

**CLIMATE CHANGE AND
AQUACULTURE IN NORTHERN
THAILAND: AN ASSESSMENT OF
RISKS AND ADAPTATION OPTIONS**



AQUADAPT
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ICONS USED IN THIS REPORT



Flood



Heavy
rain



Pond



Drought



Thick
cloud



River



Heat
wave



Reservoir



Cold spell



Hatchery

HOW TO CITE THIS REPORT

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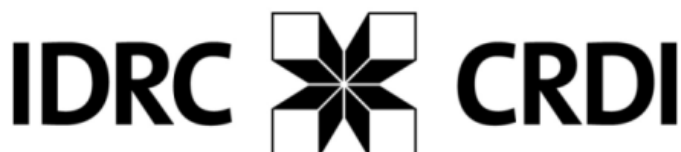
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1 EXECUTIVE SUMMARY

Fish farmers in Northern Thailand face significant risks from extreme weather events under current climate, which may become more frequent or severe in the future. This report synthesizes an evaluation with stakeholders of the risks posed by climate variability and change to aquaculture in Northern Thailand, and, the robustness of alternative adaptation options.

The foundation of the assessment was a set of multi-disciplinary research studies, farmer surveys, interviews with officials and experts, reviews, and stakeholder engagement activities undertaken as part of the AQUADAPT project. The work was carried out with the aid of a grant from the International Development Research Centre (IDRC) in Ottawa, Canada.

Climate-related risks to fish farms are significant under current climate and water management

The most important climate-related risks to the profitability of inland aquaculture are season, culture-system, and place-specific; meaning that the risk profiles of individual farms vary substantially. Important climate-related risks for river-based cage culture are extreme high and low flows. For earthen pond culture, floods, droughts, and heavy rains were three important risks. For cages in reservoirs, rapid temperature changes and prolonged cloud cover were risks of greatest concern. Hatcheries worry about heat waves, cold spells, and having sufficient clean water.

Climate-related risks are managed at multiple spatial scales. Existing risk management practices and strategies at the farm level include site selection, adjusting stocking densities, and providing aeration. At the watershed and community level, the sharing of information is key; from early warnings of imminent extreme weather, through to sharing of rearing knowledge. At the sector level are schemes for compensation following disasters, as well as national policies related to standards and zoning.

Strengthening climate risk management practices in inland aquaculture requires attention be given to short-term reactions, mid-term tactics, and long-term strategies. Timely reactions to imminent threats might involve moving cages, supplying aeration, or harvesting a crop early. Tactics include a stocking calendar, so as to avoid highest risk periods, or storing water in an extra pond in preparation for the dry season. Long-term strategies are followed for years or decades, and range from diversification of income sources through migration to work, to research in alternative species and rearing techniques.

Exactly how climate will change in the future in northern Thailand is not known with much certainty which is why it is important that policies be robust and flexible

Non climate-related risks – like interest rates, rising prices of fish feed, or a fall in fish demand and prices – must also be dealt with by fish farmers. Some risk management practices help deal simultaneously with several different risks. It is important that managing climate-related risks does not inadvertently inflate other risks.

Exactly how climate will change in Northern Thailand in the future is not known with much precision. This high level of uncertainty means that it is important for measures taken today to be robust, flexible, and if possible, no regret actions. Scenarios are used in this assessment to allow analysis despite uncertainties.

Four simple climate change scenarios were created to help explore how future climate might impact different culture systems in different climatic zones. In the *wetter* and *drier* scenarios: total rainfall was assumed to increase or decrease respectively. In the *more seasonal* scenario: rainfall in the wet season months increased, and decreased further in the dry season months. On the other hand, in the *less seasonal* scenario: the wet season months became a little drier, and dry season months a little wetter.

These four climate change scenarios were then combined with alternative assumptions about the future demand for farmed fish and water, in order to create a broad set of plausible futures in which to test specific adaptation strategies. Altogether, 16 longer-term strategies were identified based on proposals of stakeholders and expert analysis. The benefits of pursuing specific, long-term strategies like investing in new technologies or infrastructure, establishing insurance or improving early warning systems, is shown to vary across scenarios; that is, no strategy is perfectly robust or worthwhile under all conditions. At the same time, several strategies are low regret, and could be combined with others to develop flexible and robust adaptation pathways for inland aquaculture.

An examination of the content of five recent aquaculture policies revealed no direct references to adaptation to climate change, but some recognition of the significance of floods, droughts, and the quality of water resources under current climate conditions. Most policies were found to be sensitive to the effects of climate change, implying that it would be worth considering ways to mainstream concerns about adaptation within these policies.

Based on these evaluations, recommendations were derived for policy, practice, and science. For policy and planning, these were: (1) strengthen the management of climate-related risks under current climate; (2) modify key aquaculture development policies, plans, and strategies to take into account climate; (3) increase awareness of the importance of the aquaculture stake in inland water resources management; (4) enhance the sharing of good risk management practices among fish farmers; (5) collaborate with private firms and fish farmers to provide new risk sharing options; (6) establish and implement a zoning policy for aquaculture; (7) invest in research and development on climate-resilient aquaculture technologies and rearing practices; and (8) draft a new climate and water strategy for inland aquaculture.

For fish farmers: (1) Identify and evaluate climate-related risks as part of business planning; (2) Invest in farm-level risk reduction measures as appropriate; (3) Monitor innovations in fish farming techniques for opportunities to improve resilience; (4) Establish and strengthen fish farming organizations and networks so can better represent interests in water management decisions.

For researchers, important areas for further research include: (1) develop climate risk management tools for fish farmers; (2) Ecosystem-based adaptation in pond and river culture; (3) Long-term aquaculture sector strategies for adaptation; (4) Contributions of aquaculture to household resilience; and (5) Aquaculture adaptation in mainland Southeast Asia Region.

Climate-related risks to fish farms are significant today; some are likely to become even more serious under future climate change. Fortunately, good practices in risk management exist which can help in the short-term, and in the long-term there is a set of low regret, robust and flexible options worthwhile considering.

2 THE ASSESSMENT

2.1 RATIONALE

Half of the aquatic animal food consumed by humans is now from aquaculture.¹² The expectation is that this fraction will grow, as will the significance of aquaculture in global food security.⁶³ Today, aquaculture production is important to livelihoods, food security, and economic development in many countries.²²

In recent years in Thailand, the aquaculture sector has contributed about 40-50% of the total yield of aquatic animal products.^{9, 17, 22} Policies and projects in Thailand have also supported fish farming as a way to improve livelihood security and the well-being of the rural poor.^{1, 20, 50}

Climate-related risks to fish farms are significant today; they are likely to become even more serious in the future, due to climate change and water management needs

Climate and extreme events, such as high floods and seasonal droughts, already have significant impacts on production and profits. Not much is known about how climate change might impact the valuable aquaculture sector in Thailand in the future, but there are growing concerns that the adaptation challenges may be significant, especially given concurrent difficulties in managing water resources to meet both rising demands and needs for flood protection.

This initial assessment focuses on Northern Thailand. The region includes areas which seasonally, are relatively cool and dry as well as extremely hot and wet. Geo-politically, it includes the upper reaches of key rivers (Figure 1), and thus water flows are economically significant to both national flood and drought policies in Thailand. Fish farmers in Northern Thailand grow Nile tilapia and other fish in earthen ponds, as well as in floating cages in rivers and reservoirs.

2.2 SCOPE AND PURPOSE

Overall Objective:

To evaluate with stakeholders the risks posed by climate change to aquaculture in Northern Thailand, and the robustness of alternative adaptation options

The specific objectives were to:

- 1 Identify the most important climate-related sensitivities, vulnerabilities, and risks to aquaculture.
- 2 Document existing risk management practices and strategies.
- 3 Develop scenarios to help explore how aquaculture, water resources, and climate may change in the future.
- 4 Assess the robustness of current and plausible alternative adaptation options.
- 5 Recommend improvements to risk management practices, aquaculture development policies, and investment plans that would help aquaculture to adapt to climate change.

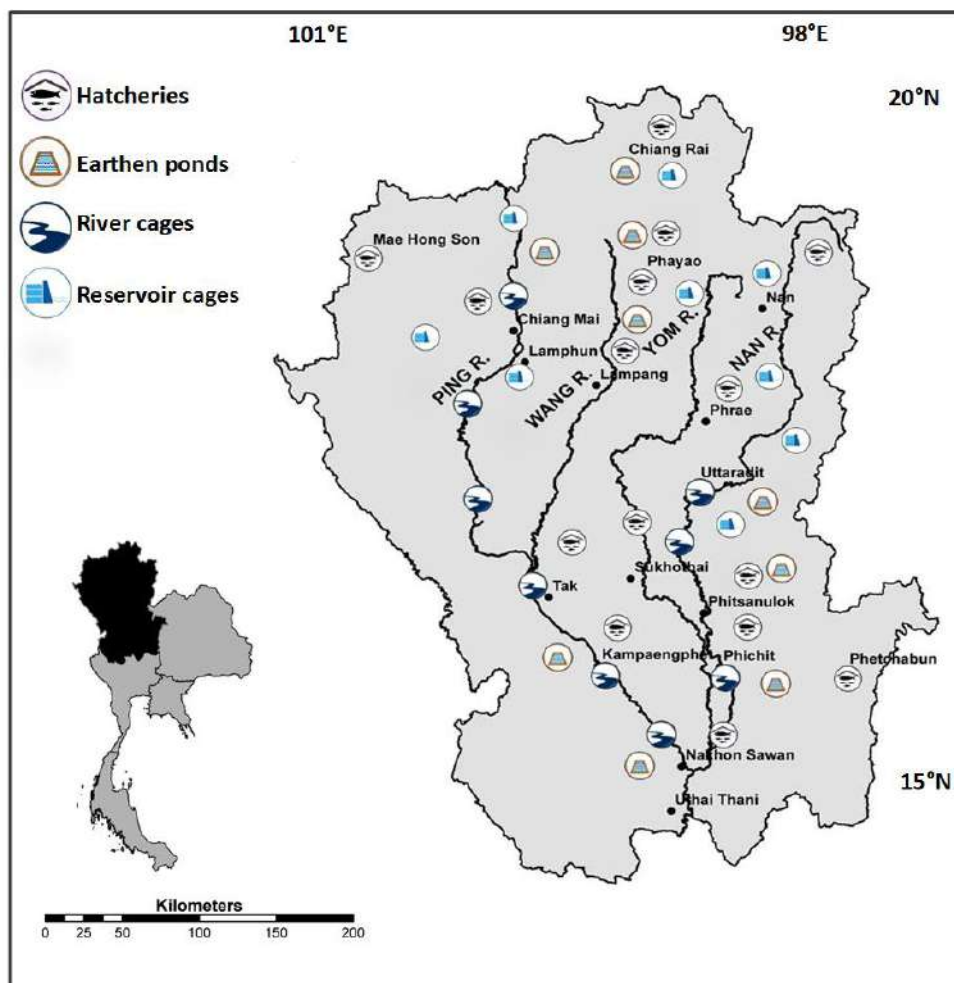


Figure 1

Map of assessment region in Northern Thailand, showing provinces in which different culture systems were investigated.

2.3 PROCESS

The process involved three main components. First, the published and documented research findings of the AQUADAPT project were synthesized. The studies included region-wide surveys of perceived climate-related risks, and management practices for pond and cage culture in rivers and reservoirs (Figure 1), as well as detailed biophysical measurements of water quality and conditions over all seasons of the year. In-depth interviews were also carried out in fish farming households and communities, as well as with hatchery managers and value chain actors. Mathematical simulation models were developed for aquaculture pond ecosystems and the water balance of river sub-basins; and where appropriate, linked with downscaled climate change projections and scenarios.

Second, and in parallel with the synthesis of research, a series of community-level assessment meetings and expert advisory group meetings were held. The views of scientific experts, policy and private sector practitioners, were also solicited through in-depth interviews and advisory group meetings.⁴⁻⁷

Third, selected existing policies, plans and strategies related to the development of fisheries, water management, and climate change were assessed. This was done through a combination of document analysis and interviews with responsible officials and other knowledgeable individuals.

The assessment process built upon a foundation of biophysical and social science investigations and consultations with stakeholders.

