

**CLIMATE RISK MANAGEMENT IN TILAPIA CAGE CULTURE IN
NORTHERN THAILAND**

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OF THE REQUIREMENTS FOR THE DEGREE OF
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AND AQUATIC RESOURCES**

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Title

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ABSTRACT

Aquaculture is important to livelihoods, food security, and the economy of many countries. Recent assessments suggest that aquaculture is sensitive to the impacts of climate change, but provide very little evidence about how fish farmers perceive and manage climate-related risks and thus guidance for adaptation.

Some fish farmers in northern Thailand rear tilapia in floating cages in rivers. The culture system is unaffected by modest fluctuations in water levels, but appears vulnerable to more extreme changes in flow. Improving risk management practices under current climate conditions is important as losses to extreme events can be high and are widespread. The objectives of the study therefore were to: (1) assess the impacts and risks from floods, low water flows and other weather and climate-related phenomena on river-based tilapia cage culture in northern Thailand; (2) assess how farmers perceive and manage climate-related risks; and (3) identify practical ways through which climate-related risks to fish farms can be reduced.

A key feature of the study design was to evaluate risks and risk management practices over a wide geographical area, and thus a range of climate and river flow regulation conditions. Another key element of the design was a focus on recent extreme floods (2005 and 2011) and low flow conditions (2012). An interdisciplinary, mixed-method, approach which combines qualitative and quantitative methods was taken. This included: analysis of secondary water flow and meteorological data; quantitative and qualitative surveys of farmers' farming practices and experiences with extreme events; direct observations during critical flow periods; and, the development of a role-playing simulation game to explore risk decisions with farmers.

A survey of farming practices documented how hybrid red and black Nile tilapias (*Oreochromis niloticus* L) are reared for 4 - 5 months in cages. Observed mean ($\pm$ SD) stocking density was $49 (\pm 16) \text{ fish}\cdot\text{m}^{-3}$, feed conversion ratio $1.47 (\pm 0.43) \text{ kg feed per kg fish}$ and yield density $26.6 (\pm 8.1) \text{ kg}\cdot\text{m}^{-3}$. Input costs were dominated by feed (70%) and stock (16%). Most farms borrowed money and participated in contracts with firms that supplied feed and collected harvests. Fish farming was usually a component of a portfolio of household activities but for some a core business. A case-control study showed that households with good access to river front, financial capital, and social networks are more likely to farm fish.

Surveys in four fish growing regions of northern Thailand showed that extreme high and low water flows adversely impacted a substantial fraction of farms, causing damage to cages, fish deaths, slow growth and disease problems. Economic losses are significant and often result in financial debt. Compensation and assistance following floods is modest relative to the losses and coverage is incomplete. Probability of extreme flows and impacts vary among locations, are highly seasonal, and vary among years.

Perceptions of climate-related risks are influenced by exposure and other factors. Recent experience of negative impacts from extreme flows increases levels of concern about risks. Risks from droughts were perceived to have significantly worsened. The overall level of awareness of climate change among fish farmers was relatively high although understanding of longer-term risks, uncertainties and adaptation options was more limited.

Farmers use a combination of adjustments in rearing practices, cropping calendars, as well as financial and social measures to manage those risks which they perceive as being manageable. Many risks are seasonal, vary between rivers and are place-specific meaning that the risk profiles of individual farms can vary substantially. Individual risks are often addressed through multiple practices and strategies; conversely, a particular management practice can have a bearing on several different risks. Farmers recognize that risks must be managed at farm and higher spatial and administrative scales.

Experimental investigation of risk decision behaviour using a role-playing simulation game found, as hypothesized, that more frequent or larger impact floods reduced cumulative profits. Farmers slightly reduced their stocking densities when playing in games with a high likelihood of floods but did not do so as expected when impacts from floods were larger.

Contrary to initial expectations farmers found it harder to learn – choose most optimal density or improve score within a game – when floods were common or had large impacts. Farmers learnt most when risks were decreasing and least when they were increasing. Providing information about likelihoods prior to a game had no impact on performance or decisions.

This thesis is one of the first in-depth analyses of the climate-related risks faced by farmers who culture fish in river-based cages. The findings show clearly that climate-related risks are an important factor in production decisions, and that the losses associated with impacts of extreme flow events can be large. The study also shows that fish farmers manage multiple climate-related and other risks simultaneously, with an emphasis on actions at the level of the farm, while also acknowledging the importance of actions at the river scale. Fish farmers learn about levels of risk in particular locations through experience. In evaluating adaptation responses they consider shorter- and longer-term, as well as generic and systemic, options. This thesis, through a detailed exploration of a cage-based aquaculture system in northern Thailand, significantly expands the knowledge-base for evaluating the impacts of extreme events, and thus climate change on aquaculture. The study also suggests that a focus on strengthening the management of climate-related risks can be a practical way to build capabilities to adapt to future climate change.

ชื่อเรื่อง	การจัดการความเสี่ยงจากภูมิอากาศต่อการเลี้ยงปลานิลใน กระชังในภาคเหนือของประเทศไทย
ชื่อผู้เขียน	นางพิมพ์กานต์ เลอเบล
ชื่อปริญญา	ปรัชญาดุษฎีบัณฑิตสาขาวิชาเทคโนโลยีการประมงและ ทรัพยากรทางน้ำ
ประธานกรรมการที่ปรึกษา	รองศาสตราจารย์ ดร.นิวัติ หวังชัย

บทคัดย่อ

การเพาะเลี้ยงสัตว์น้ำมีความสำคัญต่อความมั่นคงด้านอาหารของครัวเรือน และเศรษฐกิจของหลายประเทศ จากการประเมินพบว่าการเพาะเลี้ยงสัตว์น้ำในปัจจุบันเป็นกิจกรรมที่เปราะบางต่อผลกระทบจากความเสี่ยงจากการเปลี่ยนแปลงทางด้านสภาพภูมิอากาศ แต่มีข้อมูลที่เกี่ยวข้องกับการรับรู้และการจัดการความเสี่ยงด้านภูมิอากาศของผู้เลี้ยงปลารวมถึงการเสนอแนวทางในการปรับตัวยังมีน้อยมาก

ผู้เลี้ยงปลาในเขตภาคเหนือของประเทศไทยบางรายเพาะเลี้ยงปลานิลในกระชังในแม่น้ำ ระบบการเลี้ยงดังกล่าวไม่ได้รับผลกระทบจากการเปลี่ยนแปลงของระดับน้ำมากนัก แต่จะมีความเปราะบางมากในเรื่องของกระแสน้ำที่ในแม่น้ำมีการเปลี่ยนแปลงอย่างฉับพลัน ดังนั้นการปรับเปลี่ยนวิธีการจัดการความเสี่ยงภายใต้สภาพภูมิอากาศปัจจุบันนั้นมีความสำคัญเป็นอย่างยิ่งเนื่องจากความสูญเสียจากสภาพอากาศที่รุนแรงและพบว่ามีอยู่ทั่วไป

วัตถุประสงค์หลัก ของการศึกษานงานวิจัยนี้มี 3 ข้อ ด้วยกัน (1) ประเมินผลกระทบและความเสี่ยงจากน้ำท่วม น้ำไหลน้อย รวมถึงเหตุการณ์ที่เกี่ยวข้องกับสภาพอากาศและภูมิอากาศอื่น ๆ ที่มีผลกระทบต่อการเลี้ยงปลานิลในกระชังในเขตภาคเหนือของประเทศไทย (2) การประเมินผู้เลี้ยงปลาที่มีการรับรู้และการจัดการความเสี่ยงด้านภูมิอากาศได้อย่างไร และ (3) ระบุแนวทางเชิงปฏิบัติที่ผู้เลี้ยงปลาใช้ในการลดความเสี่ยงด้านภูมิอากาศ

ลักษณะสำคัญของการออกแบบการศึกษานี้ เพื่อประเมินความเสี่ยงและหาแนวทางการจัดการความเสี่ยงในพื้นที่ที่มีลักษณะทางภูมิศาสตร์แตกต่างกัน โดยพื้นที่ศึกษาครอบคลุมสภาพภูมิอากาศและการจัดการการไหลของน้ำในแม่น้ำที่ต่างกัน ลักษณะสำคัญอีกอย่างหนึ่งของการศึกษานี้คือการเน้นที่เหตุการณ์น้ำท่วมใหญ่ที่เกิดขึ้นในปี 2548 และ ปี 2554 และ เหตุการณ์น้ำไหลน้อยในปี 2555

การศึกษานี้ ใช้วิธีวิจัยแบบผสมระหว่างการศึกษาเชิงคุณภาพและเชิงปริมาณ และประกอบกับการวิเคราะห์ข้อมูลทฤษฎีของการไหลของน้ำจากข้อมูลกรมอุตุนิยมวิทยา สํารวจเชิงปริมาณและเชิงคุณภาพเกี่ยวกับแนวปฏิบัติในการเพาะเลี้ยงสัตว์น้ำรวมถึงประสบการณ์เกี่ยวกับสภาพอากาศ รุนแรง การสังเกตกระแสน้ำในช่วงวิกฤต และการพัฒนาเกมจำลองสถานการณ์เพื่อสำรวจพฤติกรรมการตัดสินใจทางด้านการจัดการความเสี่ยงของผู้เลี้ยงปลา

การสำรวจแนวทางปฏิบัติในการเพาะเลี้ยงสัตว์น้ำนั้นครอบคลุมวิธีการเพาะเลี้ยงปลาทั้งแบบและปลานิลในกระชังซึ่งใช้เวลาเลี้ยงรอบละ 4-5 เดือน ค่าเฉลี่ยของความหนาแน่นของปลาที่เลี้ยงในกระชังคือ 49 ± 16 ตัวต่อลูกบาศก์เมตร อัตราการเปลี่ยนอาหารเป็นเนื้อคือ 1.47 ± 0.43 กิโลกรัม ของน้ำหนักอาหารต่อกิโลกรัม ของน้ำหนักปลา และให้ผลผลิต 26.6 ± 8.1 กิโลกรัมต่อลูกบาศก์เมตร ต้นทุนหลักมาจากค่าอาหารปลา (70%) และค่าพันธุ์ปลา (16%) ผู้เลี้ยงปลาส่วนใหญ่กู้ยืมเงินและทำพันธะสัญญากับเอกชน การเพาะเลี้ยงปลาโดยทั่วไปถือเป็นส่วนหนึ่งของกิจกรรมภายในครัวเรือนนอกเหนือจากกิจกรรมอื่นๆ แต่สำหรับบางครัวเรือนการเพาะเลี้ยงปลาถือเป็นธุรกิจหลัก จากการศึกษาแบบควบคุมที่มีปัจจัยรบกวนแสดงให้เห็นว่าครัวเรือนที่มีการเข้าถึงพื้นที่ติดแม่น้ำ แหล่งเงินทุน และเครือข่ายทางสังคมมีแนวโน้มที่จะเลี้ยงปลามากกว่า

การสำรวจการเลี้ยงปลาในพื้นที่ภาคเหนือของประเทศไทยแสดงให้เห็นว่าปัญหาจากน้ำไหลแรงและน้ำไหลน้อยนั้น ส่งผลกระทบต่อฟาร์มเพาะเลี้ยงปลาเป็นจำนวนมาก สร้างความเสียหายให้แก่กระชังปลา ทำให้ปลาตาย ปลาโตช้า และเกิดปัญหาปลาเป็นโรค ความสูญเสียทางเศรษฐกิจมีมูลค่าสูงและทำให้ผู้เลี้ยงปลาเป็นหนี้ การชดเชยและความช่วยเหลือที่ได้รับจากเหตุการณ์น้ำท่วมนั้นยังมีน้อยเมื่อเทียบกับความสูญเสียจริง การคุ้มครองดังกล่าวนี้ไม่ครอบคลุมโอกาสเกิดเหตุการณ์การเปลี่ยนแปลงการไหลของน้ำและผลกระทบที่เกิดขึ้นในแต่ละพื้นที่ที่มีความแตกต่างกัน และแต่ละพื้นที่จะขึ้นอยู่กับฤดูกาล ซึ่งค่อนข้างแตกต่างในแต่ละปี

การรับรู้เกี่ยวกับความเสี่ยงด้านภูมิอากาศขึ้นอยู่กับความเสี่ยงที่เกษตรกรเผชิญและปัจจัยอื่นๆ ประสบการณ์ที่ผ่านมาเกี่ยวกับผลกระทบทางลบที่ได้รับทำให้ความกังวลเกี่ยวกับความเสี่ยงเพิ่มขึ้น ผู้เลี้ยงปลารับรู้ว่าการเสี่ยงจากเหตุการณ์น้ำแล้งนั้นได้รับผลกระทบมากกว่าความเสี่ยงทางด้านอื่น ๆ โดยภาพรวมผู้เลี้ยงปลาตระหนักเกี่ยวกับการเปลี่ยนแปลงภูมิอากาศมาก แม้ว่าจะมีความเข้าใจเกี่ยวกับความเสี่ยงในระยะยาวยังไม่แน่นอน และมีแนวทางในการปรับตัวที่ค่อนข้างจำกัดก็ตาม

ผู้เลี้ยงปลาใช้การปรับเปลี่ยนวิธีการเลี้ยงปลาที่หลากหลาย มีการปรับเปลี่ยนปฏิทินการเลี้ยงปลา รวมถึงการใช้มาตรการทางการเงินและทางสังคมเพื่อจัดการความเสี่ยงต่าง ๆ ที่ผู้เลี้ยงปลารับรู้ว่าจะสามารถจัดการได้ ความเสี่ยงหลาย ๆ อย่างขึ้นอยู่กับพื้นที่และฤดูกาล หมายความว่า

ว่ารูปแบบความเสี่ยงของแต่ละฟาร์มนั้นค่อนข้างแตกต่างกัน ความเสี่ยงแต่ละอย่างมักจะถูกจัดการด้วยวิธีการและกลยุทธ์ที่หลากหลาย เช่นเดียวกับการจัดการด้วยวิธีการอย่างใดอย่างหนึ่งก็สามารถช่วยลดความเสี่ยงได้หลาย ๆ อย่าง ผู้เลี้ยงปลาทราบดีว่าจำเป็นต้องจัดการกับความเสี่ยงทั้งในระดับฟาร์มเพาะเลี้ยง รวมถึงการจัดการในระดับพื้นที่และการบริหารจัดการน้ำที่กว้างขึ้น

การสำรวจเชิงทดลองเกี่ยวกับพฤติกรรมการตัดสินใจด้านความเสี่ยงโดยใช้เกมสถานการณ์จำลองพบว่ายิ่งความถี่ของการเกิดหรือผลกระทบของน้ำท่วมเพิ่มมากขึ้นเท่าไรยิ่งทำให้กำไรสะสมของผู้เลี้ยงปลาลดลง ซึ่งตรงกับสมมติฐาน ในขณะที่เล่นเกมผู้เลี้ยงปลาจะตัดสินใจลดความหนาแน่นในการลงปลาหากพบว่าโอกาสในการเกิดน้ำท่วมเพิ่มสูงขึ้น แต่กลับไม่ลดความหนาแน่นในการเลี้ยงปลาลง เมื่อพบว่าผลกระทบเพิ่มขึ้น ตรงกันข้ามกับที่คาดการณ์ไว้ จะเห็นได้ว่าผู้เลี้ยงปลาเลือกระดับความหนาแน่นในการลงปลาที่เหมาะสมเพื่อเพิ่มคะแนนในเกมนั้นผู้เลี้ยงปลาเรียนรู้ได้ยากกว่าถ้าน้ำท่วมเกิดบ่อยขึ้นหรือส่งผลกระทบที่รุนแรงขึ้น ผู้เลี้ยงปลาเรียนรู้ได้ดีที่สุดเมื่อความเสี่ยงลดลงและเรียนรู้ได้น้อยที่สุดเมื่อความเสี่ยงเพิ่มขึ้น การให้ข้อมูลเกี่ยวกับโอกาสที่จะเกิดน้ำท่วมก่อนเล่นเกมไม่มีผลต่อการกระทำหรือการตัดสินใจในเกม

วิทยานิพนธ์นี้เป็นการวิเคราะห์เชิงลึกชิ้นแรกเกี่ยวกับความเสี่ยงด้านภูมิอากาศที่ผู้เลี้ยงปลากระชังในแม่น้ำ พบว่าจากการศึกษาแสดงให้เห็นถึงความเสี่ยงทางด้านภูมิอากาศมีความสำคัญต่อการตัดสินใจเกี่ยวกับการผลิตซึ่งความสูญเสียที่เกี่ยวข้องกับผลกระทบจากเหตุการณ์การเปลี่ยนแปลงของการไหลของน้ำที่รุนแรงอาจมีมูลค่าสูง การศึกษานี้แสดงให้เห็นว่าผู้เลี้ยงปลาจัดการกับความเสี่ยงด้านภูมิอากาศและความเสี่ยงอื่น ๆ ได้ในเวลาเดียวกันโดยเน้นที่การจัดการในระดับฟาร์ม แต่ก็ให้ความสำคัญกับการจัดการในระดับแม่น้ำด้วย ผู้เลี้ยงปลาเรียนรู้เกี่ยวกับระดับความเสี่ยงในแต่ละพื้นที่ผ่านทางประสบการณ์และได้คำนึงถึงการปรับตัวทั้งในระยะสั้นและระยะยาว ทั้งแบบทั่วไปและอย่างมีระบบ จากการสำรวจอย่างละเอียดเกี่ยวกับระบบการเพาะเลี้ยงสัตว์น้ำในภาคเหนือของไทย วิทยานิพนธ์นี้ได้ขยายองค์ความรู้ในการประเมินผลกระทบของเหตุการณ์สภาพอากาศรุนแรงและการเปลี่ยนแปลงภูมิอากาศที่ส่งผลกระทบต่อระบบการเพาะเลี้ยงสัตว์น้ำ การศึกษานี้เสนอว่าควรให้ความสำคัญกับการพัฒนาศักยภาพการปรับตัวต่อความเสี่ยงด้านภูมิอากาศที่สามารถปฏิบัติได้จริงเพื่อที่จะช่วยให้เกิดการสร้างเครือข่ายในการปรับตัวต่อการเปลี่ยนแปลงภูมิอากาศในอนาคต

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CHAPTER 1

INTRODUCTION

This thesis is about how fish farmers perceive and manage climate-related risks. This introductory chapter describes the rationale, objectives, design, key concepts and organization of the thesis.

1. Rationale

The rationale for studying the management of climate-related risks in tilapia river-based cage aquaculture was based on four arguments.

First, aquaculture is important to livelihoods, food security, and the economy of many countries, including Thailand. At the same time, aquaculture is known to be sensitive to the impacts of climate change (De Silva and Soto, 2009; Pickering *et al.*, 2011; Frost *et al.*, 2012; Doubleday *et al.*, 2013). While there is a large literature on aquaculture production techniques in Thailand, less is known about the decision-making behavior of aquaculture farmers. In particular, there has been almost no work on how farmers perceive and manage climate-related risks in this sector.

Second, cage-based aquaculture in rivers faces different challenges from those in ponds on private land and river-based cage culture is understudied (but see: Chaibu *et al.*, 2004). The water environment in rivers is much less easily controlled than that in ponds. Extreme high and low flows can both be expected to have direct effects on production and profits, but have not been systematically studied, despite many reports in popular media of mass mortality events.

Third, improving risk management practices under current climate is important, because many farmers continue to lose fish crops to floods and low flows. It has not been clear, however, why some farmers were able to successfully reduce risks, whereas others could not. It also appears likely that risk attitudes and perceptions may vary among farmers, affecting decisions on management practices.

Fourth, a climate risk management approach appears a promising and practical way to address challenges posed by a variable and changing climate in the aquaculture sector. It

has not been clear, however, to what extent and which specific risks might be manageable at the farm level and which might require larger-scale, coordinated, responses. Eitherway, a key premise of this thesis is that better risk management under current climate should also help fish farmers deal more effectively with climate change.

2. Research objectives and questions

This thesis has three main objectives, each supported by 1-3 more specific research questions (Table 1). Objective 1 focuses on impacts and relatively objective measures of risk. Objective 2 focuses on how farmers perceive and manage risks. Objective 3 synthesizes the understanding from the first two objectives in order to derive suggestions for practice and policy.

3. Study design and research strategy

The approach adopted to investigate the three objectives was based on a few simple strategies.

First, was to select sites across a wide geographic range, and rivers with different levels of flow modification, within northern Thailand (see: Figure 12 for map and Figure 13 for climate). This created opportunities for meaningful comparisons of risks, perceptions and practices among sites with different climates and flow regimes.

Second, was to focus on recent extreme events. High flood peaks in 2011 and 2005, provided clear events for respondents to recall. For low flows the recent 2012-3 dry was also an extreme event. The occurrence of recent extreme climate events was an opportunity to study the impacts of, and responses to, extreme events.

