning for production of freshwater fish fry in a variable climate in Northern Thailand. Environ Manag 56:859–873

Watanabe S, Hirabayashi Y, Kotsuki S et al. (2014) Application of performance metrics for climate models to project future river discharge in Chao Phraya River Basin. Hydrol Res Lett 8:33–38

Whangchai N (2015) AQUADAPT Project. Activity 1.2.Climate-related sensitivities of aquaculture production. 5th Activity Report. 15 February 2015 Unit for Social and Environmental Research, Chiang Mai University, Chiang Mai.