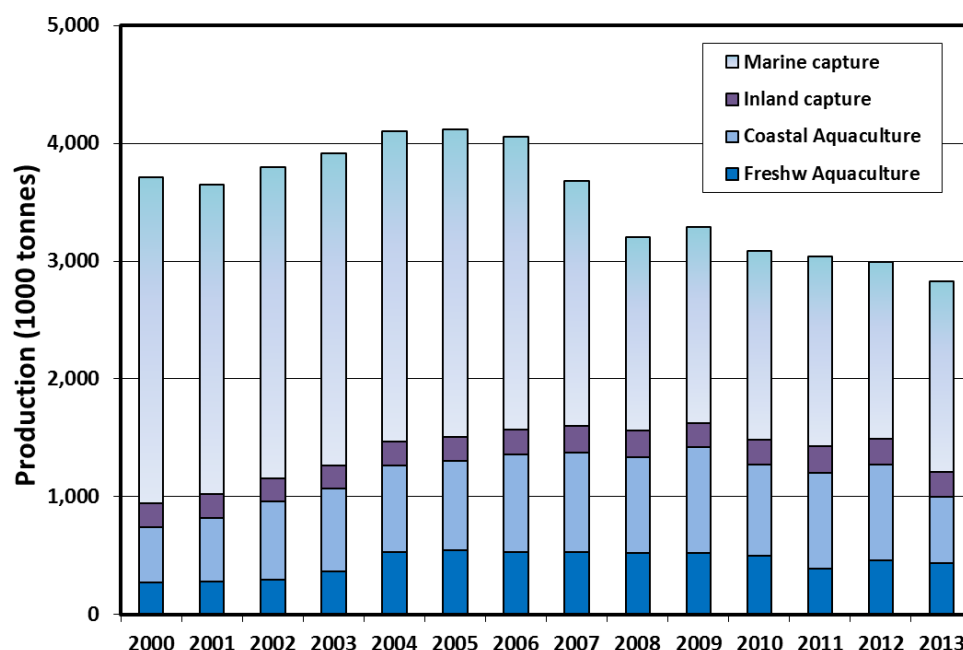
3 INLAND AQUACULTURE

3.1 PRODUCTION TRENDS

Aquaculture provides significant livelihood, employment and other ecological, social and economic services to people living in Thailand.^{1, 61, 62, 69} The sale of fish and wages earned on farms or in processing factories, enables people to buy other staple foods.²² The contribution of aquaculture to total fisheries production rose from just below 20% in 2000 to peak around 43% in 2009. In 2013 it was back down to 35%.

Figure 2

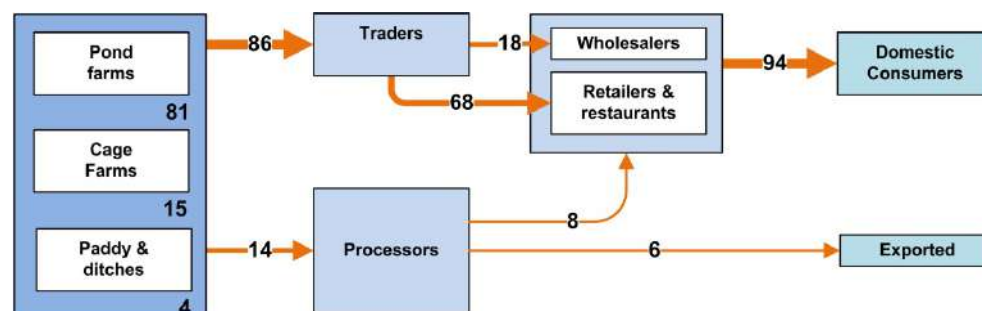
Capture and culture fisheries production in Thailand 2000-2013.¹⁵



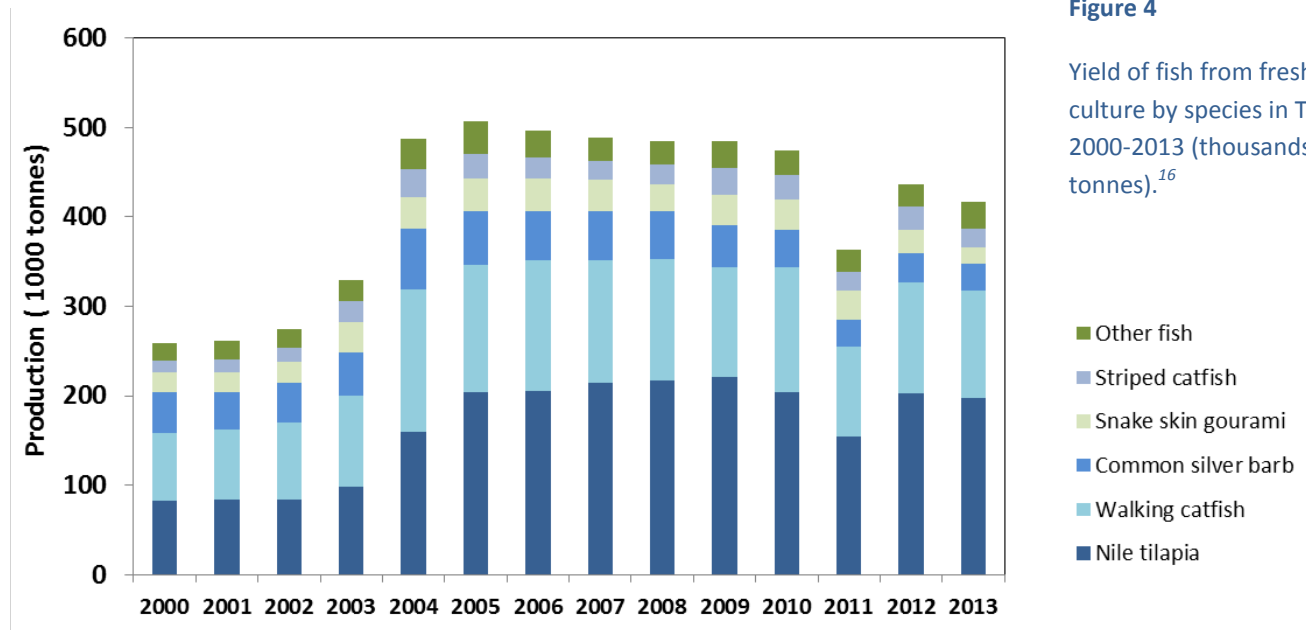
Use of marine and freshwater fisheries products is distinct. Marine products are frozen and canned, whereas most freshwater fish is eaten fresh. Non-food use of marine products is also high, and includes use as inputs to fish meal (for aquaculture). Fish consumption in Thailand is moderately high and increasing – it now averages around 30 kg per capita per year. Just over a third of fish consumed are from freshwater sources.¹ The contribution of aquaculture to total fish consumption within Thailand has risen even more strongly than overall consumption, reaching 44% in 2009. Most tilapia are consumed domestically (Figure 3). Tilapia is the most common species grown in Thailand (Table 1).

Figure 3

Product volumes in the national tilapia value chain. Numbers in arrows are estimated percentages of total volume of 221,043 tonnes produced for 2009.



A large number of freshwater species are cultured in Thailand. The most important by volume are listed in Figure 4. Herbivorous and omnivorous species are the most important for small-scale aquaculture, and include carps, gouramis, catfish and tilapias. Typically, between 14-20% of the production each year is from Northern Thailand.



3.2 CULTURE SYSTEMS

Five main culture systems for tilapia were recognized in the assessment (Table 1). Rearing practices in earthen ponds were much more diverse than those using cages, which were invariably commercially-oriented.

Pond feature	Earthen Ponds			Cages	
	Integrated	Commercial	Subsistence	River	Reservoir
Stocking Rate (fish/m ²)	2-3	2-3	1	100	60
Culture Period (months)	6	6-7	14	4-5	4-5
Feed type	Pellet feed	Pellet feed	Vegetable and food scraps, pellet feed	Pellet feed	Pellet feed
Manure inputs	Yes	No	No	No	No
Water Renewal Rate	Seldom	10% per day	seldom	Continuous (except in very low flows)	Continuous (at cage scale)
Harvest	Simultaneous	Simultaneous	Staggered	Simultaneous	Simultaneous

Table 1

Major features of different Tilapia culture systems studied.^{35, 39, 59}

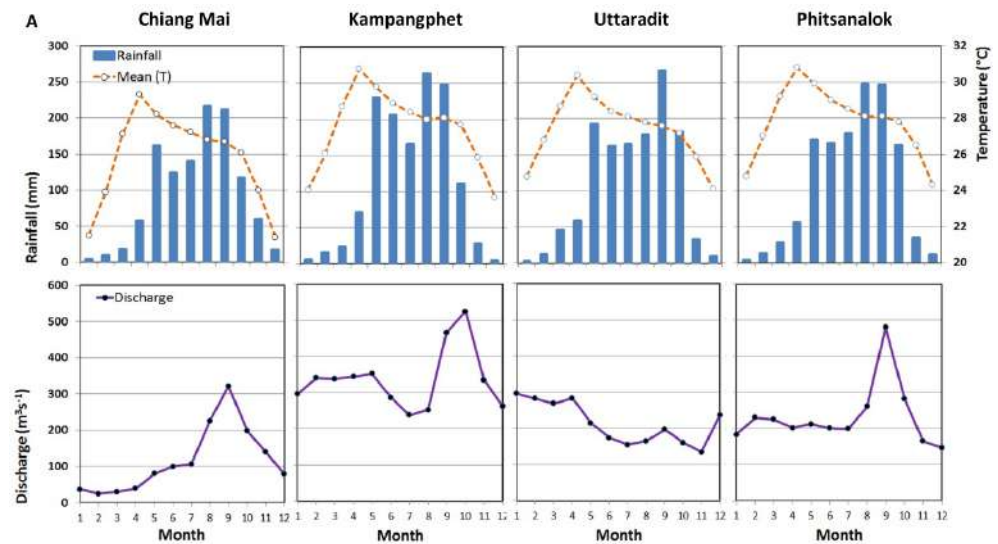
4 CLIMATE

4.1 SEASONS IN NORTHERN THAILAND

The climate of Northern Thailand is highly seasonal (Figure 5A), with most rainfall between May and October. Mean air temperatures are relatively cool between November–February, with the lowest temperatures found further North and at higher elevations.

Figure 5

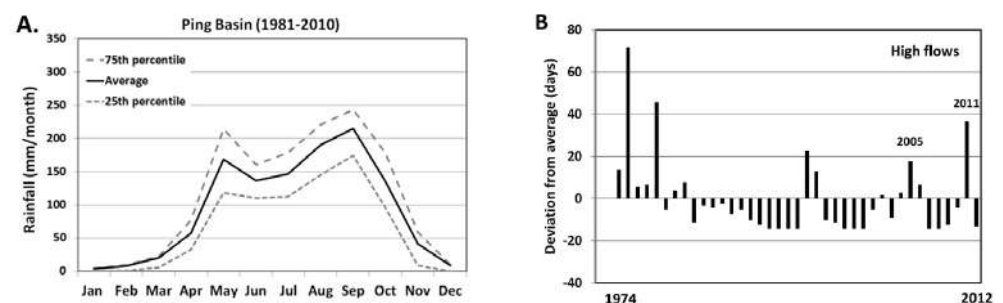
Seasonal patterns in climate and flow conditions in four fish farming study regions, (A) mean monthly rainfall and temperature (B) mean discharge ($\text{m}^3 \text{s}^{-1}$) each month for representative monitoring stations.⁴³



Annual patterns of mean discharge show peaks which lag behind that of precipitation (Figure 5B). This is particularly clear in the Upper Ping around Chiang Mai, where dry season flows are very low compared to other regions. Peak flows in the Upper Ping are strongly associated with tropical storms or monsoon anomalies, especially towards end of wet season; whereas minimum flows are influenced by human activities, such as irrigation, land-use, and dams.⁴⁵ Flow regimes in other regions are modified even more profoundly by the operations of water-related infrastructure. For example, in Uttaradit, the typical wet season peak is over-ridden by river regulation at a monitoring station in the city, and relatively close to Sirikit Dam (Figure 5B). Inter-annual variability in rainfall and discharge is also significant (Figure 6). A detailed analysis of the last 90 years of flow and climate records, for the Upper Ping at Nawarat Bridge, found that peak flows have not increased since 1921, whereas minimum flows, annual and wet season discharge, show a downward trend.⁴⁵ Analyses of the last 38 years suggest decreases in annual rainfall.⁵¹

Figure 6

(A) Variability in average monthly rainfall for the Ping Basin (1991–2010)⁶⁴ and (B) variability in days with high discharge ($>200 \text{ m}^3 \text{s}^{-1}$) at Nawarat Bridge (1974–2012).⁴³



4.2 FUTURE CLIMATE – TRENDS AND UNCERTAINTIES

The future climate of Northern Thailand is highly uncertain, especially with respect to rainfall.³³ Studies using different climate models, downscaling procedures, emission scenarios and statistical techniques, give different results.⁴³ For this reason, four qualitative climate change scenarios – *wetter*, *drier*, *more seasonal*, and *less seasonal* – were constructed to capture a range of plausible future climates likely to be significant for aquaculture (Figure 6). Under the *wetter scenario* rainfall increases in both wet and dry seasons; whereas in the *drier scenario* it decreases in both seasons. In the *more seasonal scenario* rainfall increases in the wet and decreases in the dry; whereas in the *less seasonal scenario* the pattern is reversed. Mean temperature increases in all scenarios, but in the *less seasonal scenario* we assumed no change in incidence of extreme heat waves relative to baseline, in order to maintain this as a ‘benign’ scenario.