Third, was to approach understanding of the beliefs, perceptions and attitudes of fish farmers using multiple methods. To this end a mixed method approach (Mason, 2006) was used in which qualitative techniques, such as informal visits to farms and in-depth interviews, helped design and then interpret, findings from quantitative, structured, questionnaire surveys.

Fourth, the research and analysis was done in steps and guided by the research questions. By breaking the overall study into smaller parts and addressing one or at most a few closely related questions at a time the large task became much easier to complete.

Table 1 Main objectives and specific research questions addressed by thesis.

1. Objective 1: Assess the impacts and risks from floods, low flows and other weather and climate-related phenomenon to river-based tilapia cage culture in northern Thailand
1.1. What have been the impacts of floods, droughts and other climate and weather phenomenon on fish farms?
1.2. What is the likelihood of suffering those impacts in different places and times of the year?
1.3. How do river basin and water management affect fish farms?
1.4. Who gets to farm fish and where?
2. Objective 2: Assess how farmers perceive and manage climate-related risks;
2.1. How do fish farmers understand, perceive and communicate climate-related risks?
2.2. How do fish cage farmers manage risks from floods, droughts and other climate and weather phenomenon?
2.3. What are common rearing and business management practices in river-based aquaculture farms?
2.4. How does expected likelihood or severity of an event influence risk decisions?
3. Objective 3: Identify practical ways through which climate-related risks to fish farms can be reduced.
3.1. How could farmers reduce the climate-related risks at the farm level?
3.2. How could farmers reduce climate-related risks at the community and river reach or basin level?
3.3. What are possible strategies and practices to adapt to and reduce climate-related risks under current and future climate?

4. Key risk concepts and terms

Risk refers to the chances of a loss given some event or condition. The specific ways in which risk is defined and used, however, varies substantially among professions, sectors and disciplines (Measham and Lockie, 2012). For some problems and definitions it is possible to precisely quantify risk, but in many other cases estimates are very approximate or do not justify quantification. Consider the case of fish farming in cages in a river. Risk here might be expressed as the probability of all, 20% or 50% of a crop being lost due to a flood in the wet season. Alternatively it might be expressed in terms of profits, varying from reduced profit, through no profit, to a major loss. All floods or only flood events above a certain peak height or river discharge level might be considered as 'risks'.

Risk is usually described as being composed or produced by a combination of factors. One commonly used definition in the environmental and natural sciences is to define risk as a product of hazard, exposure and vulnerability (Birkmann, 2013). Hazard refers to the harmful phenomenon like a flood, earthquake or dam failure. Exposure is a measure of how likely a particular person, object or place is likely to actually experience that hazard when it occurs. Vulnerability is a measure of how sensitive the system of interest is if it is exposed.

Consider the example of fish farming in cages in a river. A very high flood peak of 7m, one that is experienced only once in 50 years, poses much higher risks of loss of profit and deaths of fish than a more typical wet season flood peak of 5m that occurs on average every 5 years. The risks from a very high flood *hazard* are higher than from a lower more typical flood. If a farmer places her cages in mid-stream in a narrow part of the river the risks she faces from fast flows are higher than that of another farmer who has their cages along the river banks in a wide meandering part of the river where flows, even after increasing during flood conditions, are still slower. The cages in mid-stream of a narrow channel are more *exposed* to the flood peak than those along the banks in a wider stretch of the river. Two farmers with cages along the banks may have similar exposure to the same hazard but still differ significantly in vulnerability and thus risk. One farmer, for instance, may be wealthier and have more strongly built cages, more financial resources and better connections to local government officials than another. The former farmer finds out about the flood earlier and can take protective measures and after the floods recede is able to quickly re-invest to fix damaged cages and buy or acquire, as part of assistance

schemes from government, new fish to stock his cages. He is less *vulnerable* than another farmer who is poor, built weak cages and knows few officials.

A risk definition based on combination of hazard, exposure and vulnerability is used as a starting point for some of the analyses in this thesis. It should be noted also that there are many variants of this basic definition of risk. Exposure is sometimes referred to as 'physical vulnerability' (Birkmann, 2013). Others just consider exposure as part of vulnerability or the hazard: for example, in the influential disaster pressure and release model risk which explains disasters as arising from a combination of hazard and vulnerability (Blaikie *et al.*, 1994). In the fish farming example above the reason some cages are in fast flowing sections and thus may be more exposed and vulnerable is because the safer sites are already taken by people with more power and influence. Social and physical dimensions of vulnerability are often inter-related. Studies of risk in both the environmental and social sciences often elaborate the factors and relationships which create and underlie vulnerability in detail (Turner *et al.*, 2003; Adger, 2006). Many studies have shown that political, economic and social factors can be very important, overwhelming simple differences in levels of hazards (Blaikie *et al.*, 1994).

Once more sources of vulnerability are recognized the possibility that risk will be evaluated differently by different stakeholders increases. Moreover, in situations with high uncertainty and complexity, risk identification and evaluation may be highly contested among stakeholders (Antón *et al.*, 2013). The view of experts or authorities, for instance, may not be trusted. In these, and other situations, more participatory approaches to identifying, measure and reducing risk are appropriate (Lockie and Measham, 2012). Fisheries officials, for example, may want fish farmers to take almost no risks at all as they worry about having to pay compensation or provide replacement fish fry; whereas, farmers know that some risks may be worthwhile given expected profits a few months later. Reaching a shared understanding of risks takes discussion and exchange of views in which there is usually no single, correct, value for what is a relevant risk.

How risks are communicated is important for perceptions. Risk communication or the exchange of information between stakeholders about the existence, level, sources or acceptability of risks is influenced by many factors including language. Words and images may scare people or encourage them to act (Nerlich *et al.*, 2010). An important challenge in

communicating the risks of climate change is that it is in the future and the effects may not yet be visible (Moser, 2010a).

Studies of risk perception identify the factors which lead to differences in how individuals perceive risks. These studies show that perceptions of risk are influenced by values, attitudes and culture (Leiserowitz, 2006). Perceived risk can be increased or decreased through social relations, circumstances and experiences (Kasperson *et al.*, 2003). People tend to pay more attention to recent events (Weber, 2010). They also are more concerned about something if they feel they have some control over exposure to risks and consequences (Weber, 2010). High uncertainty can also reduce perceived risk.

In simple terms risk management is the actions taken to reduce risk. A wide range of actions are covered, for example, including moving away, building resilience, putting protective measures in place, and providing insurance. An acceptable risk is one that requires no further action (Renn and Klinke, 2012). A tolerable risk is one for which further risk management is warranted. An intolerable risk should be eliminated completely, for example, by not trying to grow fish in a particular reach of the river at all.

A climate- or weather-related risk is one which is influenced by climate or weather respectively. Weather, climate, climate variability and climate change are not interchangeable terms although they are related and insights about risks related to one may help with understanding others. Climate is average weather: it is a statistical measure (IPCC, 2007). Depending on the specific measure of climate being considered that might require a decade or more years of data to be able to express clearly. For example the climate in Chiang Mai in April is very hot with a mean maximum temperature of around 35C. Of course depending on the weather the maximum might reach 41C or only 30C on a particular day. Climate variability refers to variation in mean and other statistics at time and space scales beyond an individual weather event (IPCC, 2007). Some years and decades, for example, are much wetter than others; if it was very much higher than that might be considered an extreme climate event. An extreme weather event is an individual event that is rare, for example, one which occurs only at a particular place only once in 10 or 50 years.

5. Organization of thesis

Although the chapters of this thesis are written as standalone papers, they are conceptually and logically connected (Figure 1). Chapter 2 reviews previous studies, secondary sources and published documents about the impacts of climate, seasons and extreme events on cage aquaculture in Thailand. Chapter 3 describes key aquaculture rearing and business management practices. Chapter 4 explores problem of access to, and selection of, cage rearing sites, a key factor in exposure to extreme flows. Chapters 2 through 4 lay the foundations for the more detailed work on risks in Chapters 5 through 8.

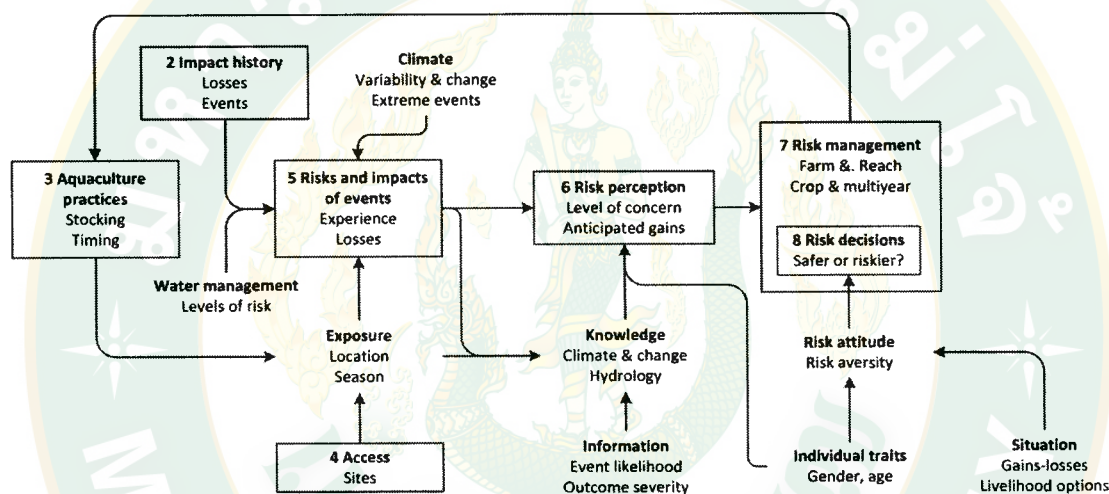


Figure 1 Conceptual relationship among main chapters of this thesis (boxes with leading number).

Chapter 5 analyzes risks of extreme events and their impacts under current climate. Seasonal and locational differences are assessed. Attention is given to exposure and the impacts of river-basin water management. Chapter 6 explores factors associated with differences in risk perception. Factors such as past experience of extreme events, knowledge of climate and river flows, and gender or age, are explored in detail. Chapter 7 looks at risk management practices at the farm and reach levels as well as possible strategies for dealing with longer-term changes in climate. Chapter 8 examines in more detail the risk decision behavior of farmers in an experiment using role playing simulation games on hand-held tablets. Measurements are made of

risk attitudes and rates of learning about local risks and how these influence risk decisions. Chapter 9 concludes the thesis with a brief synthesis of the key messages in response to each of the research objectives and questions. There is also a short reflection on the main limitations of the study and suggestions for future work.



CHAPTER 2

IMPACTS OF FLOODS AND DROUGHT ON FISH CAGE CULTURE IN RIVERS

1. Introduction

Due mainly to the continual reduction of stocks of aquatic animals in natural habitats, both in coastal and inland fisheries, aquaculture is now considered a very important sector in Thailand. In 2011, the volume production of aquatic animals captured or harvested from natural waters decreased by 40.2 % relative to 2005. In contrast, the aquaculture industry continued to grow between 2000 and 2011. In 2011, aquatic products particularly from aquaculture industry increased by 89 % relative to 2000 (Figure 2). Quantitative data of aquatic products in Thailand indicates that the products derived from aquaculture such as shrimp, fish and mollusk possess more economic value-added than aquatic animals from natural habitats, and the overall production volume from the aquaculture industry is likely to continue to increase (Figure 3).

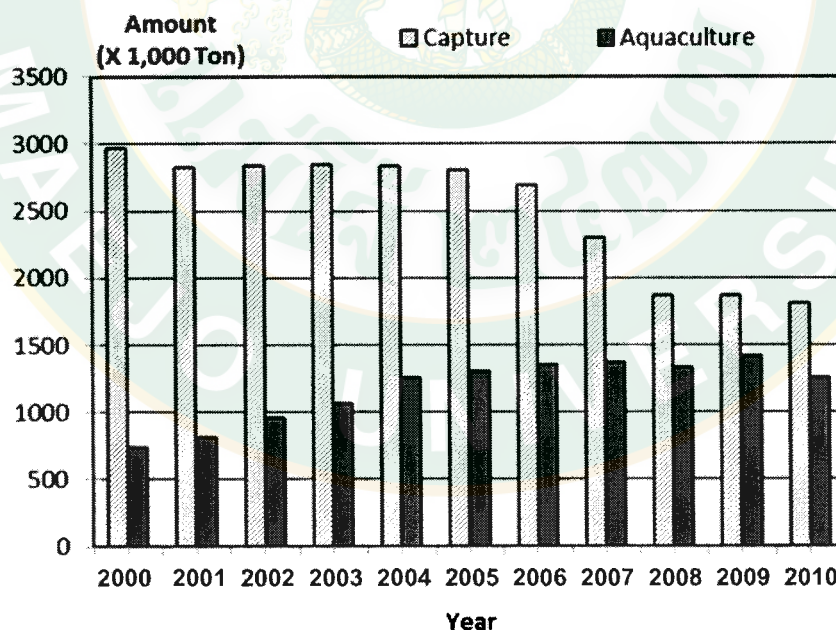


Figure 2 Quantity of fisheries production in Thailand from capture and aquaculture (DOF, 2012)

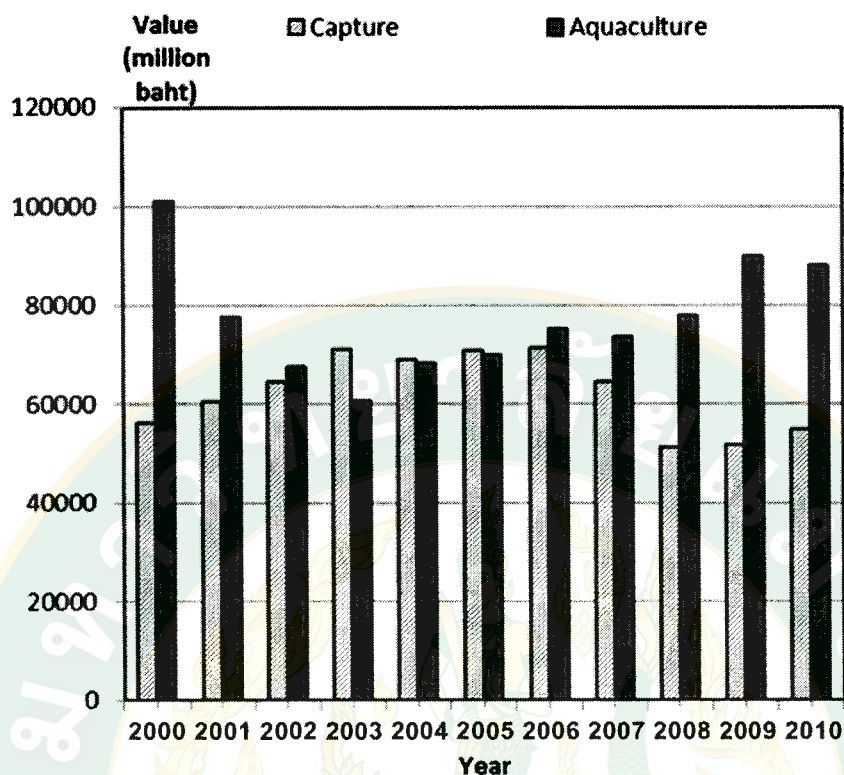


Figure 3 Value of fisheries production in Thailand from capture and aquaculture (DOF, 2012)

Aquaculture not only generates revenue for farmers; it also stimulates various aquaculture-related businesses. Aquaculture plays a significant role in Thailand's economy. Analysis of contributions to the Gross Domestic Product (GDP) during 2004-2006 revealed that aquaculture was valued at 2.1 % of the country GDP (DOF, 2013b).

Fish cage culture in Thailand is gaining its popularity since it does not require private land. A report from Department of Fisheries shows that fish cage culture had increased from 1,938 farms in 2003 to 6,462 farms in 2009, and that the quantity of fish cage production had increased from 6,097 tons in 2003 to 36,238 tons in 2009 (DOF, 2012). The most common species cultured were Nile Tilapia, Hybrid Red Tilapia, Catfish, Carp and Giant Gourami (DOF, 2012). Fish cage farming in rivers has some advantages over earthen pond system arising from flow of water through cages. High quality water will pass through cages and bring wastes outside, reducing the accumulation of organic wastes and increasing dissolved oxygen which is a significant factor for high-density fish culture.

Climate change could directly and indirectly affect aquaculture production (Handisyde *et al.*, 2006; Allison *et al.*, 2007). A potentially important indirect effect is that climate change may reduce marine capture fisheries, and this, in turn, could reduce the quantity of fish meal available to be used as input for commercial feed in the aquaculture sector (Deutsch *et al.*, 2007; De Silva and Soto, 2009). A more direct impact arising from climate change is from increases in average temperature which could positively or negatively affect growth and survival rate of different aquatic animals (De Silva and Soto, 2009). Temperature changes are also likely to alter risks of disease in aquaculture systems (Karvonen *et al.*, 2010; Baez *et al.*, 2011a). In order to assess the potential impacts of future climate change on aquaculture it is vitally important to understand how aquaculture production is sensitive to current climate, including: changes of seasons, unusual weather conditions, and extreme events such as floods and droughts.

Since there has been almost no published scientific research on the impacts of flooding and drought on fish cage culture in Thailand, this article also reviews evidence about impacts from news reports, and government documents. The primary purpose of this article is to underline the importance of the challenges posed by a variable and changing climate to aquaculture, and thus needs to identifying promising adaptation options.

2. Floods

Cumulative heavy rainfall causes extreme flood events, raising levels and speeds of water in rivers, that in turn, damage cages, kill fish and force farmers to sell undersized fish at low prices to cut losses. In major floods fish may also escape or become ill as they fail to adjust to abrupt changes in water conditions. High turbidity and low water quality during flood events, for instance, may increase susceptibility to fish diseases such as the bacteria *Flavobacterium columnare* (McAndrew, 2002).

In response to imminent extreme flood events fish farmers may respond by moving cages into slower moving water along the river bank or by harvesting fish early. Moving fish quickly is difficult as they are easy to injure and it increases costs.

Floods are an important source of climate-related risks leading to significant losses and damages in aquaculture operations. It is difficult, however, to precisely predict the impacts in a changing climate as must also consider hydrology, infrastructure and water

management in each river. Patterns of run-off and flow after over-topping banks depend on topography and other factors (Ficke *et al.*, 2007). Fish farmers, therefore, need to plan and manage risks to reduce flood damages, for instance, by considering the proper size and time for stocking aquatic animals in cages so they reach marketable size before period with the highest risks of extreme flood.

The loss of production during and following major flood events disrupts the wider aquaculture industry. The Fisheries Technology Transfer and Development Bureau in the Department of Fisheries reported that during 2003-2011 a sum total of 111,053 persons engaged in aquaculture in Northern Thailand had been impacted by severe floods, especially in 2006 and 2011, with the total amount of compensation of 536 million Baht. The total amount of losses incurred to cage-based operations constituting about 15 percent of the total amount of compensation (**Figure 4**). In 2005, the total damaged areas of aquatic cages *for which compensation was given* was 234 square meters; 32,604 square meters in 2006; 586 square meters in 2007; and 52,210 square meters in 2011. The risk of flooding is highest during August to November.

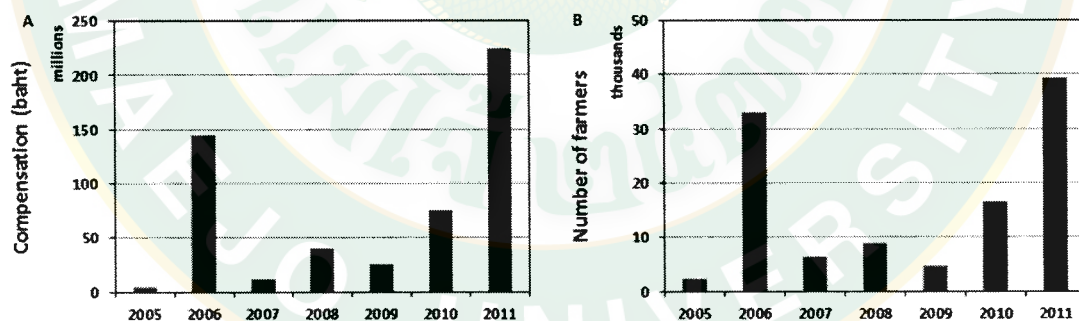


Figure 4 Disaster-related losses to inland aquaculture farms from flooding in Northern Thailand during 2005-2011: (A) Total value of relief compensation paid out to farms; (B) and number of farmers compensated (DOF, 2013a).