Risk	Climate Scenario			
	<i>Wetter</i>	<i>Drier</i>	<i>More Seasonal</i>	<i>Less Seasonal</i>
Mean Temperature	↑	↑	↑	↑
Total Rainfall	↑	↓	–	–
Flood risk	↑	↓	↑	↓
Drought risk	↓	↑	↑	↓
Prolonged cloud cover	↑	↓	↑	–
Intense rainfall risk	↑	↓	↑	–
Cold spells	↓	–	–	↓
Heat waves	↑	↑	↑	–

Figure 7

Future climate scenarios and their implications for water-related risks to aquaculture production. Arrows indicate direction of change relative to historical baseline. A horizontal line means no significant change in either direction.³⁵

To help define plausible differences among scenarios, we analyzed historical and downscaled projected climate data for the period 2040-2059 under 2 different emission scenarios.^{31, 66} The wettest and driest climates from 9 different global climate models were used to set indicative average levels of change for total rainfall of +15% for the *wetter scenario*, and -5% for the *drier scenario*. The model with the lowest and highest combined rainfall in May and October were used to set indicative average levels of change for those two months: -20% for the *more seasonal scenario*, and +10% for the *less seasonal scenario*. In the *more seasonal scenario* the rain deficit is imagined as being transferred to the wet months (Jun-Sep); whereas in the *less seasonal scenario* it is shifted to the dry months (Nov-Apr). Temperature increases were estimated at 1.5-2.0C, with higher values at the warmest times of year (May).

Other studies have shown that the effects of changes in overall precipitation on run-off and river discharge depend on timing.⁵¹ Decreasing trends in precipitation, especially for the wettest August-September-October period, would translate into projected decreases in annual stream flow of the Ping River of 13-19%.^{51, 56} Seasonal shifts however, suggest that stream flow will be a little higher in the dry season, especially in April, against very low baseline values; but decrease in the rainy season months, with peak flows shifting from September to October.⁵¹

Statistical analysis of downscaled regional climate projections was used to put meaningful bounds on the four qualitative climate scenarios

5 RISKS AND SENSITIVITIES

5.1 MECHANISMS OF CLIMATE IMPACTS

The combination of the likelihood of that climate-related condition occurring and the magnitude of negative impact, is a climate-related risk. Table 2 summarizes our understanding of climate-related risks to the profitability of fish farms.

Table 2

Mechanisms of impact of key climate-related risks and how risks might be affected by climate change and other factors.



Climate-related risk	Impact mechanisms	Key climate driver	Climate change concern	Interacting factors
Earthen ponds				
River-bank overflow flood	Escapes Exotics introduced Damage to ponds and equipment	Tropical storms bringing 3-5 days rains to catchment of nearby water courses	Increased likelihood	Irrigation infrastructure
Flash flood or high run-off	Pollutants or sediment influx Stressing or killing fish	Intense rainfall	Increased likelihood	Watershed land-uses and bank-riparian conditions
Low flows, water storage	Low water quality and exchange Low DO leading to stress and death	Late start to wet season	Increased likelihood and duration of episodes	Water storage and diversions for other uses
Persistent, dense, cloud cover	Low photosynthesis in daytime leading to low DO levels at night, in turn causing stress or killing fish	Large storm systems with prolonged, thick, cloud cover	Increased likelihood and duration of episodes	High nutrient inputs and phytoplankton blooms
Heat waves, extreme high temperatures	Phytoplankton blooms impacting water quality DO Thermal stress	Seasonal transition prior to onset of rains and wet season	Increased likelihood and severity of heat waves	High nutrient inputs, low water availability for exchange
River-based cage aquaculture				
Fast flows and floods from high river discharge	Net deformation leading to collisions with fish Displace cages Fish swim until	Tropical storms bringing 3-5 days rains to catchment upstream	Higher frequency and severity	Infrastructure failures (e.g. weir collapse)



Climate-related risk	Impact mechanisms	Key climate driver	Climate change concern	Interacting factors
	exhausted Flood debris damage			
Heavy rainfall and run-off	Influx of polluted water or sediments stressing or killing fish, increasing susceptibility to disease	Intense rainfall First rains after dry period	Increased frequency	Watershed land-uses and bank-riparian conditions
Low flows and shallow water depths	Poor water quality, low dissolved oxygen Lower cage volumes means increased effective fish densities in Cages may be damaged	Late start to wet season (monsoon)	Increased likelihood and duration of episodes	Water storage and diversions for other uses
Reservoirs				
Rapid changes in temperature	Thermal destratification, exposing fish to low DO stress after sharp temperature decreases	Seasonal transition into cool/dry season Windy conditions mixing upper and lower water layers	Increased likelihood of sharp temperature changes	Reservoir management operations which influence mixing
Drought	Cages forced to move into less suitable higher density locations with risks of poor water quality	Low rainfall end of wet season Late start to monsoon	More severe or longer dry season	Dam operating rules reflecting irrigation and flood protection policies
Hatcheries				
Heat waves	Overly rapid development	warmer conditions in already high average temperature periods	Extreme high temperatures more likely in future	
Water shortages	Insufficient water for exchange leading to low water quality	Longer dry season (delayed monsoon)	More likely if less rainfall	High water demand by other users





5.2 POND CULTURE

5.2.1 OBSERVED IMPACTS

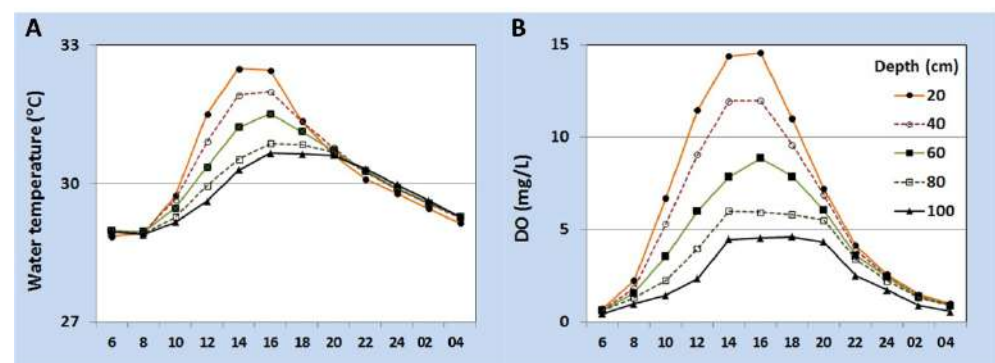


For earthen pond culture, floods, droughts, prolonged cloud cover, and heavy rains were the most important risks.^{4, 49} Cold spells in winter also reduce fish growth. Seasonal water shortages limit exchange, and make it difficult to maintain pond depths and water quality.^{49, 60} High phytoplankton concentrations in ponds can lead to low dissolved oxygen (DO) levels early in the morning, due to night-time respiration by phytoplankton.^{32, 59} Episodes of low concentrations of dissolved oxygen are major causes of fish stress; reducing growth and increasing mortality in aquaculture ponds.⁵⁹

Thermal stratification followed by rapid turnover with sharp changes in temperature, can also cause mass mortality events by dint of exposing fish to low dissolved oxygen concentrations (Figure 8).⁵⁸ The risks are highest near dawn in high-nutrient input culture systems; following a day of prolonged and thick cloud cover, which reduces sunlight and thus normal rates of photosynthesis by phytoplankton.⁵⁹ Thermal water stratification peaked around 14:00h to 16:00h each day when, differences between surface and lower water temperatures reached 1.3 to 4.0 °C.⁵⁹ Thermal de-stratification in the hot season and dry season usually occurs late at night; in the wet season however, it occurs early in the evening due to the cooling effects of rain

Figure 8

(A) Thermal stratification and
(B) Dissolved oxygen
dynamics over 24 hour period
in a high input earthen pond
on a hot day.



Simulation experiments with a biophysical model of an aquaculture pond calibrated to conditions in Northern Thailand, suggests that thermal stratification is influenced by light intensity, turbidity, and air temperature. Mean air temperature had a notably greater effect on stratification than daily air minimum-maximum temperature difference. The risk of DO levels lower than 2 mg l⁻¹ was found to increase with decreasing light intensity and high turbidity, but decrease with wind speed because of mixing effects.⁵⁷

Consumers do not like earthy-musty off-flavors in fish products. Cyanobacteria in high nutrient ponds are a potential source of odorous compounds. In a study of high nutrient ponds in Chiang Rai, the highest concentration of the odorous compound 2-methylisoborneol (MIB) was observed in October, whereas for another odorous compound, geosmin, there was no distinct seasonal peak.⁴⁸ In low nutrient input systems, to which no animal manure is added and fish are not regularly fed formulated pellets, the risks of both low dissolved oxygen concentrations and off-flavour problems are much lower than in commercial culture system.

5.2.2 POTENTIAL FUTURE IMPACTS

A *drier* climate would be a challenging scenario – especially if water demand was also high – for earthen pond culture. Under these conditions, aquaculture production would be significantly constrained in the dry season, even with high demand pushing up prices.



Pond culture in a *wetter* climate would be difficult for conventional commercial farms located in flood plains, as it causes fish escapes as well as unwelcome introductions. Less extreme, but longer duration floods may be beneficial for aquaculture relative to other land-uses; for instance, the duration and depth of seasonal flooding in the Mekong Delta of Vietnam helped explain the adoption of rice-fish integrated aquaculture by rice farmers.¹¹



Higher rainfall, apart from increased flood risks, may also mean greater likelihood of successive days of thick cloud cover; thus increasing risks of low DO episodes. The most important response is expanding the use and efficiency of aeration technologies.



The most challenging combination of conditions for ponds would probably be: a *more seasonal* climate with high water demand and low fish demand. In this situation, there would be a need for high investments to reduce risks from floods in wet, and again towards end of dry, to reduce risks from low flows and heat waves. The *less seasonal* scenario would be relatively benign even when compared to current conditions.

Warmer conditions across the full range of rainfall assumptions, on average, could have negative or positive effects. To some extent, fish may be able to acclimatize to higher water temperatures, but for tilapia and carp specifically, warmer temperatures above 30C result in increased oxygen consumption, which in turn could reduce growth rates.¹⁹ In some locations, especially cooler regions such as at higher elevations, some positive impacts are anticipated, including: faster growth rates, higher food conversion ratios (FCR), and longer-growing seasons.^{23, 47} Positive impacts in growth, however, may be offset by adverse impacts in other areas, such as loss of reproduction or increased risks of disease.^{8, 26}



Hybrid red tilapia are primarily grown at high densities in cage culture systems, but some pond farmers also grow this strain as it fetches a higher price than the conventional Nile tilapia



5.3 RIVER CAGE CULTURE

5.3.1 OBSERVED IMPACTS



Tilapia farms in Northern Thailand are adversely effected by extreme floods every couple of years. River-based culture using floating cages is well adapted to moderate changes in water depth, but are still vulnerable to high speed flows or flood waters laden with sediments, debris, or contaminants.^{5, 39} High flows exhaust and injure fish, and can damage cages.⁶⁷ Many risks are season, river, and place-specific (Table 3).⁴² Low flow velocities and depths result in low water quality, including low dissolved oxygen concentrations in cages, in turn, stressing fish and increasing the likelihood of disease outbreaks (Box 2).^{5, 14} The suitability of growing conditions varies between rivers; in part, because of topography and size, but also because of the effects of water infrastructure operations.^{39, 43} Farmers also must deal with non-climate-related risks. Most cage farms (84%) had faced disease problems in the last two years. Protrusion eyes or exophthalmia ranked higher than other clinical signs. Most farmers noticed that the risk of disease problems was similar every month; however, the worst month was April.¹⁴

Table 3

Impacts of floods and low flows (droughts) on river cage farms in two recent calendar years in four culture regions.⁴³

Event type	Year	% Farms Impacted					Income loss from deaths if impacted
		Upper Ping	Lower Ping	Upper Nan	Lower Nan	Total	Thousands Baht Mean (SEM)
Flood (high flow)	2012	25	40	19	11	24	61 (10)
Flood (high flow)	2011	61	67	67	64	65	81 (7)
Drought (low flow)	2012-3	33	26	63	34	44	63 (9)
Drought (low flow)	2011-2	34	14	11	6	18	46 (7)

5.3.2 POTENTIAL FUTURE IMPACTS



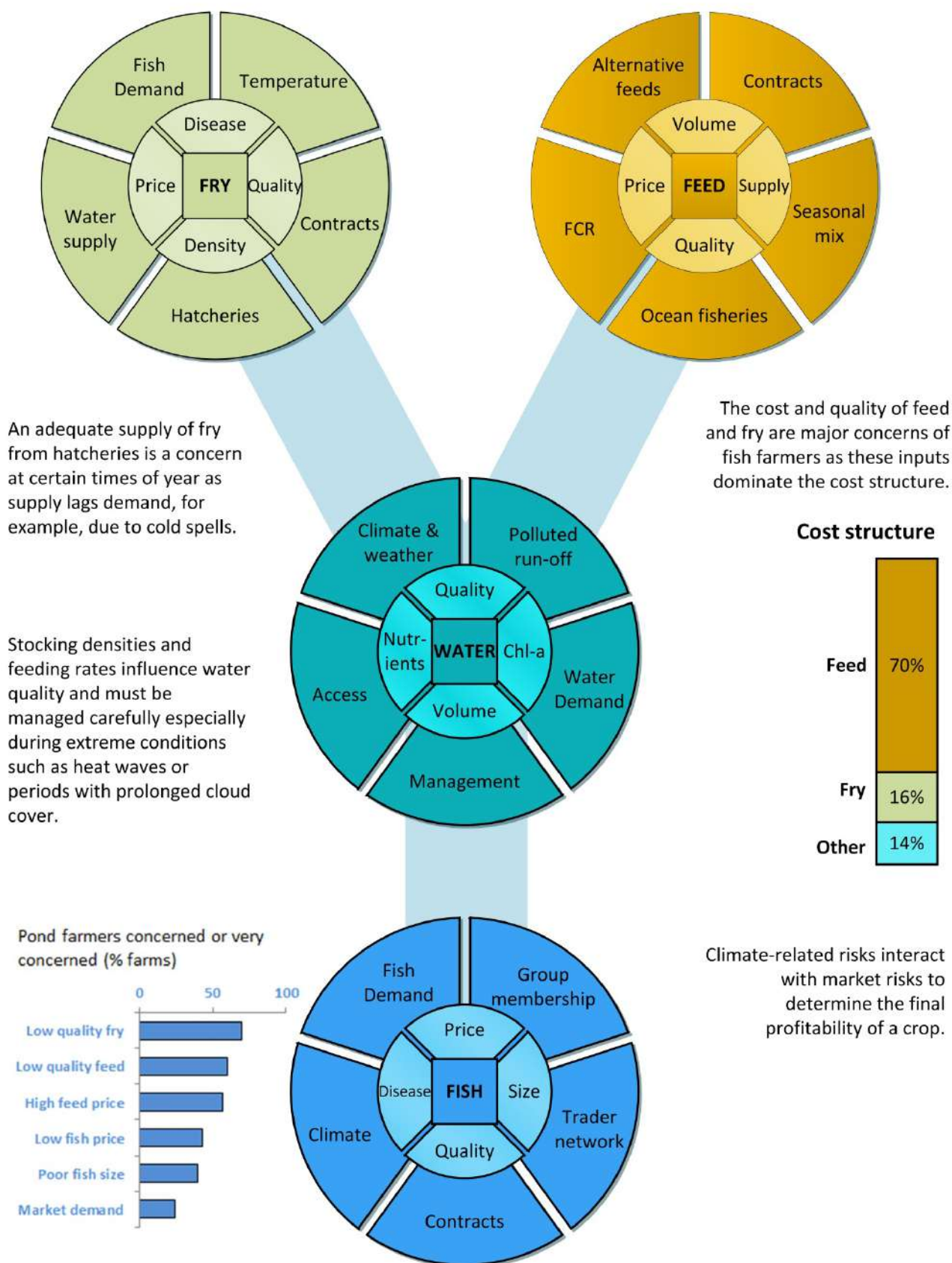
A *more seasonal* climate would be challenging for river cage culture in most locations, whereas a *wetter* climate, up to a point, would reduce issues related to low flows in smaller river sections like the Upper Ping. In other locations, a *wetter* climate, with increased risks of high flows or floods would have negative impacts.



A *drier* climate would be a challenging scenario – especially if water demand was also high – for cage culture in rivers. Under these conditions, aquaculture production would be significantly constrained, given competing needs to manage stored water for irrigation and other uses. Heat waves accompanying low flows would also have large negative impacts. A *less seasonal* climate would be more benign than the other three scenarios. Modest increases in average air temperatures would likely have only modest impacts on river cage culture, and might even be positive in cool season if water flows are sufficient; for instance, in all but the *drier* scenario.

Fish fry, feed and water are the key material inputs and thus a source of risks to profits.

Box 1





5.4 RESERVOIR CAGE CULTURE

5.4.1 OBSERVED IMPACTS



In reservoirs, important climate-related risks include those related to high or changing temperatures and droughts (Table 4). One significant risk from observations is the sharp drop in temperature at the transition period from wet to cool season; whereby, the mixing of previously stratified water column brings low DO bottom water to the surface, whereat fish are grown in cages.⁶⁸ In reservoirs with forested watersheds, low nutrient inputs mean very low phytoplankton levels; in these situations, wind waves are expected to be the main mechanism by which water is oxygenated. The infrequent but severe mass mortality events observed in reservoirs in Northern Thailand could be caused by stress to fish from exposure – following mixing of stratified waters – to very low DO levels.

Table 4

Percentage (%) of farms for which last crop was impacted by four types of climate-related conditions.

	Drought/ Low water	Heat wave	Cold spell	Prolonged Cloud Cover
Farms impacted last crop	32	45	51	50
Type of impacts (if impacted)				
Fish eat less/grow slowly	74	77	98	88
Fish weak/susceptible to disease	68	75	71	77
Fish die	87	93	84	81
Fish musty odor	26	25	18	27
Average loss (Baht)	337,000	21,000	40,000	81,000

5.4.2 POTENTIAL FUTURE IMPACTS



A *drier* climate would be a challenging scenario – especially if water demand was also high – for cage culture in reservoirs, as management to store and release water would be strongly driven by the needs of competing users. A *wetter* climate, provided it did not increase run-off of pollutants, would probably be beneficial, as would a *less seasonal* climate. A *more seasonal* climate would have complex adverse impacts, arising primarily from water reservoir management responses related to needs of other water users, and possible impacts on stratification and water turnover which can lead to mass mortality events.



Heavy rainfall or cold spells may also trigger de-stratification events in ponds or reservoirs; again, aeration technologies alongside water quality monitoring are key.



Heat waves would have negative impacts under all scenarios. Modest increases in average air temperatures would likely have only modest impacts on reservoir cage culture, and might even be positive in cool season.

5.5 HATCHERIES



5.5.1 OBSERVED IMPACTS

Extreme high temperatures appear to stress fish and increase risks of diseases, especially when they coincide with periods of low water levels near the beginning of the wet season. Heavy rainfall events – especially those after a dry period – bring in high levels of sediment, or include high concentrations of accumulated pollutants, which in turn can result in mass mortality events. Cold spells in the more northern sites reduce fish feeding and growth in all culture systems, as well as hinder breeding in hatcheries.⁶⁴



5.5.2 POTENTIAL FUTURE IMPACTS

Hatcheries are dependent on good water supply, and thus are adversely impacted under the *drier* or *more seasonal* scenarios. The *wetter* scenario would only be an issue for hatcheries located in flood-prone areas, and without protective barriers. The expected increases in temperature will result in large declines in fecundity in the three representative sites in the warmest month (April); especially in the south of Pichit, where average temperatures are already high (Figure 9A).⁶⁴ In the coolest month (December or January) at each site, the projected changes under both emission scenarios would have a positive effect on fecundity in two northern sites (Chiang Mai and Nan), but would have small negative effects in Pichit; the patterns for hatching rate are similar, but smaller and less negative (Figure 9B).



In the coolest months, warmer temperatures would have positive effects on hatching rates in all sites. In the warmer months, effects are all negative and largest in Pichit – the warmest site. The projected changes for early fry survival are smaller than for fecundity or hatching rate, but follow a similar pattern (Figure 9C). For all three key hatchery variables, the impacts (positive or negative) tend to be more pronounced in the longer-term (2080–2099), and with higher emission assumptions (RCP 8.5, Figure 9).

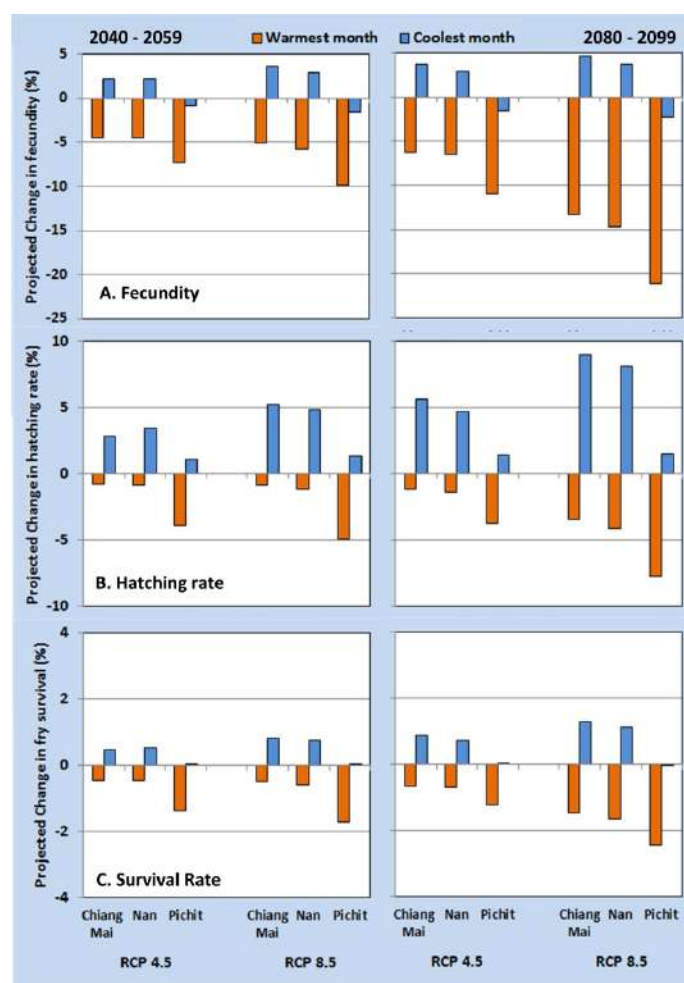


Figure 9

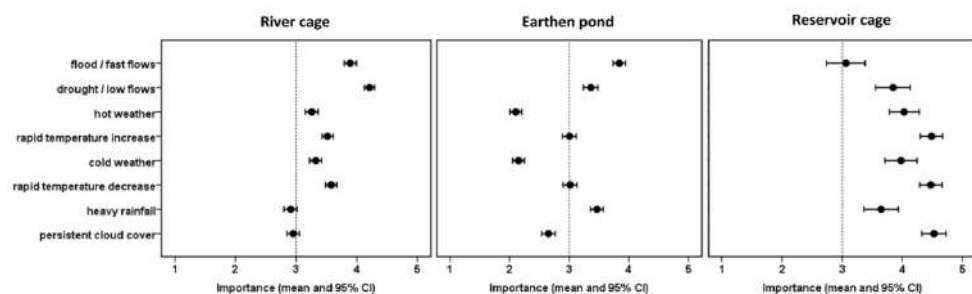
Projected changes in absolute fecundity (a) and hatching rate (b) of female Nile tilapia, and early survival of their fry (c) at three sites in Northern Thailand, under the RCP 4.5 and 8.5 greenhouse gas emission scenarios for warmest and coolest months. Change estimates are based on comparison in 2040–2059 or 2080–2099, relative to those in the baseline period of 1980–2004.⁶⁴

5.6 RISK PERCEPTION

Risk perception is important to intentions to act and what people do in response to threats or risks. Thus, having a clear understanding of how concerned different kinds of individuals in different situations is critical to the design of risk communications and many other interventions to reduce risks. Figure 10 illustrates how risk perceptions varied among climate-related sources of risk in three different culture systems. For the most part climate-related risks were perceived as lower in pond than in cage-based systems, although there was a lot of variation with respect to individual risks. Some of these risk perceptions were already highlighted in the previous pages where discussed individual culture systems.