Clearly, floods can cause significant damage to aquaculture farms. Types of losses from the floods in the Upper Ping in 2005 included fish kill (65%), mesh or cage damage

(27%) and fish escape (22%) (DOF, 2011). The Centre for Natural Disaster Prevention and Solutions, cited in FAO (2009), stated that the government spent 60 million Baht in 2004, 156 million Baht in 2005, 758 million Baht in 2006 on compensation to the fish farmers from flooding. In 2011, the most severe floods on record took place and affected vast areas of Thailand. The preliminary report on aquaculture losses from floods during 25th March – 11th April 2011 showed that 87 Districts in 11 provinces had been aquaculture operations affected by floods. The total damaged areas was over 34,945 Rais (1 ha = 6.25 Rai) including 25,490 aquatic animal ponds and 8,291 fish cages. The total loss was approximately 792 million Baht with as many as 22,382 farmers affected (Community Organization Network, 2011). A Flooding Situation Report in the Fisheries sector during 1st May – 30th December 2011 showed the total numbers of affected farmers were 134,290 persons and the impacted aquatic areas included 194,074 Rais of fish ponds; 34,968 Rais of shrimps, crabs and mullusks operations; and, 233,492 m² of cages and cement ponds (Pickering *et al.*, 2011).

Operating decisions for dams and weirs to manage floods, produce energy, or secure water to irrigate fields may also have implications for cage aquaculture as an-instream water user. Thus, fish farmers in Chainat lost more than 1.2 million Baht in September and October 2011 due to the abrupt change of water discharge in river (DOF, 2013a). In 2006, fish farmers in Ayutthaya bore losses arising from flood protection measure for Bangkok. In 2013, fish farmers in Bangkratum district of Phitsanulok province were distressed after the Royal Irrigation Department (RID) diverted surplus waters from the Yom to the Nan river. Fish sensitive to changes in water quality died in large numbers. The diverted flood waters from the Yom appeared to have degraded water quality in the Nan river. Farmers had to sell fish early (Kotham, 2010). Likewise, excessive water levels in Nam Oun Dam led to overflow with flooding impacts on fish farms. Again, cage farmers had to harvest early to avoid a complete loss (Community Organization Network, 2011).

Strong currents due rises in flood water also kill fish and damage cages. Cage farmers in Ayutthaya suffered 200-300 kilograms of fish death a day and, again, had to harvest early (Voice TV, 2012; Manager Online, 2013c). In some provinces where flood events occur repeatedly, as in Ayutthaya, where tonnes of fish usually die every year during the flooding period – flood losses are one of the main reasons for cage farmers to exit the business completely

(Manager Online, 2011). Bang Ban district in Ayutthaya has repeatedly confronted with floods such that fish farmers must bear huge losses, some with up to more than one hundred thousand Baht from fish death every year. As a result of debt burdens some farmers permanently quit fish cage farming business (DOF, 2013a).

Early and high floods in the Chi River and Moon River impacted fish cage aquaculture. Fish became more vulnerable and susceptible to diseases infection and eventually many died. Fish farmers then had to harvest and sell remaining fish before they reached market size (Manager Online, 2013c). Disease following flood events was a major cause of death in Nile and Red Tilapia as well as Striped Catfish reared in floating cages of Mun river (Daily News, 2012). *Alitropus typus* (an Isopod) which dispersed easily in the rainy season killed thousands of Nile Tilapia fingerlings (Chinabut, 2002).

If farmers who have confronted floods use their experience to analyze effects and seek measures to cope with the problems and manage risks, they can reduce losses. For example, the cage aquaculture areas in Thasung subdistrict, Mueang district, Uthaitani province, has often been flooded. Farmers in this area have learned from their experience and prepared themselves for flood situation in later years by harvesting and selling the fish products before reaching a large size, reducing risks of big losses. This practice could be seen as, in part, a seasonal, flood risk reduction measure. Mrs. Wanpen Nathong, a leading cage farmer, stated that *“careful disaster surveillance and planning could reduce losses of fish production accounting for more than million Baht altogether, and be away to save government funds used for compensating farmers for their losses”* (MCOT, 2011).

However, fish farmers can do little to control water quality which is affected by chemical run-offs from agricultural sector into rivers during rainy season. Degradation of water quality in rivers during the flood events killed fish in river cages due to the fact that accumulated volume of pollutants and waste from agricultural farms ran-off into rivers and decreased DO content, for example, the Thachin river in Suphanburi. Likewise, during rainy season in August 2013 in Uttaradit, Chiang Mai and Pitsanuloke, turbid water due to eroded soil on the riverbank flows rapidly in rivers causing fish death and losses (Manager Online, 2013b). Some fish farmers stopped production completely for that wet season due to fear of such unpredictable losses (InNews, 2013).

3. Impacts from drought

Low water depths, slow flows and poor water quality in the dry season, especially as air and water temperatures rise prior to the Monsoon, increases risks of losses. Low water depths are a major concern of fish cage farmers in the Upper Ping River (Lebel, 2008). Generally, appropriate water depth for fish cage culture should be deeper than 2.0 metres and the bottom of the cage should be at least 1.0 metre above water area (Thairath Online, 2012).

Prolonged drought in dry season with stagnant flow conditions allows quick growth of Phytoplankton that also degrades water quality in rivers. Rising temperature and stagnant waters lead to low oxygen levels which stress fish, leading to weakness and death. According to news reports, losses and damages to fish cage operations in the Mun river start between the end of December 2010 to early January 2011 when water level reach critical low levels and continue to fall until early March. In response, some fish farmers postpone stocking fish fry while others skip the entire growing season. In that year only 10 farmers persisted from the original total of 30 persons since they were afraid of further losses. Most farmers had borrow money from informal financial sources or the Bank for Agriculture and Agricultural Cooperatives (BAAC). Each farmer had to bear approximately 200,000-500,000 Baht debt. The maximum numbers of fish crop raised in a year were reduced from 3 crops to 2 crops (Komchadluek, 2010). In 2011, fish farmers in Phitsanulok province confronted with fish death due to low flow in early June 2013 (Manager Online, 2013d). The drought events temporarily or permanently led farmers to stop rearing fish in that period. Public dams or reservoirs, as well as community-based water management systems were proposed as solutions.

The drought crisis also impacted other areas in northeast Thailand. Fish farmers in Nakhon Ratchasima had to prolong culture periods for one more month as water level in the river was only half of normal levels and fish grew slowly. Under poor water conditions fish loose their appetite reducing growth rates and increasing cost to farmers arising from the prolonged rearing period (Bangkokbiznews, 2013). Also in 2013, water released from Ubonrat dam in Khonkaen were inadequate; therefore, cage farmers in Pong sub-basin decided to refrain completely from fish farming in that season. Likewise, more than half of fish cage farmers in Chi River in Mahasarakham had to stop fish production during the dry season since they did not want to take a risk of fish disease infection during low flow (Phitsanulokhotnews, 2013).

Maharakham Provincial Office, Department of Fisheries encouraged 268 fish farmers in Chiang Yuen district, Kosumphisai district, Kantarawichai district and Muang Maharakham district to completely stop fish production in their 4,776 cages during drought season since there was not enough water in the river (BioThai Foundation, 2013).

Fish cage farmers who rearing fish immediately downstream from dams or weirs need to be well-informed about water releases and closures in order to alleviate potentially disastrous damage from water infrastructure operations. Farmers in Bangkratum, Phitsanulok, for instance, suffered badly from rapid decrease of water level in the Nan River in 2013, finding it difficult to move their cages in the short time levels fell when discharge of water from Khwae Noi Bamrungdan Dam was stopped without prior notification (Manager Online, 2013a).

According to news reports, the 2013 drought crisis started to hit fish cages farming in mid-January 2013 when it became clear that water storage levels in public dams for use in dry season were unusually low. That year the Ping River went dry and was reduced to pools of shallow, discolored, polluted and reduced DO content water causing many fish deaths (Thai Fish, 2012). The Regional Irrigation Office 1 in Chiang Mai urged farmers to refrain from fish farming in the Ping River throughout the dry season of 2012 through to 2013 (Nation Channel, 2010). The drought crisis resulted in major losses across several provinces in Thailand. Proper plans to construct and operate weirs, reservoirs and other infrastructure, as well as involvement of local water users in their management may alleviate some of these dry season risks. Shrimp farmers in Chiang Rai, for example, were successful in water management by careful systems for allocation, negotiation and reuse of water (ThaiPBS, 2013).

Low water levels and cool conditions may interact. Low water temperature in the winter season also impact aquaculture in rivers and reservoirs. News reports indicate that low water temperature in cages in Lampaw dam in Kalasin province led to mass mortality, and fish farmers lost hundreds of thousand baht. As a result of the losses, supplies to markets were inadequate, leading to a significant short-term increase in fish prices (Prachachat Online, 2012). During a period of cold weather with low water levels in the Mun river, fish in cages were found to be highly infested with parasites such as *Argulus* and flukes that grow well at these lower temperatures (Manager Online, 2013a).

4. Discussion

News and government reports reviewed clearly show that floods (or high flows) and droughts (or low flows) have significantly affected fish cage farming production in many locations and in different years in northern Thailand. Identifying, creating and supporting suitable locations with adequate availability and quality of water for fish production during the entire crop season is thus a key management issue. It is difficult, however, for individual farmers to manage or control the environment surrounding river-based cage culture production sites. The challenges appear to have been amplified by a variable and changing climate with significant level of extreme events. It is recommended that fish farmers and other concerned stakeholders assess more thoroughly existing and future potential climate-related risks to aquaculture production. It is also important to identify appropriate risk management strategies and related adaptation options. These may range from increasing capacities to cope with extreme events through to improved preparedness measures that reduce losses resulting from floods and droughts. Apart from short-term actions, such as temporary moving cages towards suitable locations to avoid high flows, which are not available everywhere, more attention is needed to more strategic options such as: adjusting the fish cropping calendar to match better local climate; stocking larger size of fingerlings in order to shorten the rearing period; stocking multiple sizes of fingerlings to diversify the risks; diversifying fish species; reducing stocking densities in cages; using aerators to increase water circulation in the case of low flows; preparing contingency plan if unexpected events occur; more frequent monitoring of production sites during high risk periods; learning more about climate patterns and weather, as well as information about dam and water infrastructure operations.

Ultimately, a more holistic approach to water management is needed for the sustainability of river-based cage fish farming. Meanwhile, however, a much more systemic and research-based analysis of climate-related risks and their management is needed. The effectiveness of farmers' existing risk management practices or adaptation strategies is undocumented and unclear. A better understanding of existing and plausible alternative risk management measures would be very beneficial in reducing losses and damages in the inland aquaculture sector. Future research should also examine in-depth, the causes of fish vulnerability, disease outbreaks and cause of death during and after floods or droughts in river-based cage

culture. River flow rates and dissolved oxygen concentrations, we propose, are likely to be key, climate-sensitive, variables influencing fish growth, survival rate and production in cages.



CHAPTER 3

RIVER-BASED CAGE AQUACULTURE OF TILAPIA IN NORTHERN THAILAND: SUSTAINABILITY OF REARING AND BUSINESS PRACTICES

1. Introduction

Cage-based aquaculture in rivers and other public water bodies raises issues of natural resource management that are more familiar to fisheries management than aquaculture in fish ponds on private land (Costa-Pierce, 1998). Successful aquaculture depends on site selection, good quality water and the waste removal services of aquatic ecosystems. As practices expand and intensify concerns about nutrient pollution, impacts on local ecosystems, and competition with other river and water users increase (Bush *et al.*, 2009; Guo *et al.*, 2009).

Understanding of rearing and business management practices in river-based cage aquaculture systems is fairly limited. The vast majority of studies of cage culture have been carried out in ponds, lakes or reservoirs. From these studies a few key messages about how fish rearing and business management practices influence sustainability have emerged.

First, pellet feeds can greatly improve yields but are costly so precise management of feeding regimes and high feed quality are critical to improving feed use efficiency and profits (Waidbacher *et al.*, 2006; Kareem *et al.*, 2009; Alam *et al.*, 2012). Concerns with feed costs have triggered exploration of alternative feed sources and more integrated culture systems but these have mainly been oriented towards water management in closed pond systems on farms (Setboonsarng and Edwards, 1998; Yi *et al.*, 2003; Pant *et al.*, 2004b; Blythe, 2012).

Second, stocking density has a variable influence on yields depending on impacts on water quality and feeding efficiencies, and thus ultimately on profits (Conte *et al.*, 2008; Gibtan *et al.*, 2008; Ofori *et al.*, 2010). Relationships between stocking densities and profitability can be expected to be even more complex if feeding efficiencies fall or growth rates slow at high densities given high costs of feed and size-specific prices for harvests (Chaibu *et al.*, 2004).

Third, as fish farming commercializes additional business management, knowledge and institutional issues arise for farmers (Kusakabe, 2003; Lebel *et al.*, 2009). Access

to credit and technical support, sometimes in form of contractual arrangements, can be important factors in commercial success (Hishamunda and Ridler, 2002; Nunoo *et al.*, 2012). Markets for inputs and products, availability of credit and technical support, and government regulations on access to public waterways have a major influence on aquaculture practices and the way an industry develops in particular places (Piumsombun *et al.*, 2005; Lebel *et al.*, 2007; Loc *et al.*, 2010).

This paper analyzes an emerging industry based on cage aquaculture in the Upper Ping River in northern Thailand which helps serve the large and growing demand for farmed fish in Chiang Mai town (Chaibu *et al.*, 2004; Ungsethaphand *et al.*, 2005). This industry is based primarily on the culture of an improved strain of red Tilapia (*Oreochromis niloticus* L x *O. massambicus* and others) popular with consumers and known locally as “Tub-tim”. The paper addresses two main questions: (1) What are the rearing and business management practices of river-based fish aquaculture farms? (2) What are the main constraints and opportunities to improving the sustainability of the industry?

2. Methods

This study used mixed methods: we iterated between qualitative and quantitative approaches towards data collection and analysis (Mason, 2006). Qualitative in-depth interviews and observational time in the field were particularly helpful in understanding the social context in which farmer’s rearing practices and business strategies operated whereas quantitative methods helped understand variation in key variables and their association with multiple factors as well as prevalence of key problems and behaviors.

2.1 Study area

Fish farming practices were observed and farmers interviewed in the seven sub-districts bordering a 50km reach of the Ping River between Pak Bong, Pasang District, Lamphun Province (N 18°32’ E 98°56’) and Sob Tia in Chom Thong District (N 18°24’ , E98°42’), Chiang Mai province in northern Thailand. In this region the river forms the boundary between Chiang Mai and Lamphun provinces (Figure 5). The sub-districts were grouped according to their relative position downstream from Chiang Mai town: Pak Bong and Song

Khwaë (Upper); Doi Lor and Nam Dip (Middle); and Wang Pang, Kuang Pao and Sob Tia (Lower).



Figure 5 Cages in the Upper Ping River, Chiang Mai-Lamphun: (A) Providing pellet feeds; (B) Cages arranged in long rows along the bank; (C) Checking cages during high flows; (D) Accessing cages when water depths are low.

2.2 Survey of farm practices

We attempted to collect interviews from 286 farms comprising all of the farms known to have been active around mid-2005. Farms were identified based on lists maintained by the Department of Fisheries and supplemented by inquiries to help locate other farmers who had not formally registered. Eleven farms were not included: we could not contact 3; another 7 farms had not yet completed a first harvest; one was excluded because questionnaire was not properly

completed. The analyses here refer, therefore, to the sample of 275 farms for which completed questionnaires were obtained.

All interviews for the quantitative survey were completed between 7 October and 22 November 2005 after a series of pre-tests. Most questions covered the annual cycle of activities and production risks, but detailed information on costs and receipts from sales focused on just the last harvested crop to reduce recall bias as most farmers did not keep detailed records they could simply share. All financial transactions are reported here in the local currency (Thai Baht). Exchange rates during the study period varied between 35-39 Thai Baht per US dollar.

Approximately 80% of harvests reported occurred between June-October reflecting the main (and most recently finished) cropping season in this river reach. Questionnaires were administered by trained student interviewers and research staff in the field under the guidance of the lead author.

Based on our in-depth interview average interest repayments were around 6% per annum or 3% for a six month crop cycle that includes preparation times. To calculate fixed costs we assumed, based on interviews with farmers, that fish cages and all associated equipment lasted 5 crops. Opportunity cost of unpaid family labor was estimated from a sample-based regression of time spent taking care of fish against number of cages. Generalized linear models were used to explore associations of yield, practices and profitability with multiple candidate predictor variables.

The analysis was organized in three parts. First we explored variation in practices with various contextual factors describing the business context of farm decision-making. Second we analyzed common and unusual features of business management focusing on knowledge sources, loans, and contracts. Third we focused on the outcome of these strategies in terms of profitability, looking more closely at cost structures, selling of harvests, loan and contract arrangements.

2.3 Qualitative interviews with farmers and other stakeholders

Additional information on rearing practices, business management strategies and how individual households got started in fish farming was obtained through in-depth interviews. Altogether we conducted 82 interviews, each lasting 30-60 minutes, with: farmers

(n=40), local government officials including those involved in agriculture extension (n=12), farmer association leaders (n=2), department of fisheries staff (n=4), other government departments (n=2), bank staff (n=2), local academics involved in aquaculture, fisheries or farm business management (n=8), company agents, brokers or input-sellers (n=10) and retailers (n=2). Informants were selected purposively to provide a diversity of perspectives on key management and sustainability issues. Most in-depth interviews were done by the lead author during July 2005 – June 2007. Qualitative data in the form of fully transcribed scripts of interviews were coded, managed and analyzed using NVIVO software.

2.4 Long-term follow-up

In December 2011 we attempted to contact households which had farmed fish in 2005. Altogether we were able to contact 80. Others had changed phone numbers or did not answer calls. We made some simple checks for possible selection bias by comparing features of farms followed-up (n=80) versus those not (n=195). There was no significant difference in education level, age, years of experience, stocking densities, or farm size between followed-up and other farms (ANOVA, all $P > 0.1$) suggesting the follow-up sample was representative of the 2005 fish farming cohort.

3. Results

3.1 Fish farmers

Most fish farmers had a modest level of formal education (Table 2). Just over a third had received formal training in aquaculture. The industry in the Upper Ping in 2005 was relatively new: farmers had on average only 3.8 years of experience with cage aquaculture and the longest was 6 years. Both men and women were actively engaged in farming fish.

Most (90%) fish farmers had other income sources apart from aquaculture, such as, tending orchards, growing rice or field crops, or a small trading business (Table 2). Farms with small (≤ 4 cages), medium (5-12 cages) and large (> 12 cages) were very similar with respect to all characteristics listed in Table 2.

Table 2 Selected features of fish farmers.

Characteristic	% farmers (n=275)
Education level	
Primary	72.7
Lower Secondary	9.5
Upper Secondary	11.6
Tertiary	5.5
Livelihood apart from fish farming	
Orchards	47
Rice or field crop	22
Small trading business	21
Construction laborer	6
Training in aquaculture (%)	37
Cage aquaculture experience (years)	
1	10.9
2-3	32.4
4-5	32.7
6	24.0
Age (years)	
< 30	3.6
30-39	22.5
40-49	39.3
50-59	27.3
>=60	7.3
Gender	
Female	34.5
Male	65.5

3.2 Rearing practices

3.2.1 Stocking and feeding

Fish farms consist of sets of floating open-top cages, usually strapped together in blocks of four. The most common cage sizes used in 2005 were 4mx4m (55%) followed by 3mx6m (23%). Water depth within cages was normally around 2m. Cages were made from nylon mesh with grid size of 6-25mm depending on size of stocked fry. The last completed production cycle – for which more detailed economic information was collected – on average comprised 61% of the total cages in a farm.

Large farms stocked fish more densely and achieved higher yields per unit volume than small farms (Table 3). Survival rates and feed conversion ratios (FCR) were not significantly different across farm sizes.

Farms stocked cages with juvenile fish 30-60mm in length that have been reared in tanks or ponds at hatcheries and nurseries for approximately 3 months prior to release into river cages. Fish fry were either provided by brokers through contract or were purchased independently by farmers. The average length of time juvenile fish were reared in river cages varied slightly with season: warm-wet season only crops (harvested September-November) were significantly shorter than those harvested at other times of year (4.16 vs. 4.90 months, ANOVA, $P < 0.01$). Whenever possible fish were harvested after they had reached a market standard size of 500g ind⁻¹.

Average FCR was 1.47 ± 0.43 kg feed per kg fish produced (Table 3). Most farmers use two different feed formulations for each crop: smaller pellets for the first month and then a larger pellet formula thereafter. Farmers observed that water conditions affect feeding behavior, for example, in the cool season fish eat less. Farmers adjust feeding rates to compensate and not waste feed.

Table 3 Rearing practices of different size farms in the Upper Ping River (n=275). Different letters after means in the same row indicate significant differences.

Practice measure	Farm Size (nos. cages)			Average
	Small (1-4)	Medium (5-12)	Large (13+)	
Stocking density (fish/m ³)	45.6a	49.6ab	52.8b	49.1
Survival rate (%)	94	91	93	92
Feed conversion ratio (kg feed/kg fish)	1.49	1.45	1.53	1.47
Yield (kg/m ³)	25.1a	26.6ab	29.0b	26.6

Farmers rarely hire others for feeding because of concern that feeding will not be done properly. Most hiring was done for just a day to help with harvesting. Many fish farms are run by couples with women often doing a substantial amount of daily feeding and care tasks (Lebel *et al.*, 2009).