Figure 10

Level of concern or importance of impacts of climate-related risks to the profitability of fish farm in three aquaculture production systems based on individual responses, scored as: 5 (very concerned) through 3 (somewhat concerned) to 1 (not concerned at all)^{42, 49}



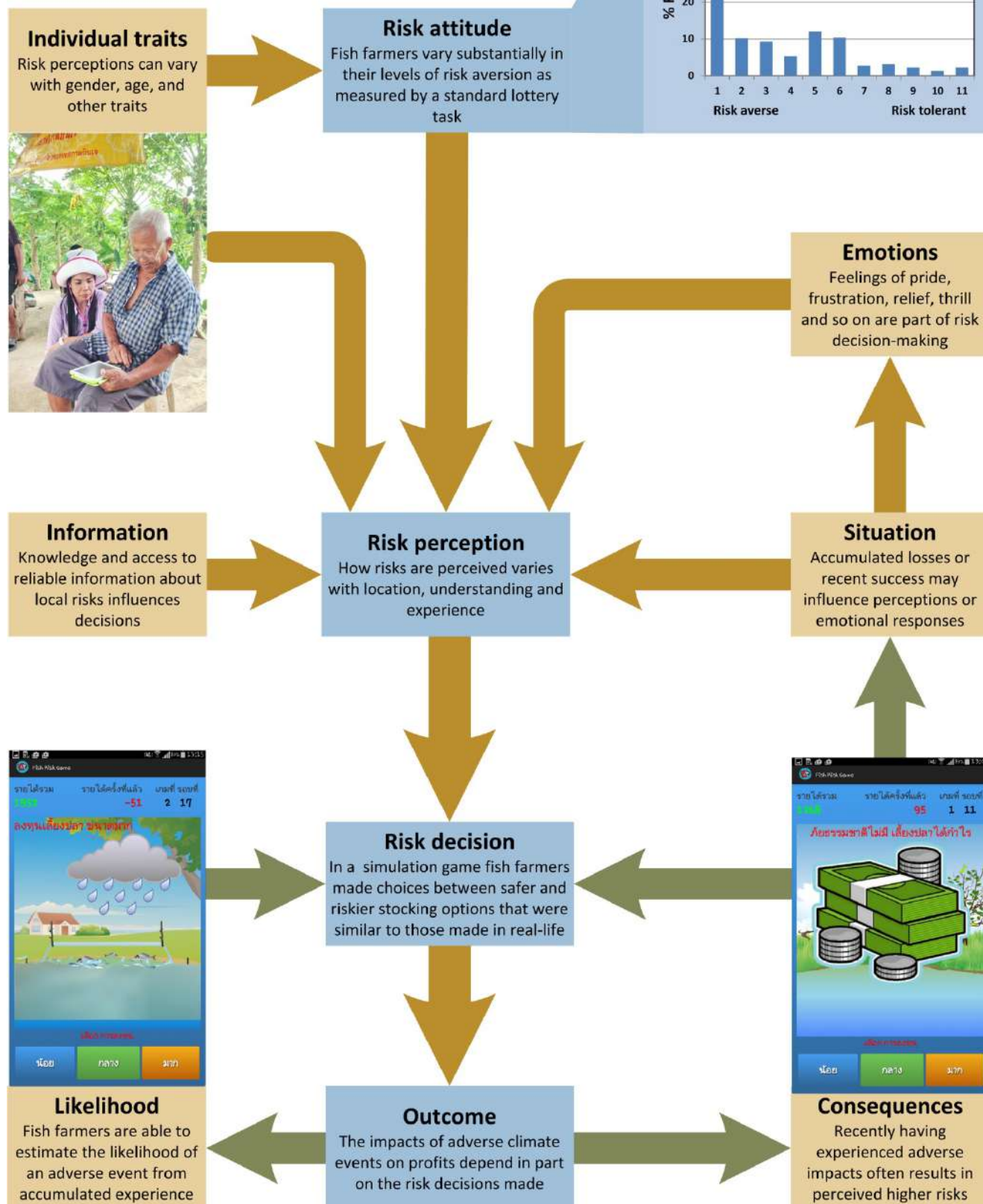
Most of our detailed understanding about perceptions of climate-related risks in this assessment comes from studies of fish farmers who rear fish in river cages.^{38, 42} For this sub-set of fish farmers we complimented surveys on levels of concern or importance of various risks with measurements of risk aversion and exploration of risk decisions in a role-playing simulation game (Box 2).⁴⁴

Recently having experienced adverse impacts from a serious flood or low-flow, drought, conditions, was associated with higher perceived risk.⁴² In a simulation game in which farmers had to make repeat decision to stock at lower, intermediate or higher densities, farmers responded to large losses following a flood with a safer, lower density, stocking decision (Box 2). The game also showed however, that it was not easy for farmers to evaluate levels of risk, or learn the best stocking strategy, from a history of experience of losses and gains.⁴⁴ The difficulty was particularly high for games in which the level of risk increased – what may happen under climate change.

Fish cage farmers, show a wide spread in attitudes to risk with some farmers being highly risk averse and others much less so.³⁸ In in-depth interviews some of these differences were explained in terms of recent experience or levels of losses and gains relative to assets held; but in other cases emotional factors related to making risk decisions were also alluded to implying that in addition to calculations, emotions also play a role in risk decision-making.

The insights from this research are important to policies and projects aimed at improving climate risk management in inland aquaculture. Risk awareness raising, for instance, is often an important part of risk sharing mechanisms like insurance as insurers are only interested in compensating for losses if victims have followed good practices in managing risks; they do not want to award mismanagement.²⁵

Perceptions of risk are important for decisions and depend on other factors

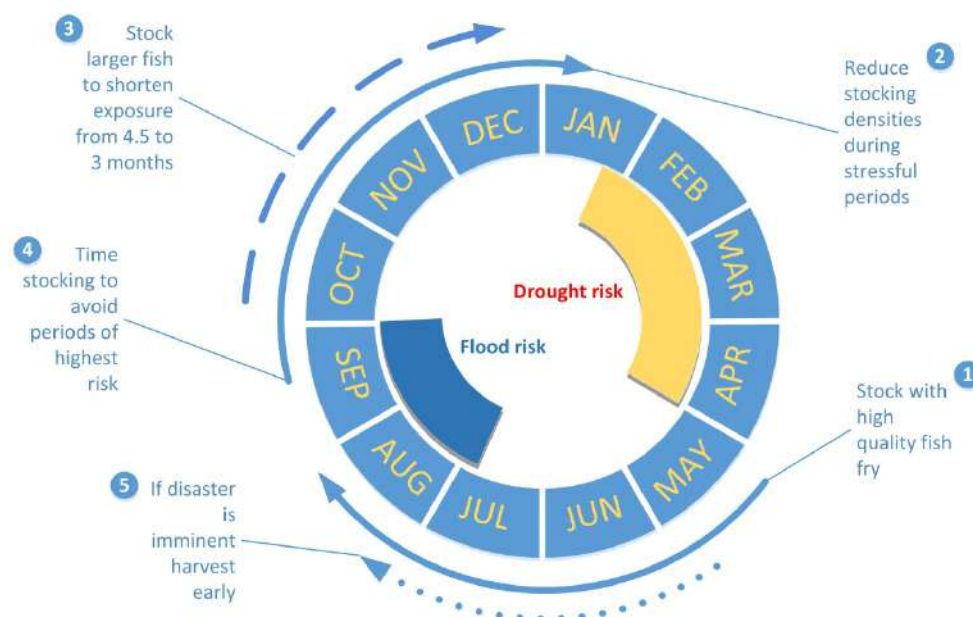


6 MANAGEMENT OF RISKS

Today, farmers use a combination of adjustments to rearing practices, cropping calendars (Figure 11), water management, as well as financial and social measures to manage climate-related risks. Individual risks are often addressed through multiple farm or household level practices and strategies. Shared risks usually require collective action.

Figure 11 Reducing risks through stocking decisions

Attention to the stocking calendar is an important way to reduce and manage risks.



Climate risk management thus involves actions at multiple spatial and temporal levels (Table 5). In the short-term, many of the key decisions and actions rest with farmers as they react to imminent threats. In the mid-term are more tactical decisions like those related to stocking. In general, short-term reactions are no-regret options, whereas the worthwhileness of mid-term tactics depends on the risk reduction benefits of the tactic, the perceived levels of risk, and estimated costs of action. Fish farmers also proposed and supported several long-term strategies at the watershed and sector level. A few of the long-term strategies like ecosystem management, zoning, species selection, and development of standards or export markets were proposed by officials (often as part of existing policies) or experts. While short-term reactions and mid-term tactics are an important and valuable part of climate risk management, it is the long-term practices or strategies which are especially critical to the challenge of adaptation to climate change, and will be the focus of the scenario analysis in Section 8 of this report.

Spatial and temporal scales	Short-term reactions Hours-days Imminent weather conditions and extreme events and emergency actions	Mid-term tactics Weeks-months (crop) Anticipated seasonally-varying conditions and risks and recovery actions	Long-term strategies Years-decade (multi-crops) Inter-annual climate variability and resilience-building actions
Farm and household level	Move cages towards banks ^R Harvest early Provide aeration Withhold feed Exchange water ^E Move fish from cages to ponds ^R	Adjust stocking date or density Strengthen cages ^{R,D} Water quality monitoring ^P Purchase and upgrade water & culturing technologies On schedule loan payments Share rearing knowledge Store water for dry season ^E Increase disease surveillance Adopt voluntary standards	Migration to diversify production locations Diversification of income sources Integration of farm activities for resource efficiency ^E Savings to help cope & recover
Watershed and Community-level	Share warning information Share market information Mutual assistance during emergencies	Adjust infrastructure operations on seasonal water allocation Coordinate purchase of inputs and sales of harvests Share rearing knowledge Engage in community and basin water management activities Share credit information Water quality monitoring ^{R,D}	Establish and strengthen growers' association to support innovation and learning of best practices Maintain natural biodiversity so watershed continues to provide services Support integrated water resources management Improve climate information systems to support regional seasonal forecasting Invest and build water infrastructure
National and sector-level	Provide disaster relief Share timely warning information with local authorities	Implement zoning- and season-dependent support or incentives Implement voluntary standards Regulate and monitor industry and market practices Provide timely compensation	Improve insurance and compensation schemes Develop alternative export markets Invest in research and development for alternative technologies and species

Table 5

Time and space scales of risk management practices relevant to adaptation. Illustrative examples only. If not relevant for all culture systems, then indicated with specific subscript: R= river cage, E=earthen pond, D = dam.⁴¹



6.1 POND MANAGEMENT

Fish farmers' should: (1) take care to avoid over-feeding; (2) manage water and sediments to prevent excessive accumulation of organic matter and waste at the bottom of ponds, which can influence other water quality parameters; and (3) use aeration and mechanical mixing interventions at critical times to reduce stress on fish from low DO concentrations, and risks of mass mortality events.⁵⁹ A key way to deal with adverse impacts of higher pond temperatures is to increase water mixing to prevent stratification (Figure 12).⁴⁷ This could be done through mechanical aeration devices, or where water is abundant, allowing more water exchange (Table 5).



Water conservation practices can help reduce pressure on ground and surface water resources, as well as reduce release of effluents from fish ponds.¹³ Integrated systems which involve re-use of water from irrigation for aquaculture or vice-versa, may help improve water efficiencies.³ A comparison of aquaculture systems in irrigated and drought-prone rainfed areas of Northeastern Thailand found that integration of nutrient and water resource flows was higher in rainfed systems, which depended more on organic inputs than chemical fertilizers.⁴⁶ Farm aquaculture ponds can be important as an on-site storage of water to supply vegetables, fruits, and paddies during the dry season; and may also be a recipient of residues and by-products from other farm activities.⁴⁶ Rice-fish farming is another way of reusing water and recycling nutrients to intensify production.² Ponds on a farm change the physical landscape. In seasonal, rain-fed systems, the water stored in ponds help reduce impacts of dry periods.

In facilitated meetings, fish farmers discussed and jointly evaluated the performance of specific practices, in particular, the key short-term reactions and mid-term tactics at the farm and watershed level (Box 3). These evaluations included estimates of costs relative to expected benefits, as well as observations on how conditions and situations of individual farms can influence these calculations.

Figure 12

Aeration using paddle-wheels is an important technique to reduce risks of mass mortality from low dissolved oxygen levels.



6.2 RIVER CAGE MANAGEMENT



Farmers use a combination of adjustments to rearing practices, cropping calendars, as well as financial and social measures, in order to curb those risks to production and profits which they perceive as being manageable.⁴¹ In the short-term, for example, providing supplementary aeration is a key action for ponds and river cages during periods of very low flow; i.e. when risks of low DO are increased (Table 5). In the case of pond culture, there may be other options to pre-treat or increase water exchange, such as supplementary groundwater extraction or drawing on small-scale water storage. In cage culture, site selection and options to temporarily move cages or fish, for example, are important when dealing with imminent extreme high flows.⁴¹

Individual risks are often addressed through multiple practices and strategies; conversely, a particular management practice can have a bearing on several different risks. Reducing stocking density, for example, is a common practice for reducing many types of risks under challenging conditions.⁴⁴ Stocking larger fingerlings, by reducing the length of culture period in risky locations or seasons, is another way to reduce exposure to multiple types of risk. An individual climate risk like flood conditions, may trigger multiple practices, such as withholding feeding, increase fish monitoring, and moving cages. As best practices in risk management are not necessarily widespread, there is therefore often value in short-term sharing of information about existing technologies and practices.



Site selection is a key way to reduce vulnerabilities to climate-related risks. If differences among sites are understood, that knowledge can be used to guide investment decisions. By the same token, if understand how risks might change with time, can also consider longer-term planning options or development of new locations for aquaculture. At the river reach level, influencing the management of water infrastructure, dredging operations, and taking action as a group are important in reducing risks (Table 5, and Figure 13).

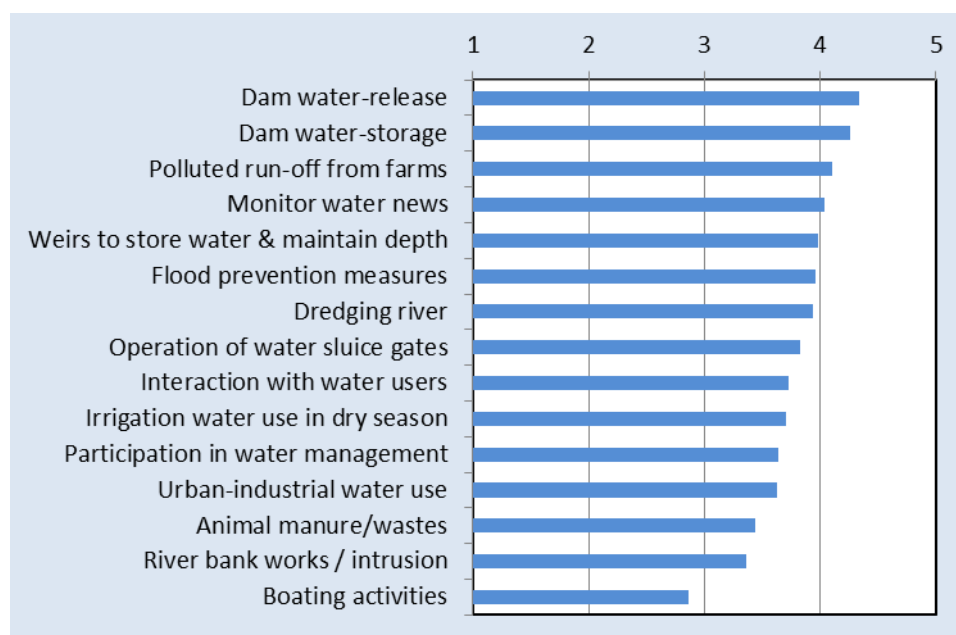


Figure 13

Level of importance given to different river reach or basin level risk management practices. Averages scores of 662 fish cage farmers on a scale of 1 (unimportant) to 5 (very important).⁴¹

Box 3

Fish farmers assessed how they were managing climate-related risks

1

Identify Risks

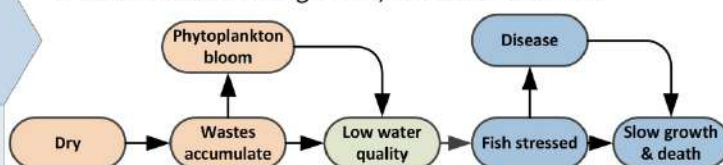


Droughts or water shortages are an important risk towards the end of the dry season. Low water availability problems may be further exacerbated by extreme high temperatures.

2

Understand impact mechanisms

Under these dry and hot conditions wastes accumulate, phytoplankton blooms and the risks of low dissolved oxygen levels increase causing stress, disease and death.



3

Evaluate response options

The benefits and costs of using versus not-using particular risk reducing techniques were estimated by fish farmers and any special conditions noted. Tips on how to use techniques were also shared.



Aeration



Reduce stocking



Skip season



Early harvest

4

Choose and plan action

After consultation fish farmers agreed that the priority should be forming a stronger fish farming group as this would help with managing many risks.



5

Implement action

On request the research group then did further consultations and analysis on the merits and limitations of different forms of group structures and insurance and shared this information through exchange visits among fish farming groups.



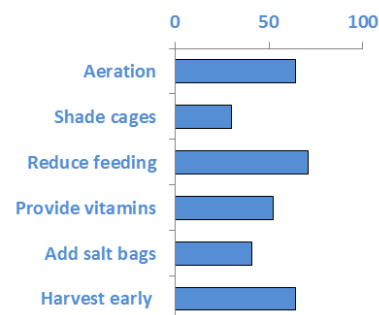
6.3 RESERVOIR CAGE MANAGEMENT

Risks are primarily managed at the farm level, with techniques like aeration and reducing feed exercised during stressful periods.³⁷ Early harvest to cut losses in response to severe conditions was another important measure, as has been observed in river-based cage culture.³⁹ Farmers also emphasize the importance of maintaining good relations with other stakeholders, monitoring weather news and reservoir water management (Table 6). Larger farms placed greater importance on risk management than small farms, even though types and levels of risk perceived were very similar. Respondents with larger farms, for example, considered water storage in dams and allocation for irrigation as more important than those with small farms.

Fish farmers also emphasized importance of watershed management for reducing risks from polluted run-off from orchards. 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 stocking densities do not exceed the assimilative capacities of the reservoir ecosystem. Longer-term strategies suggested by farmers went beyond technical measures; for example, diversification of income sources and maintaining good social relations with other stakeholders. Fish farmers perceive that climate is changing, and they expect it to continue to do so in the future. They also recognize the need for planning ahead. Risk management practices at the farm level however, need to be integrated more closely with reservoir and watershed management.



Risk management during heat waves for reservoir cages (% farms)



6.4 HATCHERY MANAGEMENT

Three strategies which would enhance adaptive capacities of hatcheries to climate change are suggested.⁶⁴ First, and with immediate benefits, is to improve the management of climate-related risks under current climate variability. The emphasis should be on improving the level of preparedness of hatcheries in dealing with water scarcity during particularly dry years, and extreme flood events in the wet season. In part, this is a water resource management issue, and therefore will require interaction with other, non-fisheries stakeholders.

Second, is to improve monitoring and information systems, so that rapid, slow-onset and newly emerging climate-related risks, are understood sooner and better by both hatcheries and their farming customers. Hatcheries currently do not systematically collect information on fecundity, hatching rates, or survival rates of fry. They also do not regularly monitor water quality or document weather conditions on site. In the short-term, strengthening early warning systems and improving understanding of risks is key. More thorough monitoring and information management would help strengthen hatchery production planning; for instance, in adjusting production schedules to deal with seasonal and inter-annual variability in climate-related risks.

Third, is to undertake research to develop better strains and new species for aquaculture; as well as improve and adapt hatchery facilities and operations. More research is needed on the effects of seasons and climate on the spawning habits of different fish species, and the impacts it has on hatchery production systems. Work also needs to continue in conventional areas such as broodstock management, improving feeds, feeding practices, disease management, and water management systems.



Hatchery production is affected by weather events and climate, and as a consequence it is sometimes challenging to meet farmer's demands for fish fry

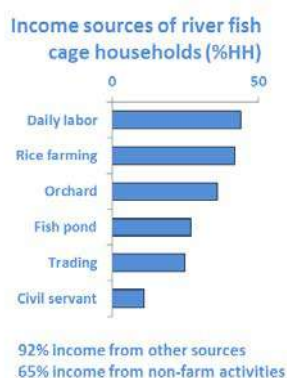
7 HOUSEHOLD RESILIENCE

7.1 RESOURCES

Households which farm fish differ with respect to the resources they can draw upon in times of crisis. Wealthier households with larger fish farms have more assets and savings; thus their capacity to cope with production losses is greater than less well-endowed households. Typically, they are also able to invest in more and better quality land, for example, with good water access and space for water storage and treatment, all of which help make their farming system more resilient to changes in quality and availability of water.²⁷

In the case of river-based cage culture, access to suitable cage sites is associated with having land near the river, and financial capital or assets like land.⁴⁰ In all forms of commercial culture, having sufficient labor is a significant issue, as taking care of fish does not take much time but requires multiple visits to cages or ponds each day.⁵⁴ Most fish farmers are middle-aged, and some are elderly.^{21, 37, 39}

7.2 PORTFOLIOS



Households with a diverse portfolio of income sources have an advantage over those dependent on a single economic activity: they are less likely to lose everything in one bad season, and they can more easily re-organize around an alternative livelihood. Most fish farming households have multiple income sources.³⁹

The key point in having a diversity of income sources is that an adverse climate event is unlikely to impact all production activities at the same time; that is, risks tend not to co-vary. Integration of other farm activities with pond aquaculture can be a way to improve efficiency of resource use, and thus reduce input costs. Integration, however, brings with it nutrient management and food safety or quality challenges, that must, in turn, be managed.⁴⁸ It may also reduce the modularity of income sources.

Mobility is important for the adaptive capacity of fish farming households. Mobility prior to commencing fish farming helped accumulate savings needed to invest in new enterprises later like fish farming.⁵³ Thus, large-scale farming households earned more remittances because they travelled further, for longer, more often, and gained higher skills.⁵² These acquired skills have been shown to contribute to adaptive capacities later. In response to production failures, following low water levels in 2013-2014 dry season, some farmers moved for employment.⁵⁵ Mobility is constrained by various household burdens, including the need to look after dependents and the requirements to feed and monitor fish.⁵⁴

7.3 SOCIAL RELATIONS

The social relations of a fish farming households are important sources of technical knowledge in rearing fish, timely information about climate-related risks, and the foundations for collective action. Social networks increase the adaptive capacities of pond fish farming households. Households with strong bonds with relatives and neighbors are better able to reduce risks and adapt.³⁰ Ties with others also increases negotiating power, and facilitates entry into fish farming.^{28, 40}

Collective action is important for influencing the management of climate-related risks at the watershed and sector levels. Studies in three villages in 2013-14, showed that pond fish farmers use social networks to access water in drought and pollution situations when traditional water management institutions were not functioning properly, or ignored their interests.²⁸ The strength of the relationship between the traditional water management group and the fish farmer cooperative was critical to level of collaboration on water management, and the amount of access fish farmers had to water at critical times. Comparisons among fish farming cooperatives in different sites, however, also underlined that the quality of bonding ties was important for less well connected farmers to access the social capital in other's networks.³⁰ The behavior of individual large-scale fish farmers in these communities is crucial: if they share the knowledge from their better external network links, then all in the community can benefit.²⁹

7.4 BENEFITS & OTHER RISKS

In areas with sufficient water resources, improvements in aquaculture practices, or the introduction of aquaculture itself, can bring significant economic benefits directly to owners of production systems, but also to employees on farms or in related parts of the commodity chain. The economic benefits, in turn, contribute to resilience to climate-related stresses and disturbances.^{10, 18, 24}

Economic benefits are not the only rewards perceived as important by fish farmers. Many growers enjoy farming fish and speak positively of its contribution to their lives. Making decisions with risk and managing risks is also a thrill, and success is a source of pride.³⁸ These attitudes to climate-related challenges are important to household resilience.

Fish farming is just part of a household's activities, and climate-related risks are just a subset of the challenges faced by a farmer. Financial sources of risks – such as debt repayments, high interest rates on loans, market prices for fish, costs of inputs, and maintaining adequate savings – also need to be carefully managed. Less obviously, but also very important, are social sources of risk; in particular, the gain or loss of relationships in networks that help secure access to assistance and knowledge of various forms.²¹ Under current climate variability, farmers do not manage individual climate-related risks in isolation from other risks; the need for the same tactics in the future is likely.⁴¹

“At home it is stressful and not much fun; being with fish is more fun.”³⁶

“Recently it has been pretty good too. I have been rearing fish, and never lost money. Truthfully: a profit every time. Better than sitting at home doing nothing. Now have some money to spend.”³⁸

8 ADAPTATION

8.1 LONG-TERM ADAPTATION STRATEGIES

While short-term reactions and mid-term tactics are an important and valuable part of climate risk management, it is the long-term practices or strategies, which are especially critical to the challenges of adaptation to climate change (Table 6). Some of these strategies or variants thereof, have already been mentioned when considering existing approaches to climate risk management. Strategies can be at farm, community, or sector level.

In the longer-term, alternative income sources and social relations, are important for dealing with impacts and risks adversely affecting fish farming [Divers]. Savings can also be important for dealing with challenging periods [Save]. Some fish farms also integrate fish farming with livestock or poultry production, or other aspects of farming system to reduce inputs costs through using onsite materials [Integ].

Table 6

Long-term adaptation strategies for inland aquaculture.³⁵

The first three strategies are primarily farm-level, the next set are implemented primarily at the community or watershed level.

Short name	Strategy	Description
[Diver]	Diversification of income sources	As a way to reduce livelihood dependence on fish farms in the case of crop failures.
[Integ]	Integration of farm activities for resource efficiency	Fish ponds only: as dry season water store for other purposes; accept nutrient inputs from other activities, such as manure from poultry or livestock.
[Save]	Savings & loans to help cope & recover	As a way to buffer household quality of life in the case of fish crop failures.
[Grow]	Strengthen farmer cooperatives and clubs	As a way to gain access to lower cost feed and other inputs, as well as credit. May improve capacity and power to negotiate with firms and state authorities. Also can assist accessing best practices [Best]. Not-specific to a particular climate-related risk or culture system.
[Best]	Support sharing of best practices	Government and private extension services regularly synthesize and distribute information on best practices. Attention to both rearing techniques, like use of aerators or feed supplements, and business management skills such as FCR calculations or anticipating market conditions.
[Ecos]	Restore and maintain ecosystem services	Wetlands reduce severity of flooding and improve storage of above and below ground water for dry season. Healthy aquatic ecosystems assimilate excess nutrients, reducing water quality problems during droughts or low flows. Watershed vegetation reduces run-off of contaminants and sediments into water used for aquaculture. Riparian vegetation provides some shading or local climate cooling useful for moderating extreme heat waves, as well as stabilizes river or reservoir banks and filters run-off.