Over the previous 12 months prior to the survey hybrid red tilapia were cultured by 94% of farmers and Nile tilapia by 17%. Just over 5% grew other species. For last crop harvested average feeding intensity was higher for Nile tilapia (1.69) than red hybrid tilapia (1.44) (ANOVA, $P < 0.01$); for other measure there was no significant difference between the two tilapia strains.

Farms increased in size on average by 2.6 cages between 2005 and 2011 (Paired $t = 2.1$, $P < 0.05$). Some farms contracted in size. The most significant changes reported by farmers in practices over the six years were decreases in stocking density and increases in use of supplemental feeds, pro-biotics and medication (Figure 1). Increases in crop length may have been a management strategy to deal with decreases in observed growth rates.

3.2.2 Use of chemicals and medication

In 2005 about 62% of the farms used at least one antibiotic. Oxy-tetracycline was the most common (45%) followed by enrofloxacin (6%) and sulfa-dimethoxine (6%). Antibiotics were primarily used, as expected, to treat disease and infections with common symptoms such as swollen eyes and gills and body lesions noted by respondents. Known common fish diseases in the area include *Streptococcus* and *Flexibacter columnare*. Fish are also infected by *Trichodina* parasites. A 5-7 day treatment of oxytetracycline or enrofloxacin was often used when juvenile fish are first added to cages to treat injuries and health problems arising in transport. Vitamin C and multi-vitamin formulations were provided in first week after fish were released by 79% of farms. Farmers said these helped to make fish strong and healthy so they would eat and grow well.

Potassium permanganate was used by 13% of farms to treat parasites and disease infections. A variety of other chemicals, including plant and animal extracts, were used rarely.

3.2.3 Managing water problems: floods and low flows

Apart from diseases and parasites farmers reported several factors affect fish production. A high proportion of farms had problems with infectious diseases (82%), suspended sediments (74%), and low oxygen levels (75%) during the past year.

High proportions of farms also had problems with low (64%) and high (75%) flows in the last 12 months. Averaged across all farms estimated losses due to low flows in the last year was 8,500 Baht. Among those farmers with low-flow related problems most responded by aeration or assisting water circulation (80%) and moving cages towards the mainstream (93%). A few harvested their crops early (12%).

Among those farmers with flood-related problems common kinds of damage and losses were: damage to nets (27%), death of fish (65%) and escapes (22%). Averaged across all farms estimated losses due to high flows or floods was similar to that of low flows of 9,640 Baht in the previous 12 months.

Floods it should be noted were a recurrent challenge, with most farmers with problems having reported 3-5 separate events they had to contend with during 2005 wet season.

According to in-depth interviews floods in 2006, although lower in height, had an even larger impact in key locations when it destroyed a weir in Doi Lor and in the process the main river channel changed course.

Virtually all farmers (96%) received information or warnings about floods. This information came from several, often multiple, sources and was perceived as helpful (98%). In response to imminent floods farmers moved cages towards banks in slower moving waters (88%) and monitored cages more closely than usual (93%). A few farms took more drastic action: harvesting the crop early (14%) or moving their crop to a pond (8%).

In interviews farmers and other stakeholders emphasized that during floods people in the community helped each other a lot. Farmers also underlined the value of maintaining relationships with local government and agencies like the Department of Fisheries (DOF) suggesting that this was part of their risk management strategy.

Most farms were registered with DOF: 92% in 2005; 98% in 2011. The most common reason (43%) given in 2005 was that officials can be asked for assistance, for example, following flood losses. DOF has brochures to give people who have never reared or are beginning to farm fish. These include suggestions not to rear fish during high flood risk or low flow periods. Officials interviewed from the Department of Fisheries and Local Government would prefer to see less risk-taking because when losses occur farmers turn to them for assistance and compensation.

Respondents in 2011 made similar claims with respect to coverage and sources of early warning. They also reported paying more attention to water-related news. This implies that since the 2005 major flood warning systems had been well maintained and remained useful in the next major flood which occurred in 2011. At the same time in 2011 most farmers still reported trends of increasing problems with diseases, floods and low flows (Figure 6).

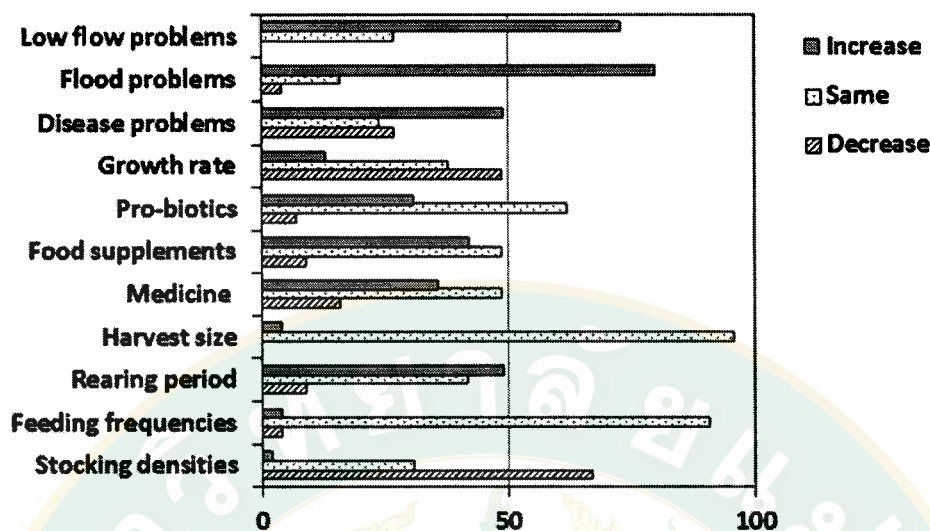


Figure 6 Changes in management practices and problems during past 5 years (2006-11).

3.2.4 Yields

Variation in yield density was positively associated with stocking density as would be expected: a 10% increase in stocking density implies a 6% increase in yield (Table 4). FCR was also significant predictor but had a negative coefficient suggesting current feeding rates were already above optimum once stocking densities were taken into account. Yields were significantly higher in the lower reach and for farmers with many sources of knowledge about rearing. The following other predictors were tested and found not to be significantly associated with yield: aquaculture training, level of formal education, farm size, fish species reared, and wet season cropping time.

Table 4 Estimated coefficients for model of ln (yield density); ANOVA, $F=72$, $df=6$, 268; adjusted $r^2=0.53$.

Parameter	Coefficient (SE)
Ln (FCR)	-0.225 (.05)
Ln (Stocking density)	0.640 (.04)
Reach	
Upper	-0.100 (.04)
Middle	-0.120 (.04)
Lower	0
Knowledge sources	
Few	-0.055 (.04)
Several	-0.125 (.04)
Many	0

3.3 Business management

3.3.1 Knowledge sources

Fish farmers were asked similar sets of questions in 2005 and 2011 about where they obtained knowledge about rearing fish. Other fish farmers and the department of fisheries – already important in 2005 – became sources of knowledge for even more farmers in 2011 (Figure 7A). Sellers of stock and feed remained important. Magazines become a more important source while television declined to be virtually irrelevant. Women and men obtained information from similar sources.

Contracting firms working through their brokers and agents provide feed and fingerlings are an important source of knowledge to farmers. When getting started in an area companies form working groups, run trainings and seminars. Support continues after: A CP Manager of several agents told us he shares his mobile number with farmers so people can call him to consult about problems at any time. His agents visit farmers frequently. Brokers and

leading farmers emphasized to us the importance of book keeping and market knowledge. Agents train farmers in record-keeping and analysis so they can monitor and forecast their crop's growth and value as well as plan ahead on feed needs.

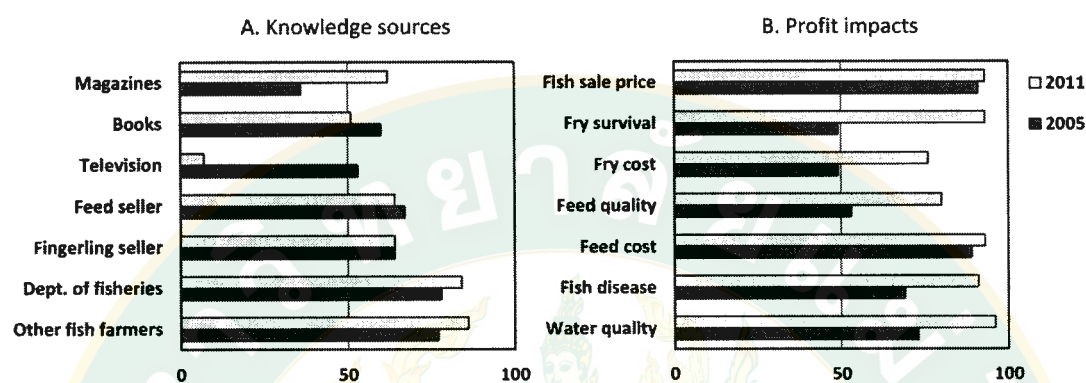


Figure 7 Changes between 2005 and 2011 in farmers' (A) sources of knowledge and (B) perceptions of factors with major impacts on farm profitability.

Associations among knowledge-related variables and practices were explored using multiple regression. Fish farmers with training in aquaculture stocked cages at higher rates (52 vs 47 fish m⁻³). Farmers who had more years of experience also tended to stock more densely (b=1.16, F=4.3, P<0.05). There were no associations with level of education, number of knowledge sources or age.

3.3.2 Loans

Most farmers (88%) borrowed money from at least one source for their operations. Of those farms taking loans the Bank of Agricultural Cooperatives (BAAC) was the most common source overall but provided more loans to fish farmers in Chiang Mai (94%) than Lamphun (65%). Loans from the BAAC are made to both individuals and groups of at least 5 people from different households. Group interest rates are nearly half regular commercial rates. Thus the BAAC Office in Chom Tong and Doi Lor had current loans to 6 groups specifically for fish farmers and another two for post-harvest processing. In addition more than 200 individuals had taken loans for fish farming activities.

The Village Fund Scheme, the next most important source, was a source for a larger proportion of farmers in Lamphun (39%) than in Chiang Mai (22%). In total the average amount borrowed by farmers in Chiang Mai (131,000 Baht) was more than those in Lamphun (88,000 Baht, ANOVA, $F=9.84$, $P<0.01$). Amounts borrowed from the Village Fund are typically smaller than from the Bank. Other rarer sources of loans were relatives (6%) and money lenders (4%). To put these figure in perspective average amounts borrowed represented on average 80% of crop costs (see section below).

From our in-depth interviews in 2006 we were able to extract more detailed information from 25 farms about total loan periods, interest rates and histories of loan and debt cycles. These confirm typical amounts per year, but also underline important year-on-year effects of success and failure on debt burdens and credit cycles, and substantial complexity in combining sources of funds and differing repayment periods. Thus typical annual interest rates in 2004-5 were around 6% for loans from BAAC, but during 2005-6 some farmers were facing, for various reasons, effective interest rates of 9-12%. Nevertheless, many farms appeared to be successful in making use of BAAC credit for their fish farming operations with some cycling through loans year after year as part of the cash flow management of their farms.

The fraction of fish farmers with loans declined from 88% in 2005 to 60% in 2011. Most continued to obtain loans from BAAC. Village funds and other unofficial sources declined to be of little importance.

3.3.3 Contracts

We heard about two main kinds of business relationships between fish cage farmers and firms with some variations in details of cost-sharing.

When a contracting firm is initially getting established and is recruiting new and often inexperienced partners farmers may be contracted to rear fish for the company. In this contract arrangement farmers do not need to make an initial investment except for cages. All other inputs are supplied by the company and the farmer gets a fixed price per kg (3-5 Baht) of the final harvest. We estimate from responses in our quantitative survey that 12% of farmers “reared fish for others” in a relationship of this sort but it was not possible to distinguish if it was with one of the major firms or another grower in our survey data.

The other, more common, contracting arrangement involves farmers putting a down-payment per fish in return for credit on feed and the promise that crop would be sold back to the firm. The arrangements of the most active broker are illustrative. The initial down-payment of 10 Baht/fish is known locally as 'insurance'. Prices at harvest are not usually fixed but allowed to vary with current market. The firm pays within 7 days of harvest subtracting costs of advanced feed and fish minus the initial down-payment per fish. On occasions down-payments are temporarily returned to farmers so they can clear old BAAC loans and get a new one. Contracts can be ended and outstanding deposits will be returned. Reputation is crucial to success for a small broker firm.

Another smaller contracting firm placed a strong emphasis on their farmers using the fish fry that come from high quality CP stock. They told us they could tell whether fish were likely to be the CP-strain by their body shape. Fry are normally paid for in cash but feed (from CP) is provided on credit that must be repaid at next round of purchases (crop) with amounts of up to 40-50 bags being advanced (or 10-15,000 Baht).

Although several firms told us they often make written contracts these are never used. We probed the sensitive question about selling the harvest outside contracts for higher prices with several farmers. Most farmers said remaining loyal to the contract was important on principle, for future business and because they were in debt. In practice farmers do sell a small amount of product, for example, that which is undersize, to other buyers. Some farmers split their set of cages among different contracting firms so they could compare quality of inputs, juvenile fish, yields, harvest services, and prices.

Most farmers we spoke to were satisfied with contract relationships. Several academics and government officials we interviewed, in contrast, were critical claiming that brokers and larger firms were making it hard for farmers, by paying lower-than-real market price, over-charging on inputs, and levying hidden fees at harvest times. Farmers who have discontinued fish farming are less enthusiastic about contracts and the pressures of having to repay loans.

In 2005 several types of arrangements could be documented but the proportion of farmers under contract could not be estimated precisely because of ambiguities in our survey.

In 2011, 71% had contracts with firms to grow fish. In 2005, certification was not yet in place. In 2011, two-thirds (69%) had received Good Agricultural Practice (GAP) certification.

3.3.4 Markets

Farmers enter into contracts, in part, because independent access to marketing channels is not straightforward. Well established brokers, especially those with extensive contract farming arrangements, claim they are able to give higher prices to farmers because they also have long-term reliable resell points in the main markets.

In our survey red hybrid tilapia above the industry standard of 0.5 kg fish⁻¹ were sold by farmers for 44 Baht kg⁻¹ during second half of 2005 whereas smaller sizes sold for 35 Baht kg⁻¹. Prices paid for black Nile tilapia were more variable and lower, averaging 40 Baht kg⁻¹ for standard size and 33.5 Baht kg⁻¹ for smaller fish.

The consumer market for hybrid red tilapia in Chiang Mai area was estimated by informants in 2005 as typically being between 7-10 tonnes of fish per day with most being sold at fresh markets (Ungsethaphand *et al.*, 2005). Consumer demand and prices rise during public festivals. In event of shortfalls fish are imported from other areas like Uttaradit or further south. Major retail outlets make advanced purchase plans and contracts with suppliers each 1 to 2 weeks and adjust retail prices accordingly. Live fish (kept in aerated tanks) in the market place fetched a higher price creating an incentive for supplying live fish.

3.3.5 Costs and Profits

Total variable and fixed costs per volume averaged 1,062 (±301 SD) Baht m⁻³. The average crop, or simultaneously harvested set of cages, cost 146,000 Baht. Feed dominated costs, followed by fish stock and unpaid family labor (Figure 8). Cost structures did not vary with farm size but total investments did: large farms spent more (1241) than either medium-size (1078) or small farms (1004) (ANOVA, df= 2, 272, F=9.1, P<0.001). Farms in the lower reach (1217) spent more than those in middle (1042) or upper reach (1065) (ANOVA, df=2,272, F=6.5, P<0.01).

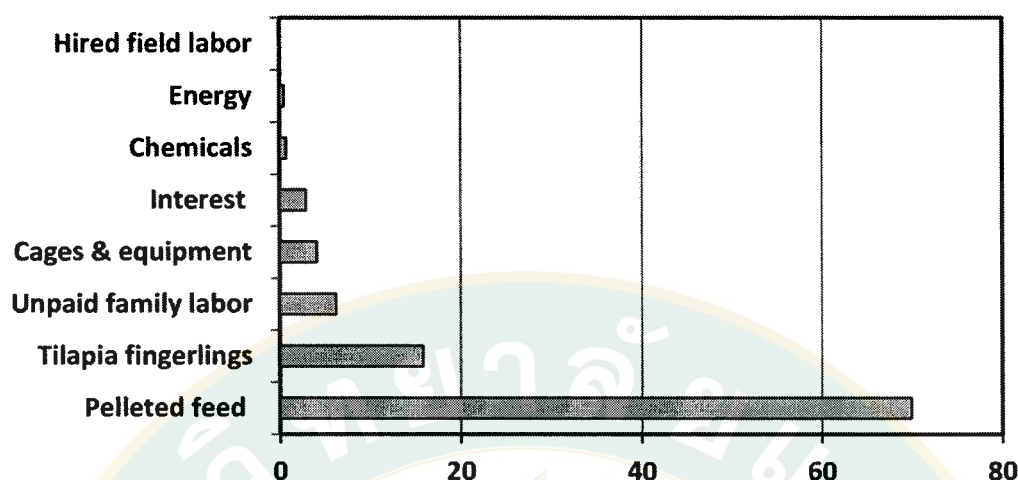


Figure 8 Average cost structure of a fish crop.

Feed was bought in 20 kg bags. Feed cost on average 20.3 Baht kg^{-1} . At the time of the survey 3 brands were in common use. The brands differed significantly in average price ranging from 19.7-21.5 Baht/kg. Pellets for young fish were slightly more expensive than for older fish.

Gross profit per unit volume (including opportunity costs and interest repayments) averaged 72 ± 262 ($\bar{x} \pm \text{SD}$) Baht m^{-3} . The high spread underlines that not everyone makes a profit on each crop: a third of farms made a loss at their last crop in 2005. The average profit per crop was only 13,241 Baht. Mean relative return on investment ((receipts-costs)/costs) was 9 ± 24 percent per crop or a period of about 6 months if allowing for some repair and cleaning time between crops.

Profitability measured by unit volume and as return on investment are highly correlated ($r=0.93$). We chose to explore relationships with profitability per unit volume.

Two profitability models were constructed the first including yield and the second stocking density which are highly correlated variables both strongly associated with profitability (Table 5). Profitability was then regressed against an additional set of candidate predictors.

Table 5 Estimated coefficients (SE) for model of profit density (Baht/m³).

Parameter	Model	Model
	Yield	Stocking Density
Yield density	8.02 (1.2)***	-
Stocking density	-	2.44 (0.69)***
FCR	-402 (22)***	-434 (23)***
Survival rate	133 (37)***	245 (43)***
Fish species (Red Tilapia)	90.0 (28)***	67.8 (29)***
Farm size	**	*
Small	97.6 (29)	80.3 (31)
Medium	57.5 (28)	43.7 (27)
Large	0	0
Wet season crop	35.7 (18)*	34.7 (19) ^a
Aquaculture training	-41.8 (18)*	-40.2 (20)*
Intercept	189 (78)***	258 (91)***
Adjusted r ²	0.68	0.64

*** P<0.001, **P<0.01, *P<0.05, ^aP=0.07

No differences were found for reach, education, gender, experience in aquaculture, loans, and other income sources and these factors were dropped from final models (Table 5). The results for both models were similar. Survival rate was positively, and FCR inversely, associated with profitability. Rearing red tilapia was more profitable than Nile tilapia. Small farmers had higher profit densities than medium or large farms. Farmers whose last crop fell in the wet season earned more than those who did not despite problems with floods.

After taking all above variables into account one unusual association pattern remained: those with formal aquaculture training had slightly lower profits than those who did not have such training.

Fish farmers were asked identical questions in 2005 and 2011 about important factors impacting farm profitability. Overall farmers appear to have become more aware of or sensitive to various environmental and market factors (Figure 7B). In particular farmers have become much more concerned about feed quality, fingerling cost and survival than they were before. For some other factors like feed price and fish sale price concerns were already high in 2005.

3.3.6 Exit reasons

Of the 80 households which had farmed fish in 2005 just under half ($n=35$) had exited by 2011. Fish farmers offered multiple and many different reasons for stopping. Financial reasons were common in particular suffering economic losses (18) and lack of capital (14). Natural resource constraints were also common, but diverse including: lack of good sites (15), floods (5) and disease (5) and low flows (2). Labor-related issues formed a third category of less common and also diverse reasons such as no time (6), no labor (4), too old (4), poor health or death (3) and finding a better job (3).

Of those who had stopped 63% had no intention of ever resuming, but 9% expected to within the next 2 years and the rest were unsure if they would or not. Ex-fish farmers noted that their main occupation post fish-farming led to reduced income in 77% of cases and to an increase in only 20%. The main occupations followed after leaving fish farming were: orchards (37%), trading (20%), and own small business (20%). Rarer occupations were becoming laborers (9%), rice farmers (6%) or being employed by a company (3%).