Short name	Strategy	Description
[Zone]	Zoning production in line with carrying capacities	Maximum number of cages in river reach or reservoir area or ponds in an irrigation/catchment area, regulated to maintain adequate water quality – especially important in dry periods with low flows.
[Iwrm]	Integrated water resources management initiatives	Aquaculture as a water user taken into account in planning allocation of water, especially in droughts. Side-effects of flood protection measures on aquaculture taken into consideration.
[Infra]	Build new and modify operations of water infrastructure	Operational rules of dams take into account uses of water by aquaculture, including river flows important to environmental quality. New or modified infrastructure takes into account water uses by aquaculture.
[Warn]	Early warning systems	Location-specific early warning systems for floods (including high river discharges and dam releases), heat waves, cold spells, and droughts.
[Info]	Improve climate information systems	Climate information system accessible to farmers so that they understand ‘normal’ level of risks. Seasonal forecasting related to onset of monsoon or ENSO phase provides indication of likelihood of high or low total wet season rainfall.
[Insur]	Improve insurance, risk sharing and compensation schemes	Mutual or weather-indexed insurance for fish farmers supported by state, but with significant private sector involvement. Compensation for losses related to operation of water infrastructure or other matters not covered by insurance. New risk sharing mechanisms between fish farmers and contracting companies.
[Trad]	Develop alternative export markets	General and/or aquaculture-specific trade and investment policies increase opportunities for export of farmed fish. Assumed to lead to higher prices. Not-specific to a particular climate-related risk or culture system. Could work in parallel with introduction of aquaculture-specific standards [Stand].
[Tech]	R&D to improving technologies	Efficient aerators, low cost water quality monitoring equipment, and measures to improve water productivity to deal better in situations with drought and low water availability. Including culture-specific innovations to deal with flooding, such as strength and design of cages or dykes, and netting for reducing losses from hatcheries and earthen ponds. Shading systems to deal with heat waves.
[Stand]	Implement voluntary sustainability standards	Incentive system to award farmers that implement best practices through better access to markets, price premiums, or other forms of support. Could include culture system specific criteria; for instance, related to carrying capacities [Zone]. Not specific to a particular risk.
[Spec]	Species selection & breeding	Testing and improvement of species and strains; for example, for high thermal tolerance or disease resistance, which would be beneficial for a range of water quality stresses that are influenced by climate factors.

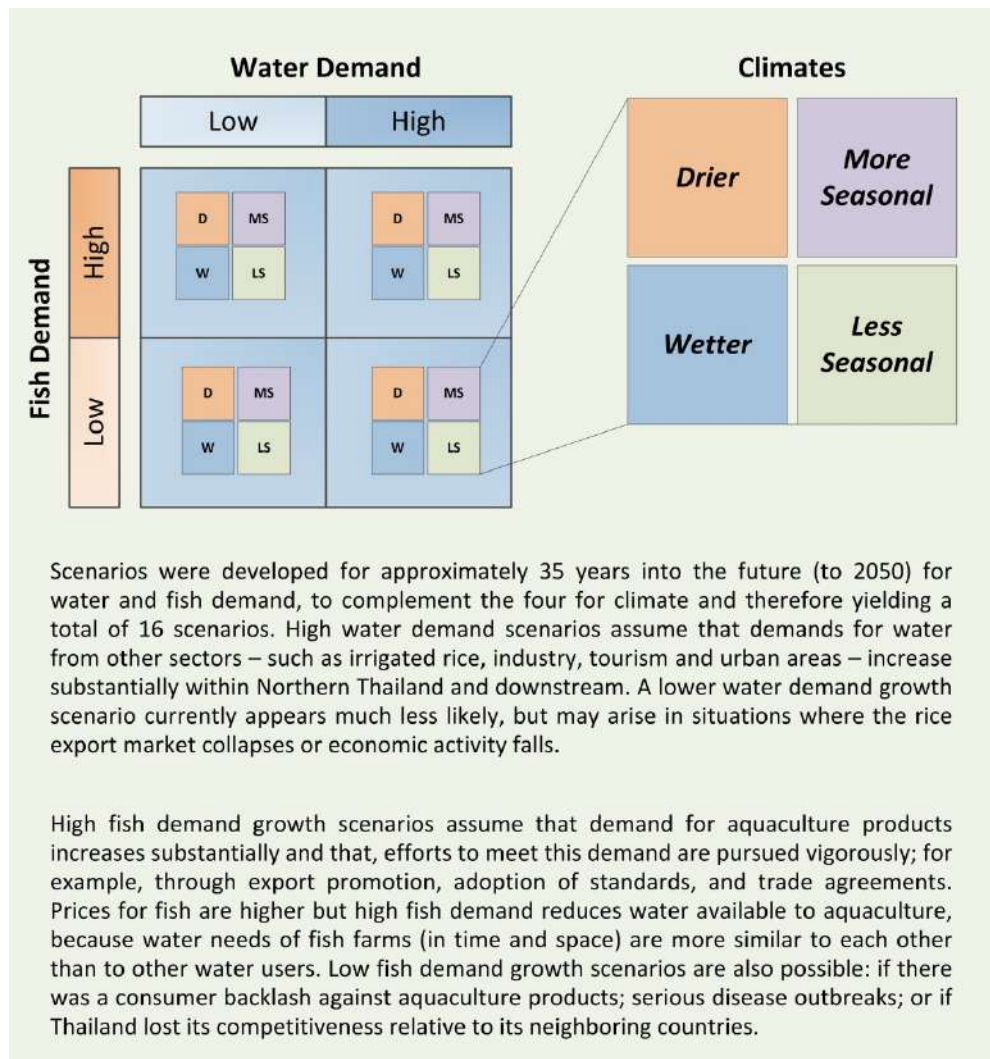
The remaining strategies are implemented at the national level to support local adaptation in the inland aquaculture sector.

In dealing with shared water resources, monitoring may be best done at the community or watershed level [Warn]. New water infrastructure – because of its long life span – is an important part of long-term climate risk management [Infra]; where risks are changing, this may imply a need for incorporating new safety margins or future decommissioning in the design. In the longer-term, the establishment and strengthening of fish farmer groups [Grow] may be quite important for the management of climate-related risks, as it can help cut input costs, improve marketing, and increase lobbying power. Wider efforts at sharing of knowledge or best practices may draw on such groups, but also the public and private extension services [Best]. Other long-term strategies include the restoration or conservation of riparian and other critical watershed ecosystems [Ecos], zoning so that production does not exceed carrying capacities or available water supplies [Zone].

In the long-term, there is also a key role for the Department of Fisheries, research organisations and the private sector, to: support breeding programs and alternative species [Spec]; improve technologies, for instance, moving towards more water-efficient, re-circulating models of pond culture [Tech]; improve the usefulness of climate information systems [Info]; and, introducing or supporting standards [Stand] that would result in more sustainable practices, as well as access to higher-value domestic export trade markets [Trad].

Box 4

Fish demand and water demand scenarios.³⁵



8.2 ROBUSTNESS OF STRATEGIES

Figure 14 summarizes whether or not a particular strategy for dealing with drought is likely to be worthwhile under each of the 16 scenarios (Box 4). For example, in a *drier* climate with higher demand for both water and fish, most strategies are helpful. On the other hand, in a *wetter* climate with lower demand for both water and fish, none of the strategies to improve water availability is worthwhile. Some individual strategies, like ecosystem restoration, are beneficial under almost all scenarios – they are win-win – whereas others, like drought insurance, are only useful under *drier* or *more seasonal* conditions, and where demand for fish is high (Figure 14). Under benign conditions there is less need to adapt; and vice-versa, under difficult conditions a greater need.

Apart from water availability for aquaculture, the four climate and two fish demand scenarios can also be used to explore the worthwhileness of strategies for dealing with other risks, such as increased flooding. Flood insurance, infrastructure, trade and early warning systems, for example, are worthwhile when there is high demand (more fish farmers) and flood risks are high. Under *drier* or *less seasonal* conditions, only ecosystem restoration – because of multiple benefits – is worthwhile. Farm-level risk reduction technologies are worthwhile when flood risks are high, even if demand for fish is low (few fish farmers).

		Climate scenarios							
		Wetter		Drier		More Seasonal		Less Seasonal	
Water Demand	High fish demand	○ Insur	○ Infra	● Insur	● Infra	● Insur	● Infra	● Insur	○ Infra
		● Warn	● Ecos	● Warn	● Ecos	● Warn	● Ecos	● Warn	● Ecos
	Low fish demand	○ Stand	○ Diver	● Stand	● Diver	● Stand	● Diver	● Stand	● Diver
		● Zone	● Integ	● Zone	● Integ	● Zone	● Integ	● Zone	● Integ
Low Water Demand	High fish demand	○ Insur	○ Infra	● Insur	● Infra	● Insur	● Infra	○ Insur	○ Infra
		○ Warn	● Ecos	● Warn	● Ecos	● Warn	● Ecos	○ Warn	● Ecos
	Low fish demand	○ Stand	○ Diver	○ Stand	● Diver	○ Stand	● Diver	○ Stand	● Diver
		○ Zone	● Integ	○ Zone	● Integ	○ Zone	● Integ	○ Zone	● Integ

Figure 14

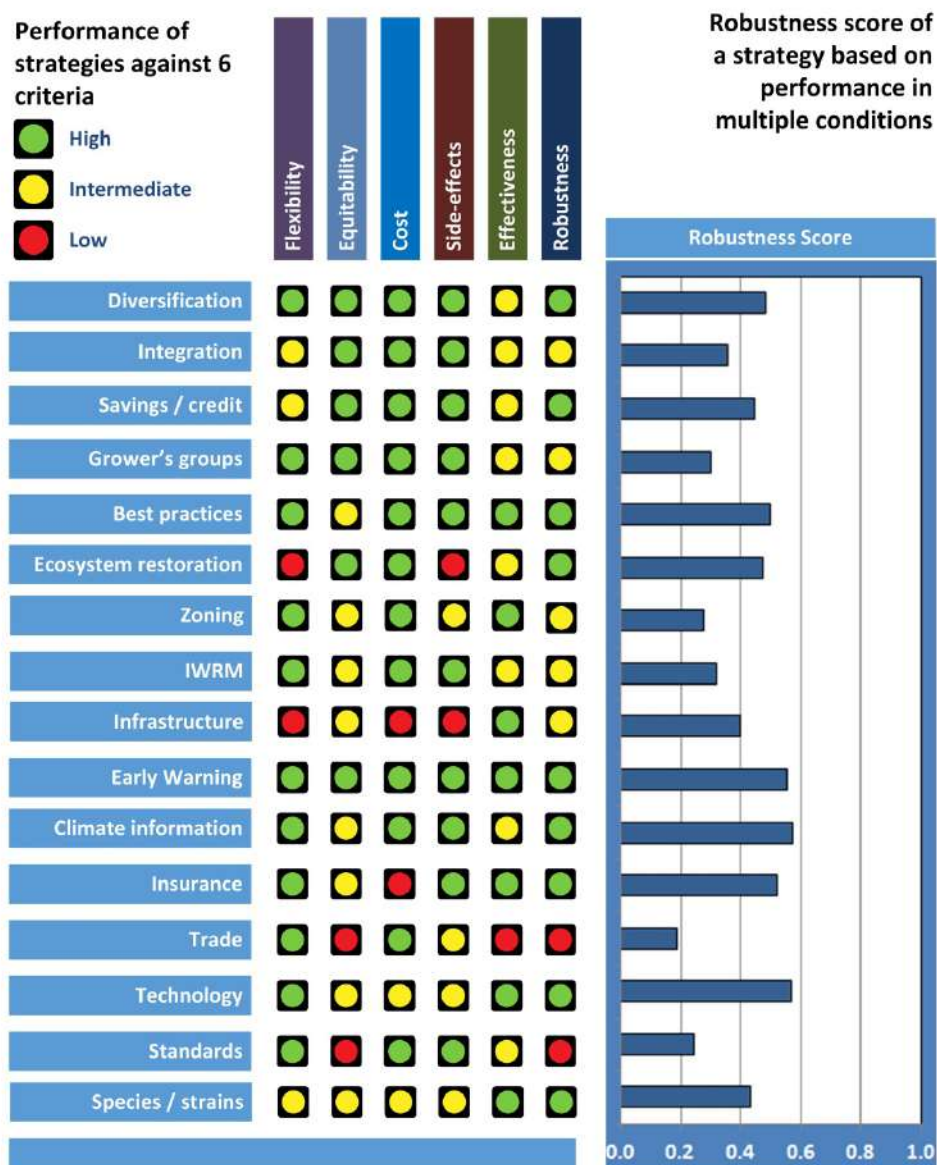
Relative value of pursuing 8 strategies to deal with drought for earthen pond fish farms in 16 scenarios.³⁵

- Strongly worthwhile
- Somewhat worthwhile
- Not worthwhile

Analyses like that for risks from drought or low water availability to earthen pond culture, were done for all the combinations of culture systems (ponds, rivers, reservoirs, and hatcheries), and climate-related risks (floods, droughts and heat waves). Here we combine these analyses to evaluate the robustness of individual strategies under different conditions. Overall, more robust strategies included technologies, insurance, and early warning systems (Box 5). Less robust were trade, standards, and zoning. Institutional or regulatory type strategies appear to be less robust on average, than informational, financial, technical or ecological ones. Some strategies are likely to reinforce each other if pursued in parallel, like improving early warning systems and climate information systems. Other strategies may interact more negatively, like investments in infrastructure and ecosystem restoration. Apart from robustness a successful adaptation strategy may also need to satisfy other criteria like not costing too much and flexibility (Box 4).

Box 5

Successful adaptation strategies satisfy multiple criteria



8.3 ADAPTATION PATHWAYS

Strengthening climate risk management practices in inland aquaculture requires attention be given to short-term reactions, mid-term tactics, and long-term strategies at household, community, and national scales. An important finding of this assessment is that the benefits of pursuing specific long-term strategies often vary widely across scenarios for climate, water, and fish demand. The implication is that adaptation pathways in the aquaculture sector must maintain significant flexibility, so that, over time, strategies can be abandoned, switched, combined, or new ones introduced, as conditions and knowledge change. Thus, adaptation pathways for and with inland aquaculture are needed, which allow reasonable actions to be taken now; for instance, to strengthen management of climate-related risks, or build resilience to climate-related stresses and shocks, while also leaving flexibility in households, and the sector as a whole, for adjustments of strategies in the future.³⁴

As vulnerabilities already vary greatly with context, it is to be expected that adaptation pathways will also be diverse. Adaptation in and with aquaculture will often require combinations and sequences of actions, some of which will be contingent on how climate is anticipated to change, how it actually changed, and the impacts of past responses and other factors. Figure 15 illustrates one possible pathway for the case of rainfed ponds in areas where water in the past was seasonally short, but projections suggest *wetter* conditions. In this case, possibilities of expansion depend on investments in infrastructure and hatcheries.

The decisions and investments made by individual households in fish farming to deal with climate-related risks are at central to adaptation pathways for aquaculture. Access to good sites, sufficient water, and suitable technologies and information, however, also depend on broader processes of development – including markets, innovation and regulations – and their interactions with other parts of the aquaculture sector. Policies that promote the sustainability of aquaculture will make associated livelihoods more resilient.

Strengthening climate risk management practices in inland aquaculture requires attention be given to short-term reactions, mid-term tactics, and long-term strategies at household, community, and national scales

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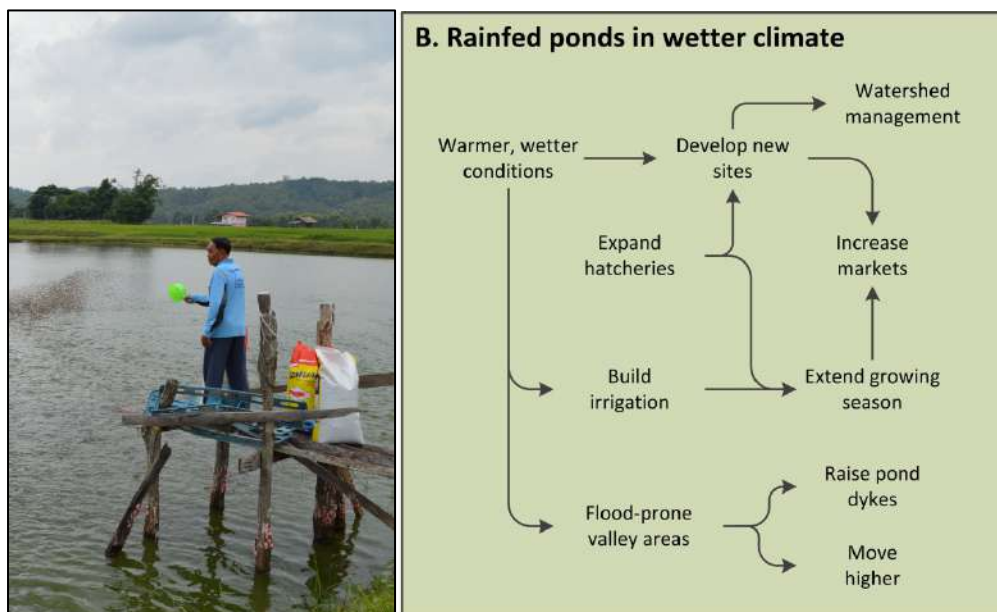


Figure 15

Example of an adaptation pathway for aquaculture in a climate scenario that is favorable to the expansion of aquaculture where land is available with good water supply.³⁴

9 IMPLICATIONS

9.1 RECOMMENDATIONS FOR POLICY AND PLANNING

- 1 **Strengthen the provision of weather and climate information to fish farmers.** In particular, develop systems to improve the provision of information about emerging seasonal conditions such as likelihood of water shortages or above normal rainfall, for instance, related to the El Nino – Southern Oscillation or monsoon development. Existing early warning systems for extreme weather events, such as floods, in a format appropriate to fish farmers and hatcheries should also be supported. This is a no-regrets strategy that would yield significant immediate benefits in terms of improving the management of climate-related risks under current climate, while the system improvements would also contribute to capacities to adapt to future changes in climate.
- 2 **Adjust existing aquaculture development policies, plans, and strategies to take into account climate.** This can be done in several ways. First, by including special provisions for dealing with extreme weather events, such floods or unusually dry periods causing serious drought. Second, by incorporating the notion of inter-annual climate variability, into the logic of targets and budgeting, so that there is some flexibility to take into account year-to-year differences, for instance, in the allocation of water for aquaculture. Third, by embracing long-term strategies which are capable of dealing with uncertainty and change such as those which arise when considering future climate. Policies on standards, registration, and hatchery services, for example, could do more to mainstream concerns with climate change.⁶⁵
- 3 **Increase awareness of the importance of the aquaculture stake in inland water resources management.** In particular, engage more closely in watershed, river, hydropower, irrigation, and flood protection deliberations at national as well as local levels. Ensure aquaculture interests are represented in water user groups and other related water management organizations, especially those related to irrigation and river management. Involvement in these and broader integrated water resources management debates, should lead to more informed decisions on infrastructure and demand-side management.
- 4 **Enhance the sharing of good risk management practices among fish farmers.** In particular, document and acknowledge the role of local innovation and practice-based knowledge in extension services, fish farming cooperatives, and local networks. The sharing of knowledge is important in building adaptive capacities to deal with a range of risks, including those which are climate-related, but also for example, the management of diseases. Improved management of fish stress and disease is one of the key ways to reduce climate-related risks as both are often part of causal chain leading to slow growth and high mortality.

- 5 **Collaborate with private firms and fish farmers to provide new risk sharing options.** In particular, evaluate in detail the options for providing mutual or index-based insurance for aquaculture, and how these might interact with conventional compensation approaches. Risk sharing in contract farming relationships should be monitored, and perhaps also regulated by the government.
- 6 **Establish and implement a zoning policy for aquaculture.** Policies should take into account, the local carrying capacities of the environment and seasonal differences in water flows or availability. In the case of river-based or reservoir-based cage aquaculture it is important that overall stocking levels in a reach do not exceed local carrying capacities of surrounding aquatic ecosystems, especially during periods of low flows or volumes. In the case of earthen ponds on private land within irrigation schemes or drawing on and draining into natural water courses similar considerations should hold. The zoning policy should include provisions for regular review of zones, to allow adjustment for changes in climate and water resource conditions.
- 7 **Promote and support the improved regulation and management of pollution that enters rivers used for aquaculture.** Pollution from urban and industrial uses is responsible for significant mass fish mortality events; on the other hand, the sustained presence of successful river cage aquaculture can be taken as an indicator of good river health and successful watershed management. High nutrient loading from human settlements, piggeries, and fertilizer run-off should also be monitored and regulated. In areas downstream from major water infrastructure support efforts to maintain releases consistent with adequate environmental flows to protect natural ecosystems and aquaculture activities.
- 8 **Invest in research and development on climate-resilient aquaculture technologies and rearing practices.** In particular, to improve water productivity, increase resistance to stress and disease, and use technologies like aeration in ways that are economically efficient. Research is also needed on technical and economic aspects of alternative aquaculture practices and species aimed at niche markets and higher value products, for example, meeting pesticide-free, organic or sustainability-oriented standards.
- 9 **Make use of understanding of risk perception in communication.** Effective communication is important to the success of many policies related to improving the management of climate-related risks. Communication strategies need to become more sophisticated, acknowledging the importance of recent experience and situational factors to how fish farmers perceive risks. Appeals to analytical merits of particular measures may need to be complemented by recognizing the role emotions play in dealing with and taking risks.
- 10 **Draft a climate and water strategy for inland aquaculture.** The strategy should provide a clear pathway for strengthening capacities to deal with climate-related risks in the inland aquaculture sector. As most climate impacts are also related to water management activities, dealing with two issues in parallel seems particularly appropriate for this sector. Close links to a parallel strategy for the coastal aquaculture sub-sector would also be beneficial as many of the problems faced, apart from sea-level rise, are similar. The 5 to 10 year strategy document should provide a framework for the overall policy response to the climate and water challenges and be updated periodically.

9.2 RECOMMENDATIONS FOR FISH FARMERS

- 1 **Identify and evaluate climate-related risks as part of business planning.** In particular, focus on seasonally-varying risks, noting times when culture system is most likely to be exposed to adverse conditions. Use this information to adjust stocking calendars, so to avoid periods with very high risk.
- 2 **Keep records of key indicators of fish farm performance and use this information to adjust practices.** Keep records of inputs, losses, and harvests. Key inputs include feed, fish fry and uses of aerators. With respect to losses note the number and times when fish and the weather conditions prevalent at the time including behavioral signs of stress. The experience of fish farmers is a critical body of knowledge for reducing climate-related risks. Record keeping helps validate insights.
- 3 **Help design and then adopt standards which make fish farming more climate-resilient.** Make sure fish farming representatives contribute to the development and refinement of producer standards, and that those standards recognize and reward good risk reduction practices. Fish farmer inputs can help ensure that their practical knowledge of plausible and good practices are taken into account. This is likely to be especially important for small farms without the land resources and financial assets to invest in complex water management systems.
- 4 **Invest in farm-level risk reduction measures as appropriate.** Commercial farms should strongly consider obtaining aeration or mechanical mixing equipment for dealing with low DO periods. In addition, they should cultivate social relations with traders and firms that may be critical in crisis times; for instance, when must harvest fish early. In fish farms adopting low intensity culture with low feed inputs and stocking densities there is usually less need for technical options, but other strategies such as integration, diversification and maintaining adequate savings may be more appropriate.
- 5 **Monitor innovations in fish farming techniques for opportunities to improve resilience.** In particular, look for ways to make culture systems more ecologically sustainable and less vulnerable to physical, market or socio-political risks. Encourage researchers to work on technical and financial innovations that would make management of risks easier.
- 6 **Establish and strengthen fish farming organizations and networks, so can better represent interests in water management decisions.** In particular, for commercial fish farms it is important to build on existing organizations focused on purchasing of feed and marketing harvest, and make their organizations more active in water management. Where groups are under-developed, start with issue-based informal network; for instance, around dry season water quality and access.

9.3 RECOMMENDATIONS FOR RESEARCHERS

- 1 **Use research findings to develop climate risk management tools for fish farmers.** Develop tools that might be used as smart mobile phone applications, which are able to use real-time information on weather conditions.
- 2 **Investigate ecosystem-based adaptation options in pond and cage culture.** In particular, attention to reducing wastes and maintaining water quality during production, through management that takes into account ecological processes within ponds, rivers, and reservoirs.
- 3 **Explore long-term aquaculture sector strategies for adaptation.** Encourage private-public partnerships on innovative, sustainable aquaculture, as well as promote long-term policies which would enable adaptation by fish farmers and other actors in value chains.
- 4 **Evaluate the contributions of aquaculture to household resilience.** In particular, build on comparisons of household livelihood portfolios to assess under what conditions, aquaculture increases resilience or vulnerability.
- 5 **Expand assessment activities on inland aquaculture to other species and regions.** Expand the assessment of risks and adaptation options to other parts of Thailand and neighboring countries; using consistent methodology, including joint assessment activities, with key stakeholders. With respect to adaptation in coastal aquaculture sea-level rise will be an additional factor to consider.

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