Next we compared households that continued to farm fish with those who had stopped. Using binary logistic regression the following variables were not associated with exiting from fish farming: species reared, completed high-school level education, received formal training in aquaculture, farm size, more than 4 years of experience, or having more than 4 knowledge sources.

3.4 Environmental and social sustainability

Much of the evidence above is relevant to consideration of economic sustainability. In-depth interviews with stakeholders directly involved in the industry, other river

users and local government officials with area-based management responsibilities suggest there are also a few environmental and social sustainability issues.

First and foremost are concerns that high densities of cages in confined reaches could result in excessive nutrient pollution and possibly other effects from chemical and medication use. Most stakeholders interviewed, including those not engaged in fish farming, believe that fish farming in rivers at current levels is a benign activity; accumulated nutrient inputs are quickly diluted and dispersed. The impacts from fish farming on water quality are believed to be less than from other agricultural activities such as pig farms or run-off from industry. Fish farmers were more concerned with risks to their operations than from them. Localized impacts on water quality are usually during low flow periods in the dry season and these impacts are primarily on fish farms themselves.

Second are concerns with impacts on native fish and local capture fisheries. In this area these are primarily recreational or very small scale supplementary activities. There is some suggestion that presence of cages improves local catches, perhaps by attracting fish, but also because are some escapees from cages. Impacts on wild fish populations have not been studied in Thailand, but have been detected in other countries, for example, as spread of pathogens from salmon culture (Naylor *et al.*, 2005). One academic active in river conservation argued that, in any case, it is better to manage the river for wild fish stock than aquaculture.

Third is the issue of access to and use of public waterways and water resources. Major waterways are public spaces and subject to laws to safeguard navigation. Fish farming has largely unfolded with modest monitoring, weak regulation and non-transparent system about where and who can farm fish. Dissatisfaction over access was expressed by a few stakeholders. Conflicts with fishers and boat users appear to be rare. Conflicts over allocation of water to irrigation or other users were not prominent. Theft, labor disputes and other social issues specific to presence of aquaculture appeared to be minor.

4. Discussion

4.1 Economic sustainability

Cage farming of tilapia in the Upper Ping River can be profitable but it requires good management of costly feed inputs, environmental risks like floods, low water quality and

disease which can cause mass mortality and business relationships that affect access to credit and markets.

Farm-level profitability for hybrid red Tilapia is known to be sensitive to feed costs, market prices, yields and survival rates (Chaibu *et al.*, 2004). In this study feed variation in feed costs within brands and size-formulations was low. Variation in market prices within species and size categories was low for red hybrid tilapia but higher for Nile tilapia. As expected yields or stocking densities, survival rate, and FCR were strongly associated with profitability. Those whose last crop was in the wet season, despite many having flood-related losses, had slightly higher profits.

Larger farms stocked more intensively and achieved higher yields than small farms, but achieved lower profit densities than small farms. A common expectation is that small farms would be at a disadvantage in commercialized settings. Studies in other countries have sometimes found that small-scale operations are less economically viable than large farms, for example, because of difficulties in accessing credit (Nunoo *et al.*, 2012). In the Thai case studied here even small farmers had reasonable access to credit as they could apply from BAAC as a group.

The average stocking densities we observed here are similar to those used in experimental work with cages in ponds previously in Thailand where fish are grown to relatively large size (Yi and Lin, 2001) but lower than highly intense systems that produce smaller fish at harvest in other countries (Conte *et al.*, 2008). Food intensities or food conversion ratios were similar to previous work reported in Thailand for cages suspended in ponds (Yi *et al.*, 1996; Yi and Lin, 2001) and for intense systems of cages in a reservoir in Brazil (Conte *et al.*, 2008) but often lower than those observed in other countries for cages in ponds, lakes or reservoirs (Waidbacher *et al.*, 2006; Gibtan *et al.*, 2008; Ofori *et al.*, 2010). Survival rates also vary among studies but several have observed relatively high rates as seen in this study for fish during their period being stocked in cages (Yi and Lin, 2001; Conte *et al.*, 2008; Gibtan *et al.*, 2008).

The high observed fraction of feed-related costs is typical of intensive production systems of tilapia (Chaibu *et al.*, 2004; Piumsombun *et al.*, 2005; Ofori *et al.*, 2010). As observed in this study feed and stocking rates are typically good predictors of yield although whether further increases in feed are sensible or not depends on intensity of existing systems

given high costs of feed (Dey *et al.*, 2005; Kareem *et al.*, 2009; Asamoah *et al.*, 2012). Dependence on pelleted feeds means the competitiveness of farmers is affected by differences in feed prices. Farms in mid-reaches of our study site where concentration of farms is highest were able to buy feed slightly cheaper; there was no advantaged detected, however, for larger farms as might be expected. In interviews academics and other experts often mentioned the potential benefits of farmers learning how to make their own feed. Such a strategy would be most plausible for groups with special or otherwise good access to cheap source of inputs to make feed.

4.2 Dynamic livelihood portfolios

Fish farming is usually a component of a household's portfolio of activities rather than a sole enterprise (Setboonsarng and Edwards, 1998): as such it may contribute to household resilience, especially if weather events or market conditions which impact on orchards and field crops are distinct from those affecting fish production. The ability to integrate cage fish farming into the daily and seasonal chores related to maintaining orchards or crop farms is important, especially for smaller farms. The time demands may also be a constraint on fine-tuning fish farm management and mobility, especially of women who frequently have feeding and caretaker roles (Kusakabe, 2003; Sullivan, 2006; Lebel *et al.*, 2009).

Very few previous studies have looked closely at either entry or exit into fish farming. Our follow-up study suggests some aspects of farmer behavior are changing as the fish cage aquaculture industry matures. Farmers appear to be paying more attention to environmental and market factors that pose risks to profitability of their operations. More recognize, for example, the importance of feed and fingerling quality. Among households continuing to farm fish there was evidence of reductions in stocking densities that suggest improved risk management practices. Two major floods in 2005 and 2011 have heightened awareness of importance of climate related risks.

This study also showed there was substantial dynamics in participation: almost half of the households followed-up had given up fish farming during the six year period of follow-up. Financial reasons were important for exiting, but so were a set of problems related to natural resources: there was a common perception that floods, low flows and disease were becoming more serious problems.

4.3 Climate, environmental and economic risks

Risk-taking behavior with respect to the seasonal monsoon-driven changes in water level and quality is both a market and a governance issue. Low flows and poor water quality in the dry season are important but less spectacular risks than the high levels associated with floods. The prospect of good prices in periods of high risk and demand act as an incentive for farmers to take greater chances with timing of their crops.

Evidence for the 2005 season showed that floods can significantly reduce profits of farms in vulnerable locations. The flood peaks on 14 August and 30 September, 2005, triggered by tropical depression associated with Typhoon Damrey, it should be noted were the highest in the 1921-2007 flood history records and considered to recur once in a hundred year (Wood and Ziegler, 2008). At the same time the 2011 follow-up findings suggest floods are not a dominant reason in themselves for leaving fish farming. Floods appear to be very important, but manageable risks. Exactly how floods and other climate-related risks – such as low flows at the end of the dry season – are assessed and managed by fish farmers deserve further study in the northern region of Thailand.

What is also apparent from this study is that farmers need to manage various water-related risks alongside market and financial risks. Changes in prices and quality of inputs as well as sale prices are major concerns. Interest rates were not mentioned much by farmers but it is clear that proper management of credit is also an important business management task.

Fish farming in the Upper Ping River is maturing as a sector, at least in sense, of standardization. Farmers are more likely to be in contract farming arrangements, less likely to have loans from informal or special sources, and more are certified and registered. Farmers now rely more on each other and what are likely to be technically more reliable and up-to-date sources of knowledge. They are also using more advanced inputs such as food supplements and medication.

4.4 Limitations

This study adopted a mixture of methods. The cross-sectional study helped document variation in practices and prevalence of various production problems; the follow-up cohort study provided evidence about changes in behavior of individuals and reasons for exit. The

use of in-depth interviews and event-based observations during major floods in 2005 and 2011 complemented more quantitative calculations of technical and economic performance revealed information about incentives, perceptions and relationships of farmers that are valuable to efforts to improve both farm and water management.

The emphasis on interview-based evidence also has some limitations. The most important for this study were probably errors in recall in responses to questions about stocking densities, yields, prices and receipts that reduced precision. The timing of our surveys, soon after major flood events, had advantages and disadvantages. On the one hand it gave us opportunity to consider the impacts of major climate events; on the other hand, it may limit the generalizability of some of the findings to other years and locations within Northern Thailand. Further studies in low flow years and other locations are needed to fully understand the set of risks fish cage farmers in rivers face.

4.5 Significance and implications

This is one of the first studies to provide detailed information on farming and business practices of cage culture in rivers. Aquaculture in ponds, reservoirs and rivers differs in key ways that are important to water management under changing conditions. First, despite similarities in key inputs such as feed and stock, flows in rivers imply that diseases, waste effluents and other contaminants generated within aquaculture systems will easily be transported and shared downstream. Second, rivers are public good important for navigation, recreation and aesthetic uses which may not always be true for water bodies on private land such as farm ponds or small dams. Third, rivers funnel pollutants accumulated through run-off along the banks and further inland in the catchment creating many risks to aquaculture.

These key differences represent both constraints and opportunities for improving the economic, social and environmental sustainability of the river-based cage culture industry. The connectivity between farms means many of the disease, flow and climate-related risks are shared by farmers working in the same river reach. This should stimulate shared concerns and incentives for collective action in support of more sustainable practices. The presence of other river users sets an upper limit on cage densities in particular locations as free passage of boats must be maintained. This helps reduce incentive to over-stock particular reaches.

Management of water for other users, such as irrigation, flood control or hydropower decision is another significant constraint on expansion that varies spatially depending to proximity to water infrastructure. The high costs of feed and relatively low FCR observed as well as patterns to reducing stocking densities all point towards more sustainable practices. The increased problems with disease and use of medication, however, suggest some key challenges persist. The sensitivity of aquaculture to pollution from within the watershed or river can be seen as a positive pressure for sustainability. If good water quality is maintained aquaculture can continue; if not it may become impossible.

These latter two pressures are incentives for active engagement of fish farmers in integrated water resources and river basin management activities. Regulation of reach-level cage or stocking density that takes into account seasonally variable discharge volumes may be needed to complement various self-organizing drivers which encourage sustainability at levels above individual farm.

Pressures to expand cage-based aquaculture in rivers around the world are likely to increase, but as shown in this paper face many challenges. To succeed fish farmers must manage a combination of market, climate and environmental risks. Further research is needed to identify ways in which farms and rivers may be better managed to support sustainable aquaculture.

CHAPTER 4

ACCESS TO FISH CAGE AQUACULTURE IN THE PING RIVER, NORTHERN THAILAND

1. Introduction

Aquaculture in rivers and other public water bodies raises issues of access and property rights more familiar to capture fisheries management than aquaculture in fish ponds on private land (Kleinen, 2006; Liu, 2007). Diverse forms of capture fisheries and aquaculture systems in Hong Kong, for example, could be arranged on a gradient from common property to private property as water is more effectively controlled and use of natural resources privatized (Lai and Lam, 1999).

Access to suitable areas to suspend cages may be restricted by both physical conditions such as flow or depth as well as social or legal limits to use of river banks or water surface. Water flows also create risks to aquaculture farms from other activities in the watershed including other aquaculture farms that may require state regulation. Current understanding of the factors affecting access in river-based aquaculture is limited, but important to efforts to improve the governance of rivers and the sustainability of aquaculture.

We propose that successful long-term management of river-based aquaculture needs to take into account the complex combination of types of goods involved: in particular, whether they are public, private, club or common goods (Ostrom, 2003). Governments often consider rivers as a public good, open for all to use for transport or recreation provided those uses don't interfere with others rights. Fish in the river are common pool resources that usually need active governance by the state or communities or co-management to reduce risks of over-exploitation. River banks may effectively be privately owned down to or near the waterline. Moreover, public administration boundaries of different agencies frequently separate rivers from their watersheds and even areas on opposite banks.

Aquaculture farms make use of flows and space in the river. They also require access to river banks. This suggests the likelihood of ambiguity with respect to property rights that may result in resources being treated as open-access (Belton *et al.*, 2009). Effective control

of resources, however, may depend on more than property rights; in particular, access or the “ability to derive benefit from things” (Ribot and Peluso, 2003). In the case of aquaculture significant up-front costs to set up a farm and to invest in feed before harvest a crop can mean that capital or access to credit is an important pre-requisite. There may be other labor or social constraints that are also important.

Access to aquaculture livelihood is important because such activities can make a significant contribution to household incomes (Irz *et al.*, 2007). The contribution of private-sector and project -driven aquaculture to poverty prevention, alleviation and rural development, however, is complex and context-specific (Hishamunda and Ridler, 2003; Belton and Little, 2011).

Non-governmental organizations and governments use demonstration projects and other training activities to encourage farmers to adopt aquaculture practices. A typical example are the recent efforts to transfer practices of successful commercial firms to small-scale fish farmers on Volta Lake, Ghana (Ofori *et al.*, 2010). Relatively few studies, however, have had a clear control or comparison group which would allow stronger inferences about who gains access to and benefits from aquaculture. One exception is Puomogne *et al.* (2010) who found no significant differences in household economics of 62 farmers with and 38 without fishponds in an area in western Cameroon after 30 years of aquaculture development projects. In their study more than three-quarter of ponds had been abandoned. Difficulties in transferring technical knowledge and access to high-quality seed were identified as key barriers. In general, the outcomes of interventions have often been modest, whereas market or commercially driven extension has often had much bigger impacts – both negative and positive (Belton and Little, 2011). Additional research on how different kinds of households establish successful farms is needed, especially in riverine settings.

Over the past few years an industry has developed around the rearing of hybrid red and Nile tilapia (*Oreochromis niloticus* L) in mesh cages suspended in the Ping River in northern Thailand (Chaibu *et al.*, 2004). Fish farming is usually a component of a portfolio of household activities but as farm size increases may become a core business (Chapter 3). This paper addresses the questions of access to river-based cage aquaculture through a detailed

analysis of this evolving industry in northern Thailand. The main question is a simple one: which households farm fish in cages in the river?

2. Methods

2.1 Study area

Fish farming practices were observed and farmers interviewed (Figure 9) in the seven sub-districts bordering the Ping River between Pak Bong, Pasang District, Lamphun Province (N 18°32' E 98°56') and Sob Tia in Chom Thong District (N 18°24' E 98°42'), Chiang Mai province in northern Thailand.



Figure 9 River-based cage culture in the Upper Ping River: (A) Site with good water depth all year around; (B) Site close to infrastructure; (C) Moving cages away from banks to ensure adequate depth and water flows; (D) Not all river users have access to aquaculture.

In this region the river forms the boundary between Chiang Mai and Lamphun provinces. The sub-districts were grouped into 3 reaches: Pak Bong and Song Khwae (Upper); Doi Lo and Nam Dip (Middle); and Wang Pang, Kuang Pao and Sob Tia (Lower).

2.2 Case-control study of access to cage culture sites

At the level of the sub-district fish farming is a “rare” occupation. Purely random sampling across sub-districts would yield few fish farmers and thus a very unbalanced sample that is statistically inefficient for “comparison”. For these reason we opted for a case-control sampling design (Wacholder *et al.*, 1992).

Cases were defined as a household having a fish farm in the Ping River at the time of survey and residing in one of the 31 villages with river frontage in the 7 target sub-districts. All but 5 of the 379 fish farmers registered in the two provinces came from just 7 sub-districts. Cases were relatively easy to identify because operations are visible for all to see and most are registered with the Department of Fisheries.

Controls should be selected in a way that they are a representative sample from a population of households *at risk* (Grimes and Schulz, 2005). In this study controls were defined as households never having farmed fish in cages in the Ping River and living in one of the 31 villages along the Ping River which we assumed were at risk of becoming fish farmers. Random samples for controls were drawn from pooled household lists of these 31 villages.

Our decision on how to select controls deserves further explanation. At first we considered five options for defining the base population from which representative controls could be drawn. They were to draw: (1) from the pooled population of seven sub-districts from where the vast majority of fish farmers are based; (2) for each case a control from the same sub-district; (3) from the pooled population of twenty five villages where the majority of fish farmers are based; (4) for each case a control from the same administrative village; (5) from the pooled population ca. 31 villages bordering the Ping River. Each of the options has some merits and limitations with respect to different exposure factors of interest at different spatial levels. Options 1 and 2, for example, would result in many samples being taken from villages away from water and with no fish farmers present, and thus largely document the obvious – people close to water

are more likely to have fish farms – but also provide a wide range of levels on exposure factors of interest. Narrowing the base population would arguably provide a more comparable set of controls with respect to confounders we cannot measure, for example, which might vary with proximity to river. In the end we chose option 5 because it refers to a reproducible and definable population and would require less complex travel than some of the others. It also meant excluding the 4% of cases not from river front villages.

Formal migration in and out of the study area during the past decade or so when fish farming in cages emerged was low implying current recent population registries should be a fair guide to the base population exposed especially if we excluded very recent in-migrants through our survey questionnaire.

Of 436 properties listed in our randomly drawn samples 26 had no currently occupied house. Of the 410 potential households in the sample we were unable to complete questionnaires in 12 instances or 2.9% despite repeat visits. In 9 cases the reason was that members we met were physically incapable of responding to questions because of deafness, mental disabilities, serious illness or persistent alcohol problems. The final analysis was based on 398 households of which 197 had never farmed fish in the Ping River and 201 which had. All data was collected between 22 March 07 – 23 April 07 leaving free a week-long gap for the Thai New Year holidays.

The key independent variable was whether or not a household had ever farmed fish in cages in the Ping River. This was obtained through a direct question in the questionnaire. Additional questions allowed informants to tell us about, and distinguish this condition from, having previously reared fish in ponds, in other locations, or having family members in other households having such experiences. We also distinguished between currently farming (understood to mean have fish in the water or with still having cages and location and perhaps being in process of preparing for next crop) and having previously farmed but no longer doing so. This allowed us to also consider reasons for exit

The explanatory variables of interest were about location, assets and mobility, loans and contracts, household structure, knowledge and social capital. We asked several questions about each category to get as precise and reliable information as possible. For example,

with respect to major assets we consider both land in the fish farming area and elsewhere, houses, pick-ups, cars and motorcycles

Logistic regression was used to explore associations between the outcome of interest, having ever farmed fish, with a range of candidate predictor variables. All predictors were initially or were transformed to be categorical-type before analysis. Where variables are likely to be part of the same causal chain we did separate analyses to understand patterns of co-variation more deeply.

2.3 Qualitative interviews with farmers and other stakeholders

Additional information on how individual households got started in fish farming was obtained through in-depth interviews. Altogether we conducted 93 interviews, each lasting 30-60 minutes, with: farmers (n=40), non-fish farmers living in the area (n=11), local government officials including those involved in agriculture extension (n=12), farmer association leaders (n=2), department of fisheries staff (n=4), other government departments (n=2), bank staff (n=2), local academics involved in aquaculture, fisheries or farm business management (n=8), company agents, brokers or input-sellers (n=10) and retailers (n=2). These interviews were made between May 2006 – June 2007.

Qualitative data in the form of fully transcribed scripts of interviews were coded, managed and analyzed using NVIVO software. Careful coding of transcripts allowed us to cross-check among informants. For a few issues with a lot of different responses we also clustered these against attributes of informants, for example, male or female or by stakeholder type as listed above to help understand contextual or interest-based differences in views or experiences.

3. Results

3.1 Characteristics of households in river-side villages

Table 6 provides a summary of some of the basic features of households with a history of farming fish (cases) and never having done so (controls). The study area is rural or peri-urban relatively close to important off-farm employment opportunities in Chiang Mai and Lamphun commercial and industrial centres.

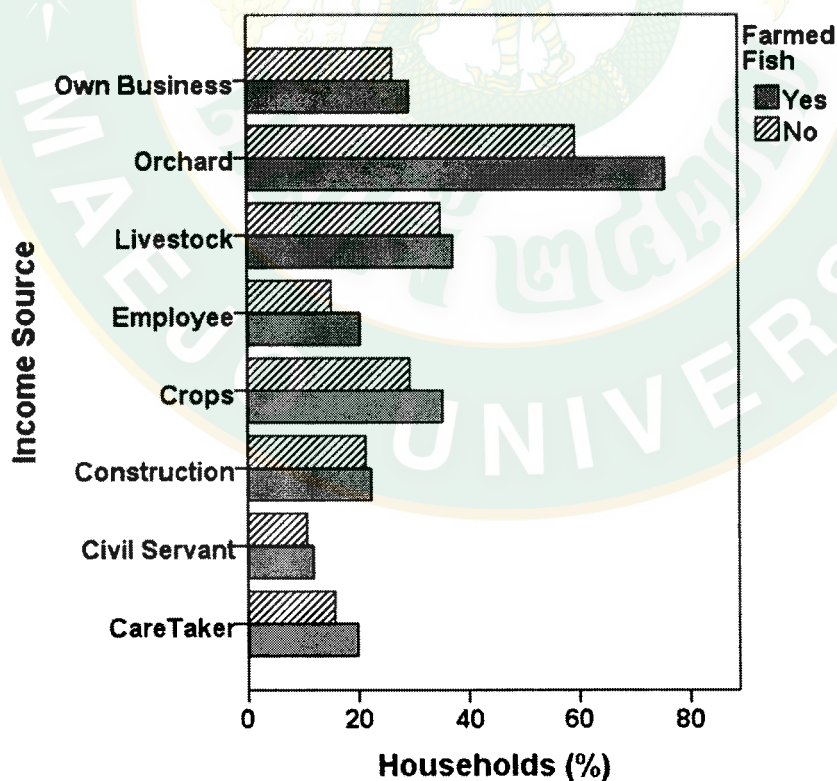
Table 6 Selected features of households who have never or who have at some farmed fish in cages in the Ping River.

Characteristic	Households which have never farmed fish (%)	Households which have farmed fish (%)
Monthly household income		
< 5000	42.6	30.3
5000- < 10,000	38.1	39.8
10,000 - < 20,000	14.2	20.4
>= 20,000	5.1	9.5
Household income from		
Agriculture	70.1	85.6
Non-agricultural activities	69.5	72.1
Highest education level within household		
Primary	33.5	23.4
Lower Secondary	19.8	15.4
Upper Secondary	25.9	26.9
Tertiary	20.8	34.3
Ownership of vehicles		
Pick-up	34.5	55.7
Passenger car	5.6	12.9
Motorcycle	84.8	95.5
Land owned (hectares)		
None	10.2	3.5
<= 0.5	54.3	50.2
0.5 – 1.0	20.3	25.9
> 1.0	15.2	20.4

Table 4.1 (continued)

Household size			
	1-2	28.4	13.4
	3-4	51.3	62.2
	≥ 5	20.3	24.4

Most households had a wide range of income sources and those with experience in fish farming more agricultural sources (Table 6). Households who had ever farmed fish were more likely to have income sources in all categories, but in particular orchards (Figure 10). A few households, mostly those with history of fish farms, had income sources related to aquaculture such as acting as middleman (4%), selling feed or chemicals (1%), selling fish fry (0.5%), or employee on fish farm (0.5%).

**Figure 10** Income sources of households that have and have not farmed fish.

3.2 Location

The associations between ever having farmed fish in the Ping River with candidate predictor variables were explored using logistic regression. Proximity and reach were significantly associated with fish farming (Table 7).

Table 7 Association of significant predictor variables with ever having farmed fish in the Ping River. Odds ratios and confidence intervals estimated from logistic regression coefficients. A value of one for categorical variables with more than 2 classes indicates the comparison group. The model has $r^2=0.26$ and correctly classifies 68% of observations.

Variable	Odds ratio	95% confidence interval
Proximity to river		
Not near bank	1	
On river bank	3.14	(1.54 – 6.40)
On river front road	3.98	(1.61 – 9.82)
Next-to-closest block to river	2.91	(1.52 – 5.59)
Area of land owned		
None	1	
<= 0.5 ha	2.77	(1.02 – 7.53)
>0.5 ha	3.00	(1.06 – 8.43)
Pick-up truck	2.14	(1.34 – 3.41)
Passenger car	2.31	(1.02 – 5.24)
Motorcycle	2.92	(1.20 – 7.11)
Social capital	2.63	(1.21 – 5.70)
Reach		
Lower	1	
Middle	3.87	(2.14 – 7.00)
Upper	2.27	(1.31 – 3.94)

Candidate variables tested which were not associated with fish farming, after adjusting for the significant predictors in Table 7, included education, various measures of household structure, and monthly income.

Households living near the river banks were 3-4 times as likely to have ever done fish farming (Table 7). Access within the river margin was not disrupted by having a road between you and the river or even another block of land, occupied or not.

In-depth interviews imply that fish farming is recognized as only being an option for those who live near the river: *“the river front has an owner; it belongs to the house next to the river.”*

An official from the Department of Navigation and Harbors told us: *“The river is public property. Owners of land who live on the banks have the right to use the river before others because it is in front of their house. They must have the right to use that public land.”*

TAO officials see proximity as good fortune: *“The Ping River is a golden opportunity for farmers: they have longan orchards and can grow fish in cages as well. They have money and are happy”*. It is a profitable livelihood that *“suits some groups who live near the river, are prepared. If others wanted to rear they couldn’t: there is no where they could do it.”*

Conversely if you start off in the wrong place access is difficult or impossible: *“We don’t think of rearing fish because our house is not near the river. If we wanted to we couldn’t because we wouldn’t know where to farm: it is their river front.”* People living farther away may invest in or hire others to watch after their fish farms. Household may also gain access to river front land through relatives with waterfront land.

At a larger spatial scale it should be noted that just over 96% of fish farms are registered by households from villages including a river border. Farms are concentrated in the area studied with few attempts to install cages further upstream and closer to Chiang Mai. The Department of Navigation and Harbors says it did not initially allow cage culture out of concerns they may be a hazard to navigation, but later relented. The municipality when interviewed expressed concerns about water quality.

Within the current growing area dredging and weirs can make sites more suitable for farming fish by increasing water depths. Local sub-district governments are often

asked to help dredge the canal or to build and repair weirs. According to informants sand-mining activities can have both positive (deeper channel) and negative effects (sedimentation) on suitability of cage sites.

Decisions about which areas are suitable for fish farming and are to be “condoned” for such practices were not easy to explain. Not everyone is happy with current patterns of access. Villagers who would like to rear fish but are not granted permission to do so in their reach don’t understand why it is okay in one village or sub-district but not another. The process for granting, approving or tolerating access is not completely transparent.

3.3 Wealth and assets

Over a third of households said they had total monthly incomes of less than 5000 Baht (Table 6). A common view of people in the area is that *“investors in this area are middle class not poor. The poor cannot start a fish farm. You need capital.”* Monthly income on its own was weakly associated with ever farming fish with the lowest income category having the smallest proportion of fish farmers (Table 6). Other more asset-oriented measures of wealth, when mutually adjusted for other predictors (Table 7), remained significantly associated with fish farming whereas monthly income did not so it was dropped.

The distribution of land areas owned was highly skewed: 7% of households overall had no land and the median land holding was 0.36 ha, whereas largest had 18 ha. Households which owned more were more likely to have a history of farming fish (Table 7) but how much land did not appear to be important. Having land is important for access to credit.

Owning a pick-up truck, car or motorcycle were each, independently, associated with an increased likelihood of ever having farmed fish by 2- to 3-fold (Table 7). These could be interpreted both as an indicator of assets as well as mobility. Overall, households were functionally mobile with 90% having at least one motorcycle, 45% a pickup, and 9% a passenger car. Few people, however, talked unprompted about the role of “vehicles or mobility” in their farm operations. One noted that for people who live further away travel time might be a consideration; another noted the value of a pick-up for bringing ice to protect crop value after a die-off.

3.4 Household structure and labor

Most households were small (Table 6). Overall population structure pooling across sampled households was: <5 at 2.9%; 5-14 at 10.7%; 15-59 at 71.7%; and 60+ at 14.7% consistent with an ageing rural population observed more broadly in the two provinces (Jones and Pardthaisong, 2000). Overall ratio of women to men was strongly skewed (1.14:1) and entirely due to differences above age 15, likely reflecting out-migration of men for work.

Fish farming was largely a recent occupation with 68.4% having started within the last 5 years and 95% within the last 10 years. The population in the study area is mostly long term residents. Only 8.3% of households had migrated into the present area and of these many had done more than 10 years ago (79%). Of all that had moved 18% claimed it was to farm fish had moved into their current locations within the last 10 years.

We considered a few different ways of describing household structure: presence of dependents (elderly or young children), number of members, number of labor-aged members, and distinguishing single women headed households. After adjustment for other variables there was no evidence that these factors were associated with having fish farms.

3.5 Knowledge and social capital

Households in the sampled population varied greatly in the highest level of education attained by its members. Prior to adjustment for significant predictors there was a significant likelihood of fish farming in households with a higher education (Table 6). After adjustment for other factors education was no longer associated with having farmed fish in the Ping River (Table 7).

Based on three different questions we defined a social capital variable which measured involvement of household members in groups. Having at least one member holding of a formal position in village, or belonging to a cooperative or another kind of association was considered as “having social capital”. Households who have farmed fish were 2.6 times as likely as those who haven’t to have social capital (Table 7).

Political and social connections matter. One successful farmer told us how *“He started when he was head of TAO. We received 1 million baht under the village fund scheme and loans were shared among the fish farmers. We made a profit. My mother has river front*

property on the Ping. At first I wasn't going to invest but my wife convinced me to. We started with two cages. Then with relatives of my wife we invested in another 6 cages together. Now my wife's relative expanded and so have I. Now I have 12 cages."

Relatives who farm fish may be another source of inspiration and support: 74.6% of households who have farmed fish also have relatives in other households who have farmed fish in the Ping. In contrast only 14.2% of households who haven't farmed fish have such relatives (O.R.=17.7; 95% CI: 10.6-29.6).

Some farmers told us that rearing fish has brought some families closer together, for example, in joint problem solving and short-term labor events like harvesting: *"Now we love our neighbours more than before because must help each other, eat together, and in the evenings get drunk together ...if the river is dry we have to get together to figure out what to do."* We note there are real incentives to working well in groups, both in dealing with officials and for obtaining credit for agricultural activities.

3.6 Loans and extension services

A few other variables are reasonably interpreted as within the "causal chain" or an outcome rather than predictor of entering fish farming and so were explored separately from the main logistic model in Table 7.

Households which have farmed fish were 4.9 times as likely to have a loan from BAAC and 3.5 times from the Village Fund than those which do not (Table 8). Land title deeds are used as collateral.

"There are people who would like to rear fish but they don't have the capital, they don't have a good site. Before you can farm fish you have to a site and lot's of capital. Fish cage farming has high costs."

A group requesting a loan from BAAC for aquaculture must have at least 5 farmers. A wife and her husband count as one person. Farmers told us banks wanted them to join together in associations and not apply as individuals. Banks provide lower interest rates than the informal sector.

Table 8 Fish farmers have a history of taking loans that exceeds the control or background rural population in the area. Results from single logistic regression model.

Predictor	% of fish farmers	Odds Ratio	95% Confidence Interval
Loan from BAAC	89	3.17	(1.79 – 5.61)
Loan from Village Fund	73	2.26	(1.42 – 3.62)
Loan from relatives or friends	21	1.20	(0.67 – 2.14)

As might be expected fish farmers were more likely to have been approached by Department of fisheries (O.R. = 3.3) or private firms (O.R. = 21) encouraging them to rear fish in the river than those who did not farm. As both firms and the department are more likely to approach households that live near the river proximity was also tested as a possible confounder, but found to not significantly alter associations.

3.7 Exit reasons

From our survey of current fish farming and control households in 2007 we were able to get some insight into characteristics of households that exit. The likelihood of households who have ever farmed fish stopping was significantly associated with four factors (Table 9). Households who had contracts with a company were more than 10-times less likely to exit fish farming. A farmer told us that after a price drop he persevered because *“If I stopped rearing I could not pay back the loan. So I increased number of cages from 2 and 4. And I sold the tractor and invested in fish.”*

Table 9 Association of significant predictor variables with having exited fish farming among those households who have at one time or another farmed fish in the Ping River. Odds ratios and confidence intervals estimated from coefficients of the multiple predictor variable logistic regression model.

Variable	% of fish farmers (n=201)	Odds ratio	95% confidence interval
Have formal contract with a company	58.2	0.09	(0.04 – 0.19)
In Chiang Mai province	66.2	0.39	(0.19 – 0.82)
Single woman headed household	12.4	11.5	(2.34 – 56.2)
Household with dependents	31.8	2.37	(1.12 – 5.04)

Households in Chiang Mai province were half as likely to exit as those in Lamphun. There was no difference, however, among upper, lower and middle reaches. The difference in provinces – which are on opposite banks of the river – could be related to differences in types of support received from fisheries extension officers or credit arrangements. Farmers in Chiang Mai, for instance, made much more use of the Bank of Agricultural Cooperatives than those in Lamphun, who drew more frequently on the Village Fund Scheme.

Households headed by a single woman were more than 11 times as likely to leave fish farming. A household with dependents, defined as other members aged below 5 or more than 60, was over twice as likely to exit.

Other variables important to entry into fish farming (Table 7) did not appear relevant to exit like: social capital, land-holdings, proximity to river, or vehicle ownership.

4. Discussion

The first significant set of fish cage culture operations in the Ping River began around 1999. Over the next couple of years the number engaged expanded with various households entering and some leaving the practice.

Virtually all farmers rearing fish come from households in villages bordering the Ping River. Comparing households with and without history of farming fish showed that it was those with good access to farming sites, financial capital, and local social networks that get to farm fish.

Proximity to the river front, and by implication, good access to river water surface and banks, was an important factor explaining which households enter into fish farming and operated at a very micro-level. Proximity is important but not absolute: some households without direct bank access farmed fish and many households with river frontage do not farm fish.

There was also important along-the-stream variation in distribution of fish farms with farming more likely in upper and middle than lower reaches. The specific reasons were not quantitatively verified but appear to reflect differences in suitable areas available to farm fish. Experts and many farmers were emphatic about the importance of water depth in constraining where and when fish farming can be done. Water depths need to be at least 3m so that cages will float freely above the river bed. Water velocities and other biophysical factors effecting variation in quality of culturing sites deserve further study.

Fish farming, like many other agricultural activities, requires significant investments up front before any income is made. Having land and house which can be used as collateral on loan requests is helpful, both to get started and to roll-over repayment schedules when bad-luck strikes such as a flood. Assets which can be used to obtain loans are more important for entry into aquaculture than monthly income levels.

All three common types of vehicles – pick-ups, passenger cars and motorcycles -- were associated with having farmed fish even after adjustment for each other and key asset wealth variable like area of land owned. Vehicle ownership could be both a driver and an outcome of participation in fish farming. Unfortunately with our cross-sectional approach and lack of detailed questions on history of when vehicles were purchased relative to entry into fish farming we could not separate the relative importance of these two relationships.

Variables describing household structure and labor were not strongly associated with ever having farmed fish, but were associated with stopping once having started. Households headed by woman, although infrequent, and households with dependents were both more likely to have given up fish farming. These latter two associations suggest labor issues may be a reason for stopping to farm fish. Our interviews with women engaged in fish farming imply that they usually continue to bear the brunt of household work and family responsibilities even if they were the primary manager of the fish farm or had a leadership role in community affairs (Lebel *et al.*, 2009). At the same time households who have farmed fish tended to have more income sources overall and with orchards as an individual category being significantly more common.

Social capital of a household was associated with fish farming. Our in-depth interviews imply that this mainly through social networks, which get replicated and reinforced in formal structures, like village committees, local government positions, and credit groups. There appears to be to several incentives for working well with others and doing things in groups when it comes to being a successful fish farmer. Many of these groupings were either triggered by, or substantially reinforced through, the investments of contracting firms and other brokers for inputs or selling of harvests, and to a lesser extent, knowledge and other support from extension work by the Department of Fisheries. At the same time there was no specific, dedicated, fish cage growers' association. Individually the social network variables such as belonging to a cooperative or association were a bit difficult to interpret directly as predictors, as they could easily also be a consequence of fish farming.

Drawing these findings together it is clear that the river from view of aquaculture is not a simple public good in which anybody can start a fish farm. Fish farm sites are somewhere between a private and a club good. Although many speak about the river as belonging to everyone, from the perspective of cage aquaculture it belongs to those who live near it with the right connections. The importance of social capital, connections through committees, positions and group membership is consistent with this mode of access. Many fish farmers start through invitations by firms and the DOF. The Ping fish farming industry thus has emerged out of a combination of market-driven, private interests, and public extension support (c.f. Belton and Little, 2011).

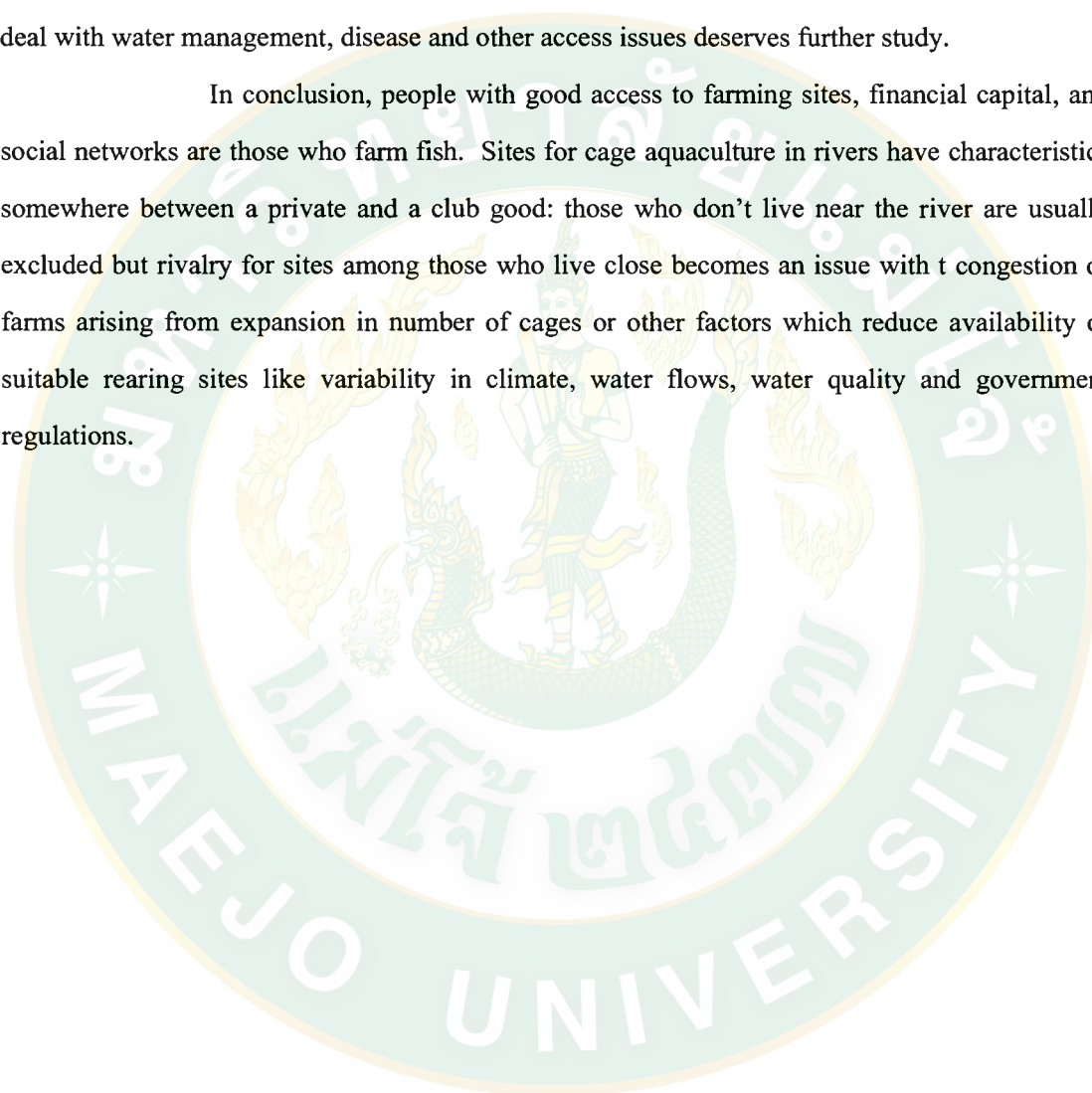
A few other studies have had designs that enabled identifying factors influencing access to aquaculture and its socio-economic consequences. A study of fish farmers in Tanzania found only 8% accessed credit (Wetengere and Kihongo, 2012). Poor households lacked information about credit sources and found it difficult to meet requirements for collateral assets given current bank lending practices. The author's suggest that higher profitability and improved access to credit would increase adoption of aquaculture practices. More successful fish farmers became local government leaders (Wetengere, 2010) underlying the links of aquaculture to social capital. Previous studies of training interventions to promote aquaculture in Thailand have identified the importance of access to credit (Tain and Diana, 2007). In Cameroon lack of access to good stock and poor knowledge of how to use local inputs as feed resulted in many farmers exiting or never entering aquaculture (Pouomogne *et al.*, 2010).

This study is significant as one of the first reports of how household characteristics may influence participation in cage aquaculture in public water bodies, in particular in the understudied context of aquaculture in rivers. This raises questions about the governance of aquaculture in rivers, as property rights are not well defined and several factors appear to influence access. At this stage there is little evidence that aquaculture activities significantly, adversely, impact on the use of rivers by others, for example, recreational fisheries, but if operations were to expand this may change raising concerns about the fairness of privatization of a common pool resource.

This study also illustrates the importance and feasibility of detailed analysis of social factors in addition to conventional focus on technical practices for understanding how aquaculture develops in particular places. Our study was methodologically innovative in the sense of the care taken to construct a comparison group by which to assess which households farming fish. The retrospective study design, however, also had some limitations for understanding access. We could not obtain detailed and accurate information about household conditions at times of entry which was often 5-10 years earlier. As a consequence for some relationships it was not possible to clearly distinguish between factors influencing entry from the consequences of participation in fish farming, for example, some asset variables. In other cases – such as for proximity to rivers' edge – temporal sequence could be reasonably inferred.

Future research on cage aquaculture in rivers should consider more closely how climate, disease and other business risks are managed as this appears important for economic sustainability. Detailed investigations of how biophysical risks vary among rivers with different flow variability and among potential cage sites within rivers is also needed. Finally, many fish farmers are part of local groups and networks. How these groups help farmers collaboratively deal with water management, disease and other access issues deserves further study.

In conclusion, people with good access to farming sites, financial capital, and social networks are those who farm fish. Sites for cage aquaculture in rivers have characteristics somewhere between a private and a club good: those who don't live near the river are usually excluded but rivalry for sites among those who live close becomes an issue with the congestion of farms arising from expansion in number of cages or other factors which reduce availability of suitable rearing sites like variability in climate, water flows, water quality and government regulations.



CHAPTER 5

RISK OF IMPACTS FROM EXTREME WEATHER AND CLIMATE IN RIVER-BASED TILAPIA CAGE CULTURE IN NORTHERN THAILAND

1. Introduction

The importance of freshwater aquaculture to global fish supplies has grown substantially over the past few decades. Although there are important constraints to further growth or intensification in particular places (Boyd *et al.*, 2012), aquaculture is going to remain an important part of the global food systems for many years to come (Silva, 2012).

There is a growing realization that aquaculture is sensitive to climate change. Several regional and global assessments have now been completed, most with an emphasis on marine and coastal aquaculture (e.g. Callaway *et al.*, 2012). These initial assessments, suggest that freshwater aquaculture systems are moderately well-buffered against certain types of climate-related perturbations, such as sharp changes in air temperature or intense rainfall, but less so against other shocks and stresses such as drought (Pickering *et al.*, 2011). In some locations, small increases in temperatures may even benefit production (Pickering *et al.*, 2011), but large shifts would usually be detrimental (Yazdi and Shakouri, 2010).

The reliability of assessments of the impacts of climate change on aquaculture depends in part, on having a good understanding of how current climate influences aquaculture production. This information is often lacking for species and locations of interest. While improving management of risks under current climate and adaptation measures towards climate change may reduce impacts, it will not always eliminate them. Effective loss and damage systems to deal with exceptional and residual impacts are also needed, but to be properly designed, they require a good understanding of the level of risks and impacts in different locations, seasons, and years, as well as local capacities and knowledge of good management practices (Beach and Viator, 2008; Warner and Geest, 2013).

Most climate-related aquaculture research so far, has focussed on the effects of temperature; for instance, exploring the implications of shifts in thermal regimes (e.g. Vass *et al.*, 2009; Baez *et al.*, 2011b). Floods, droughts, and extreme or unusual weather, are an important,

but less well-studied set of risks to freshwater aquaculture farms. Only a few previous studies have measured impacts in any detail. Catfish farms in the U.S., for example, are adversely impacted by extreme weather, including flooding, droughts, freezing, hurricanes, and storms (Hanson *et al.*, 2008). Mapping, based on a time series of remote-sensing images of flood extents in the floodplain of the Rio Paraná in Argentina, was used to explore potential new areas for aquaculture development that would avoid and minimize risk from flooding (Handisyde *et al.*, 2014). However, it did not analyse the levels of risks faced, or impacts experienced, from extreme events by existing farms.

A study conducted in 2005-6 in the Upper Ping River near Chiang Mai in Northern Thailand, found that serious flooding in 2005 impacted 75% of fish cage farmers (Chapter 3). Another more recent study of earthen ponds, culture systems across Northern Thailand, documented impacts and concerns of risks associated with floods, droughts, and unusual or rapid changes in weather on fish production (Pimolrat *et al.*, 2013).

Studies of agricultural systems, suggest that short-term preventative and coping measures to deal with floods and droughts may be insufficient, resulting in significant residual, longer-term loss and damage to property and livelihoods (Bauer, 2013; Yaffa, 2013). In highly seasonal and variable climates, both droughts and floods may be important (Brida *et al.*, 2013). In some cases, such as the forced selling-off of livestock, coping measures may have short-term merits, but undermine livelihood sustainability and adaptation in the longer-term (Warner and Geest, 2013). Not much has been published about losses and damages in aquaculture, although some relevant work has now been done in studies exploring emerging or proposed insurance schemes (Beach and Viator, 2008; Shaik *et al.*, 2008; Chhikara and Kodan, 2012). These studies identify difficulties in getting accurate measures of losses as an important barrier, suggesting the need for more impact information, and alternative approaches to developing insurance; for example, weather index-based (Linnerooth-Bayer and Mechler, 2006; Wang *et al.*, 2013).

This paper analyses the direct impacts of extreme weather, low and high flow events, seasonality, and other climate-related phenomena on river-based cage aquaculture of tilapia in Northern Thailand. It addresses two main questions: (1) what have been the impacts of floods, droughts, and other climate and weather phenomenon on fish cage farms? (2) What is the likelihood of suffering those impacts in different places and times of the year?

2. Materials and methods

An interdisciplinary, mixed-method approach was taken that included: analysis of secondary water flow and meteorological data; quantitative and qualitative surveys of farmers' experiences with extreme events; and direct observations and measurements during critical periods (Figure 11).



Figure 11 The risks of extreme high (A) and low (B) flows that impact cage aquaculture production vary seasonally and spatially.

2.1 Study region

In this study of tilapia cage aquaculture in the rivers of Northern Thailand, study sites were grouped by provinces and rivers into four fish farming regions for analysis (Figure 12): Upper Ping (Chiang Mai and Lamphun), Lower Ping (Kamphengphet, Tak and Nakhon-sawan), Upper Nan (Uttaradit), and Lower Nan (Phitsanalok and Phichit). As will be shown in detail later, the four regions differ significantly in flow regimes and climate, providing opportunities for comparisons that can help comprehend the importance of climate and variability, in flows to inland aquaculture in rivers.

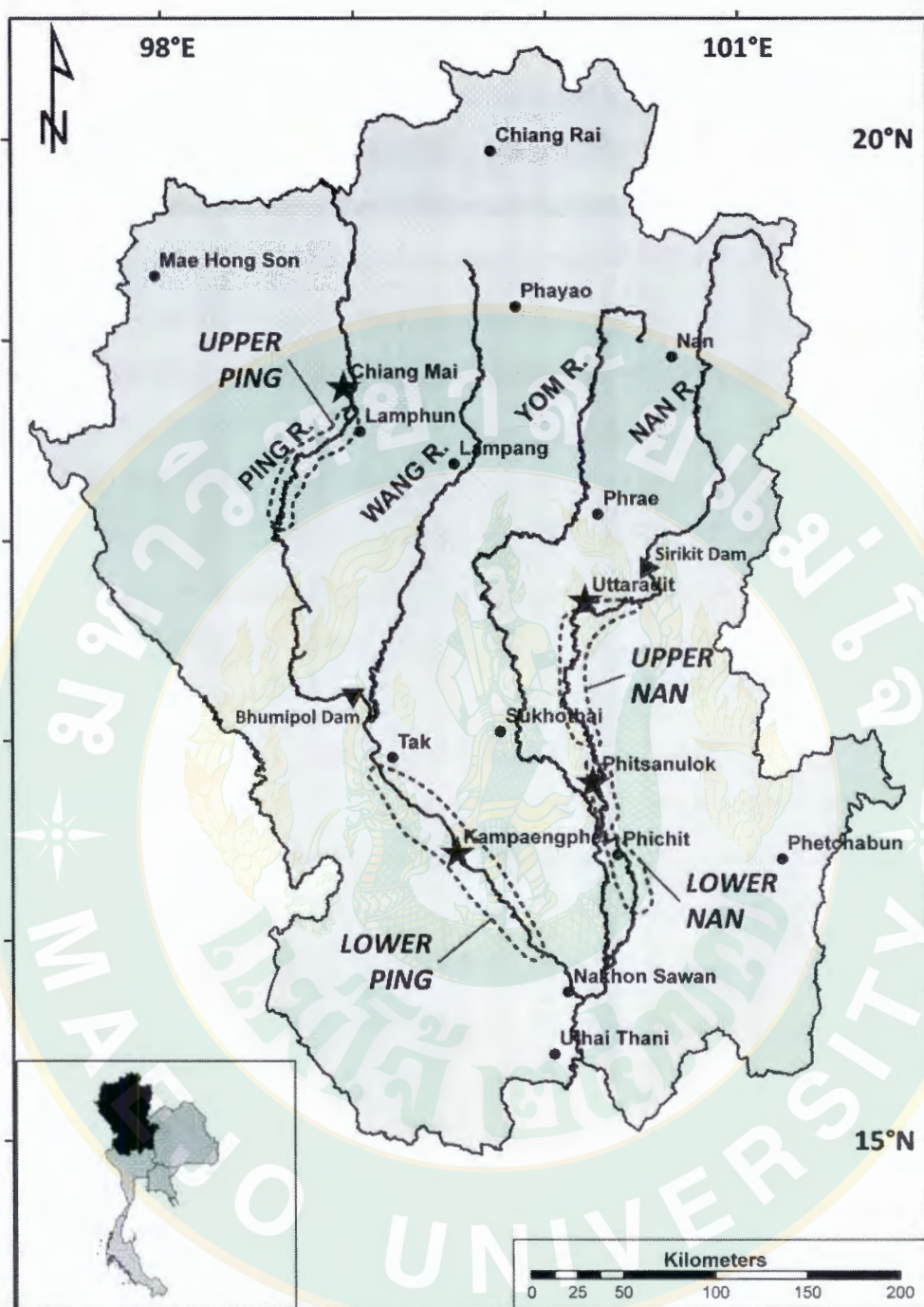


Figure 12 Map of study area in Northern Thailand. Stars indicate approximate locations for which more detailed climate and flow information was obtained, and the four fish farming regions are outlined with dashed lines.

2.2 Interviews and observations

An effort was made to interview all fish farmers who are or have reared tilapia – red hybrid (*Oreochromis mossambicus* x *Oreochromis niloticus*) or black Nile (*Oreochromis niloticus*) – in cages in the rivers within the northern region of Thailand. At the end of the survey, a total of 662 fish farmers were interviewed: 186 in Upper Ping; 141 in Lower Ping; 265 in Upper Nan; and, 70 in Lower Nan. Interviews were carried out using a structured questionnaire of largely closed questions that covered individual, farm, and site level characteristics, as well as detailed sections about the impacts from flood and drought in the last two calendar years. Less detailed information was also collected about impacts and concerns with other weather phenomena, like hot and cold spells. The analysis here focuses on the information about impacts. Interviews were conducted between 9 October 2012 and 21 March 2013. At the time of the surveys the average exchange rate was around 1 USD = 30 Baht.

In-depth interviews were also carried out with the following 68 informants: fish farmers (36), company agents (2), department of fisheries officials (18), officials from other departments (3), local government (4), and university academics (3). All interviews were taped, fully transcribed, and coded using NVIVO software. Interviews were done with a pre-prepared guide of key questions tailored to each stakeholder group. The guide was a reminder to interviewers about which topics should be covered, but in practice, the conversation was allowed to flow as naturally as possible. Informants were encouraged to explain their reasoning or observations behind claims, views, and choices. The analysis reported here focuses just on responses related to the impacts of extreme weather and climate, with an emphasis on those resulting in, or exacerbating, low and high flow conditions. Illustrative quotes from informants are shown in italics in results. Apart from the main set of interviews, direct observations and additional interviews were made during, and soon after, periods with unusually high and low flows, between July 2012 and October 2013.

2.3 Secondary data and document review

Previously published articles on climate and hydrology of Northern Thailand were supplemented with analysis of secondary datasets from the Royal Irrigation Department, Thai Meteorological Department, and the Department of Fisheries. These datasets supported more

detailed exploration of seasonal patterns and inter-annual variability, in flow-related conditions important to river-based aquaculture.

2.4 Data analysis

Associations between categorical outcome variables with two states (binary), and other continuous or categorical predictor variables, were studied using logistic regression. Results are reported within text for significant associations, using estimated odds ratios and the 95% confidence intervals (CI). Associations for continuous outcome variables were explored using general linear models and analysis of variance (ANOVA).

3. Results

The findings are organized as follows. First, the climate and flow regimes in the four fish farming regions are described. Second, the key features of river-based fish aquaculture system are summarized. Third, seasonal differences in climate- and flow-related risks are evaluated. Fourth, the observed impacts of floods and droughts are assessed. Finally, patterns in inter-annual variability are explored.

3.1 Climate and hydrology

The climate of Northern Thailand is highly seasonal (Figure 2A), with most rain fall between May and October and December to March especially dry. Mean air temperatures are relatively cool between November-February with the lowest temperatures found in Chiang Mai or the Upper Ping region (Figure 13A).

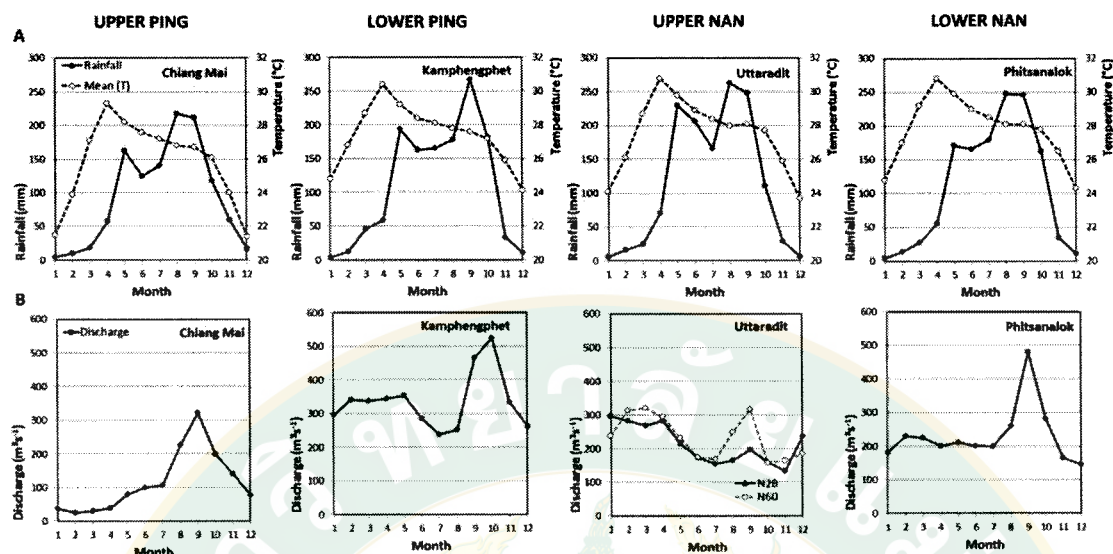


Figure 13 Seasonal patterns in climate and flow conditions in four fish farming study regions: (A) Mean monthly rainfall and temperature for 1981-2010 in Upper Ping (Chiang Mai), Lower Ping (Kamphengphet), Upper Nan (Uttaradit) and Lower Nan (Phitsanulok) regions; (B) Mean discharge ($\text{m}^3 \text{s}^{-1}$) each month for representative monitoring stations in Upper Ping (Chiang Mai P1, 1981-2010), Lower Ping (Kamphengphet, N15), Upper Nan (Uttaradit, N60-N2B, 1991-2010) and Lower Nan (N5A, 1991-2010).

Annual patterns of mean discharge show peaks which lag behind that of precipitation (Figure 13B). This is particularly clear in the Upper Ping, where dry season flows are very low compared to other regions. Peak flows in the Upper Ping, it should be noted, are strongly associated with tropical storms or monsoon anomalies, especially towards end of wet season; whereas, minimum flows are also influenced by human activities, such as irrigation, land-use, and dams (Lim *et al.*, 2012). Flow regimes in other regions are modified even more profoundly by the operations of water-related infrastructure including hydropower dams, water gates, weirs and irrigation diversions. 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 (N2B) but not completely, at a station further downstream (N60, Figure 13B). River regulation for irrigation is apparent in Phitsanulok (Figure 13B).

3.2 Fish farm practices

Fish are farmed in floating, open-top mesh cages, typically around 4m x 4m in areas and 2m deep (Chapter 3). Cages are stocked with juvenile fish that have been reared in tanks or ponds for around 2-3 months, prior to release in river cages, where they may be reared for typically a further 3-5 months. Fish are usually harvested after they reach the market standard size of at least 500 g fish⁻¹.

All farms recruited to this study had recently reared tilapia. In the Upper and Lower Ping as well as Lower Nan regions, this was mostly red hybrid tilapia, but in the Upper Nan region, black Nile tilapia and catfish were also common (Table 10). All subsequent statistics and findings reported in this paper refer to cages with tilapia, unless otherwise noted. Average stocking density overall of tilapia was 45 fish m⁻³, with a mean significantly lower in the Upper Ping than other regions (ANOVA, $P < 0.01$). Farmers in the Upper Ping were also more likely to have decreased stocking densities in the last 5 years (Table 10).

Two thirds to one half of the farmers in each region were in contract farming arrangements with firms that supplied feed on credit, and later deducted purchases when they bought the harvested crops. Fish stock and medication was also often provided. Fish cage farming households almost always had other sources of income (Table 10). In the Upper Ping region, which lies near Chiang Mai city and the Lamphun industrial area, incomes from orchards which require less labour and non-agricultural work were common. In the Upper and Lower Nan, relatively more had incomes from rice farming. About a third of households who farmed fish in river cages in the Nan regions and Lower Ping, also had earthen fish ponds, providing them with additional management options under conditions of extreme low or high flows.

Table 10 Rearing practices and farm characteristics in four study regions.

Farm practices	Upper Ping (n=186)	Lower Ping (n=141)	Upper Nan (n=265)	Lower Nan (n=70)
Species stocked (%)				
Red hybrid tilapia	94	99	77	99
Black Nile tilapia	20	9	64	11
Bagrid catfish	27	11	81	6
Other species	9	15	19	9
Stocking density of tilapia: fish m ⁻³ (mean)	42	48	47	45
Decreased stocking densities in last 5 years (%)	33	13	23	27
Cage aquaculture experience: years (mean)	9.2	5.4	7.9	6.2
Contracts for sale of harvest (%)	79	64	49	87
Household income (%)				
Rice farming	32	27	53	57
Orchards	66	21	26	24
Fish ponds	15	33	31	29
Trading	32	24	23	20
Salaried employee	65	57	39	54
Non-agriculture income	81	67	53	60
Fish cage income only	0.5	13	11	6

3.3 Seasonal and spatial differences in hazards

High and low-flow related constraints to fish farming vary seasonally and spatially (Figure 14). Farms in the Upper Ping are much more likely to face unfavourable flow conditions than the other regions (Figure 14). Fast flows are a problem in August and September, whereas slow flows in March and April. In the Lower Ping, fast flow problems are a month or so later in the year than in the other regions. In the Upper Nan, problems are comparatively rare, but do follow expectations based on rainfall: as a result of Sirikit Dam operations, periods with low depth problems begin at end of the wet season in October. In the Lower Nan, even more farmers face similar early dry season low-flow challenges, but these persist – in this case, as a consequence of operations of Naresuan Dam and related irrigation diversions.

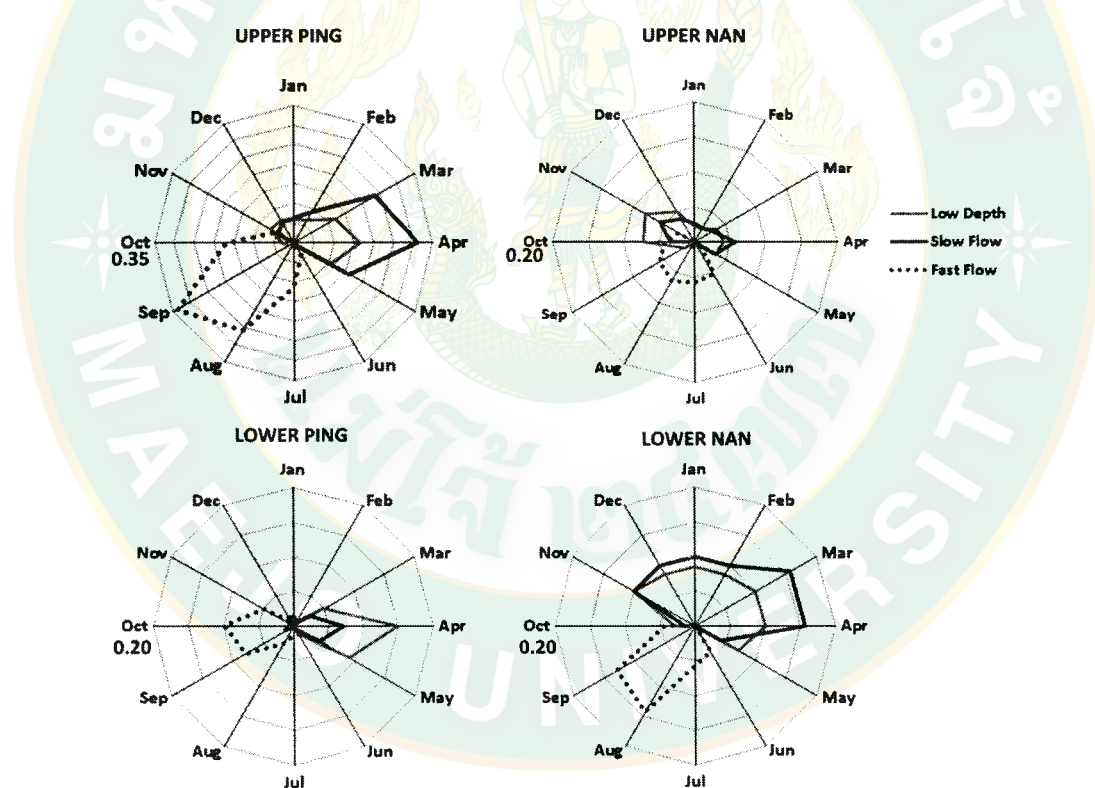


Figure 14 Seasonal flow-related constraints on cage culture in four river regions: proportion of farms facing unsuitable local site conditions in each month. Note that the scale for Upper Ping (0.35) is different from other for regions (0.20), implying much larger risks of being impacted for similar-sized polygon.

3.4 Impacts of recent floods

Farmers were asked about whether they were adversely affected by droughts (low flows), and floods (high flows), in last two years. Consistent with instrumental record, the wet season floods of 2011 were much more severe than 2012 (Table 11). For floods, the effects in the severe event in 2011 were similar across sites, but in 2012, site differences were greater. Mean losses of income from escape or death of fish among those farms adversely impacted were highest for the 2011 flood, but comparable in magnitude across regions (Table 11). These figures are around double the average profit farmers not impacted by floods or droughts received from their last harvested crop or about 36,000 Baht. In comparison, a study in the Upper Ping region in 2005 found that 75% of farms were affected by high flows, with an average loss of 12,700 Baht (Chapter 3).

Table 11 Impacts of floods and low flows (droughts) in two recent calendar years in three culture regions.

Event type	Year	% Farms Impacted					Income loss from deaths if impacted Thousands Baht Mean (SEM)
		Upper Ping	Lower Ping	Upper Nan	Lower Nan	Total	
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	33	26	63	34	44	63 (9)
Drought (low flow)	2011	34	14	11	6	18	46 (7)

Farms impacted by the 2011 floods were more likely to have an aquaculture-related debt, even after taking into account differences among regions (Odds Ratio=1.91; 95% CI=1.38-2.65). There was no evidence, however, that having been impacted by floods in either year, or just in 2011, was associated with problems in making debt repayments.

The main types of impacts experienced were similar in two years (Figure 15). Fish deaths were the most important individual impact. Apart from the common impacts listed, floods also occasionally allowed fish to escape, damaged banks, or made it impossible for farmers to safely access their cages to take care of fish.

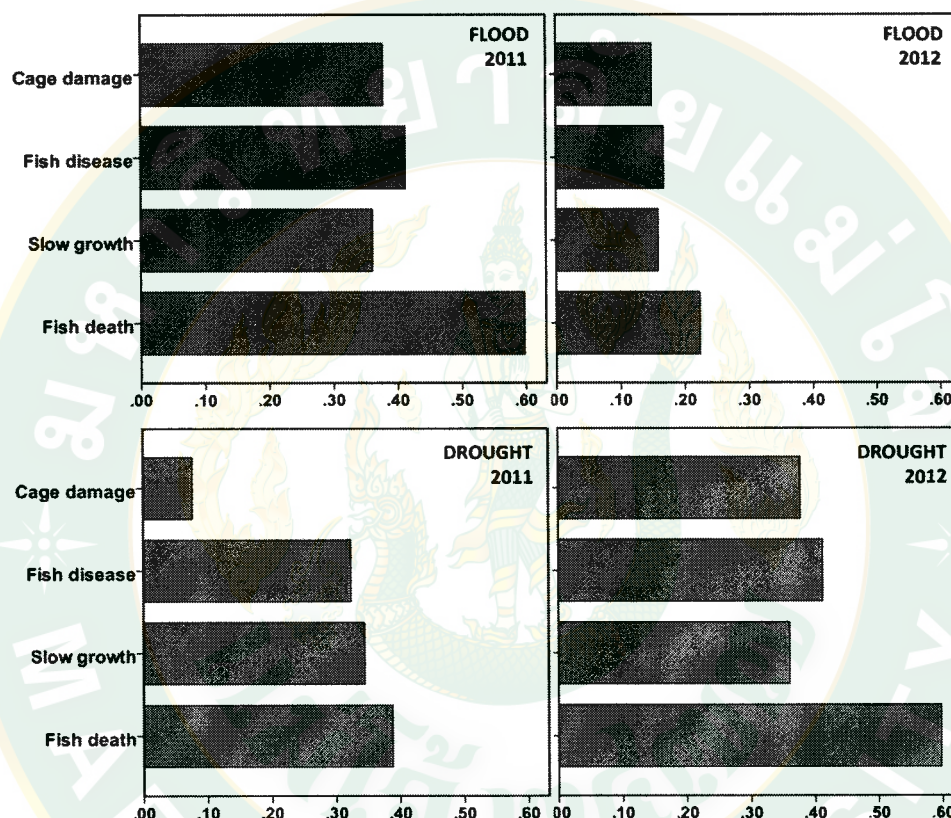


Figure 15 Percentage of all farms which experienced various types of adverse impacts from flood and drought conditions in 2011 and 2012.

Taking into account the different number of years farmers have had cages exposed to local flow and climate conditions, the average risk of being impacted by a flood per year was 0.30. Farms in the Lower Ping (0.44) had a significantly higher risk than in the Upper Ping (0.30), Upper Nan (0.24) or Lower Nan (0.25) (ANOVA, Tukey's HSD, $P < 0.05$).

Raising tilapia in good sites and with normal seasonal flooding conditions is not a problem: “*when floods come, I am not worried, because cages float up and down following the water levels.*” In-depth interviews about floods underline that fast flows, above about 1ms^{-1} , begin to distort cage mesh, constraining space and making it more likely for fish to strike each other and cage sides. Direct observations and reports from farmers also suggest another reason fish may die in fast flows: they become exhausted trying to maintain position in current so as not to be swept against rear of cage. Many farmers are also concerned about sediments which interfere with gill breathing, in particular “*Nam Daeng*” or “*red-water*” episodes. Debris-laden floodwaters damage cages, resulting in fish escapes. Rapid increases in flow velocities, for example, overnight or when weirs break, cause the most damage as there is no time to take action to minimize losses and damage; for example, by securing cages more firmly or moving them towards the banks.

Farms which have been impacted by floods were much more likely to also have disease problems (Odds Ratio = 3.22; 95% CI: 2.08-5.00), even after adjustment for significant regional effects. Farmers suspect that flood waters transmit diseases downstream easily. Many farmers also believe that flood waters create stress, making fish more susceptible to disease.

Farmers in Upper Nan (70%), Lower Nan (40%) and Lower Ping (62%) regions, were much more likely to have received assistance after floods than those in the Upper Ping (20%). Fish farmers registered with the fisheries department were much more likely to receive assistance (Odds Ratio = 3.50; 95% CI: 1.79-6.86). Clearly, many impacted farmers in the Upper Ping (Table 11) did not receive assistance. The most common form of assistance among those who received it was cash (88%); fewer farmers received fish for stocking (22%), and feed (12%). Farmers estimated the average value of this assistance at 19,450 Baht, with no significant difference among regions. This represents a quarter to one third of the average value of reported losses from just fish deaths – not including, for instance, costs of repairing cages (Table 11). The most common source of assistance was from the Department of Fisheries (85%). Sub-district Administrative Organizations were less frequently a source (19%), and community (8%) and private firms (4%) even more rarely. Other sources that were scarcely mentioned, and were not in all locations, included: farming cooperatives (0.5%), district office (1.4%), and the village headman (0.5%).

3.5 Impacts of recent droughts and low flows

In 2012, low flows had much greater impact than in 2011 (Table 11). The impacts of low flows in both years varied substantially. Mean loss of income, if impacted, was higher in 2012 than in 2011, but comparable in magnitude to flood-related losses. The main types of impacts experienced were similar in both years, with fish death the most common, but closely followed by slow growth and disease (Figure 15). Taking into account number of years of experience at a site, the average risk of being impacted by a drought per year was 0.17, and did not differ significantly among regions. When asked about the worst drought in their experience, 52% indicated 2012-3 dry season. It should be noted, however, that fewer farms currently farming fish had been rearing fish a decade ago when there were also some serious low flow years (see Figure 5B). Just over 40% of farms were affected by both droughts and floods, whereas 18% were affected by neither.

As for high flows, farms impacted by low flows in 2011 were more likely to have an aquaculture-related debt, even after taking into account differences among regions (Odds Ratio=1.80; 95% CI=1.15-2.79). There was no evidence, however, that having been impacted was associated with problems in making debt repayments.

In-depth interviews with officials, farmers, and fisheries experts, emphasize that the key factor in periods of slow flow is decrease in dissolved oxygen concentrations, and reduced water quality. The combination of low flows and high temperatures, which occur late in dry season, just before the transition into wet season, in particular, creates high risk conditions. Ad hoc field measurements during critical periods confirm that very low dissolved oxygen conditions can arise during low discharge periods. Since cages are typically 2 m in depth, when river levels fall below this, circulation under cages is impeded, and food waste and other materials accumulate at the bottom of cages. *“With low water levels, the opportunity for fish to come in contact with toxic bottom sediments, including food wastes is increased.”* As water levels fall below 2 m, the fish density within cages also increases, leading to stressful conditions and heightened risks of poor water quality.

3.6 Inter-annual variability in risks

Field observations and interviews with farmers indicate that, flow velocities and water depths are two key variables for fish farms, which, in turn, are affected by extreme weather and climate, as well as operation and failure of water-related infrastructure. *Ad hoc* observations, measurements, and interviews with farmers about causes of high flow-related mass mortality on specific dates, suggest that when flows in the Upper Ping reach a threshold value of around $200 \text{ m}^3 \text{ s}^{-1}$ at the Nawarat Bridge Station, farmers downstream begin to have problems with high flow velocities in more vulnerable cage sites. Bank-overflow flood conditions at Nawarat Bridge, occur when discharge reaches $370 \text{ m}^3 \text{ s}^{-1}$.

Based on these observations, a more detailed exploration of risks of high and low flow events, which would have significant adverse impacts for the Upper Ping region, could be made. A threshold value of $200 \text{ m}^3 \text{ s}^{-1}$ at the Nawarat Bridge Station was exceeded on average 14.3 days per year. Deviations from the long-term average show multi-annual patterns of variability over the last 30 years, with 2011 being the highest in more than 30 years (Figure 16A). The number of days a year, for which a threshold level is exceeded, is an indicator of the extent of high flow related challenges in a year. Peak flows would be another alternative measure. The peak flood in 2005 was considered a 50-year recurrence event (Wood and Ziegler, 2008), and yet, the 2011 event was even more extreme.

The threshold for low flows, or discharge below which there will likely be impact on fish aquaculture, is more difficult to determine than that for high flows. The risks from low flows are strongly influenced by local conditions; for example, the presence of weirs that increase effective stream depths upstream but reduce them downstream. In this initial analysis for the Upper Ping region, we assumed a threshold of a discharge of less than about $5 \text{ m}^3 \text{ s}^{-1}$ at Nawarat Bridge. Below this level we expected serious difficulties with low water depth and low water velocities in many fish farming locations. This lower threshold was exceeded on average 22.4 days per year. Deviations from long-term average for low flows also show multi-year patterns (Figure 16B). In particular, it should be highlighted that 3 of the last 4 years had relatively large number of days with low flows. This corresponds with farmers' perception of increasing severity of drought in the dry season over the last 15 years or so, during which cage farming has been practiced in the Upper Ping.

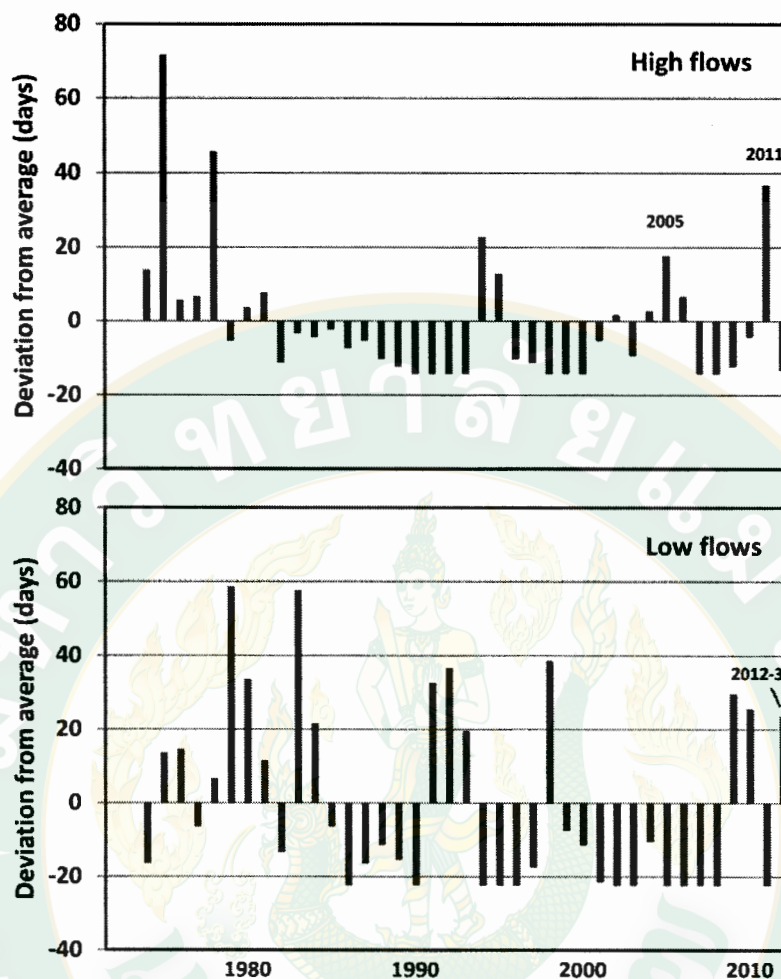


Figure 16 Annual deviation from long-term average (1974-2012) number of days with high (> 200) and low (< 5) flows (discharge $\text{m}^3 \text{s}^{-1}$) in the Upper Ping River at Nawarat Bridge, Chiang Mai.

3.7 Inter-annual variability in flood impacts

Compensation paid out to aquaculture farms of all types across Northern Thailand in the period of 2005-11, was positively associated with number of high flow days per year (Figure 17). The 2005 flood, which was severe in the Upper Ping, however, was not a year of high compensation, as the formal loss and damage system was not yet fully functional. Associations between high flow days and numbers of farmers compensated, show a similar pattern to that for value of compensation (not shown).

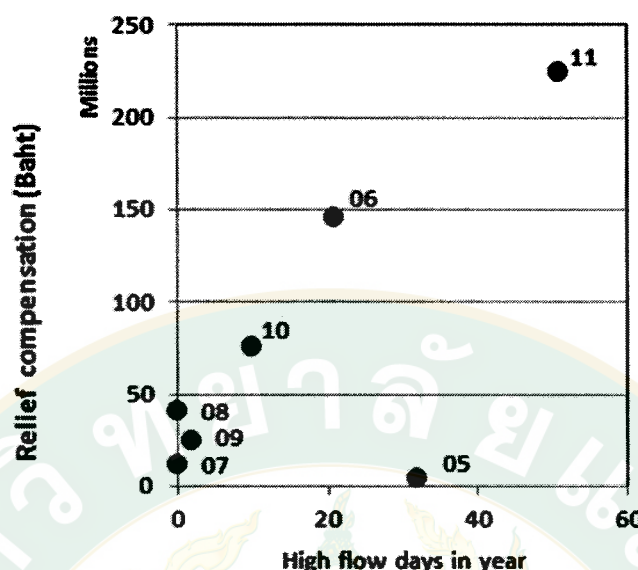


Figure 17 Association pattern between high flow days per year (defined in text for flows at Narawat Bridge, Chiang Mai), and disaster-related compensation paid out in Millions of Baht (Source: Department of Fisheries) to inland aquaculture farms in 2005-2011 in Northern Thailand. Two digit labels indicate years.

3.8 Impacts from other weather and climate phenomena

Apart from floods and droughts, farmers were also asked about the importance of impacts from other climate and weather phenomena. Farmers identified rapid changes in temperature, on average, as having the most important impact on their aquaculture system. Hot and cold weather spells were next most important. Heavy rainfall, persistent cloud cover, and shifts in the wet season, were of relatively less importance, but not unimportant altogether. In the Upper Ping farmer highlighted impacts from cold weather. On site in-depth interviews with farmers and other stakeholders, provided more detailed information about impacts for different phenomena; these will now be briefly summarized.

Extreme hot weather ($> 38^{\circ}\text{C}$) typically occurs in March through to April, coinciding with slow flows and low water levels. According to experts interviewed, rapid growth of bacteria such as *Streptococcus* increases opportunities for disease outbreaks. While fish

generally eat more when water temperatures are warmer, at the very extreme conditions, some farmers observed that fish remained in cooler lower depths, and reduced their feeding.

All informants agreed that seasonally cold weather, especially in the Upper Ping region, results in low water temperatures at which fish feed less. Effects on growth are measurable, and compensated for by extending culture periods. Parasites such as *Trichodina* and bacteria could be problems in the cold season, when fish may be more susceptible to infection.

Analysis of last crop harvested by yearly quarters, suggested that there was no net difference among growing seasons in average crop yield densities ($F=0.54$; $df=3, 602$; $P>0.5$), or profit densities ($F=1.2$; $df=3, 581$; $P>0.3$). Seasonal differences in growth rates do not translate into measurable impacts on yields or profits.

Transitions between the seasons are also believed to be associated with risks of diseases. The month most farmers believe is worst for diseases is April, which is also very hot and at the transition between the dry and wet seasons. Diseases, however, are potentially significant problems in all months of the year for many farmers: *“Diseases always happen, no matter if it is early in wet season or the cold season.”*

Heavy rainfall is a problem at the very beginning of the wet season, as run-off can be high in wastes, pollutants, and pesticides, which impacts fish health and cause death. Rapid changes in water quality are a source of stress, reducing feeding and growth. At other times of year, negative impacts are less, but still important; for example, through temporarily increasing turbidity, this reduces feeding rates and can kill fish.

Persistent cloud cover was observed by some farmers to lead to reduced feeding – a fact attributed by one farmer to low oxygen levels. Another farmer had observed that turning on a water pump *“helped fish by providing more dissolved oxygen; sometimes fish lack oxygen such as early in the morning or late in the evening after a day of high cloud cover.”* It should be underlined that conditions behind weirs, in deeper pools, and dredged trenches, as favored by farmers during periods of extreme low flows, take on the conditions of a pond or reservoir instead of a river.

4. Discussion

4.1 Risks and impacts under current climate

The highly seasonal climate and extreme rainfall events are major determinants of flow conditions in the rivers of Northern Thailand (Figure 15). River regulation also influences flow regimes – effectively reversing natural seasonal patterns in fish farming regions in the Nan River downstream from Sirikit Dam and near Naresuan Dam. High and low flows impact a large fraction of farms, causing significant losses: as much as 40% of farms being affected by both high and low flow in the last two years. The risks of adverse impacts from high and low flow are strongly seasonal, and vary spatially among major river regions (Table 11). Death of fish, reduced growth, and damage to cages, are all common impacts that result in significant losses of income (Figure 15).

Additional observational and experimental research, on the mechanisms by which high flow impacts fish growth and survival, as well as farm profitability, is needed. However, this current study does provide some initial insights. Observations by the researchers of fish in cages, suggest that fish need to maintain a position in fast moving water, which ultimately leads to exhaustion, and finally their death, if having to maintain balance for extended periods. Farmers and other stakeholders believe that high sediment loads in flood waters, interfere with fish breathing or oxygen availability. Observed reduced growth following high flow events is likely correlated to stress, but may also reflect difficulties in providing feed to fish during high flow periods: farmers may not be able to safely access all cages, and feed pellets are more likely to be swept downstream uneaten.

Damage to cages is another important impact of floods (Figure 15). Li and colleagues (2005) argue that for cage culture in canals, velocities should be around $0.1\text{--}0.6\text{ m s}^{-1}$. Using thicker mesh which would be one way to make cages stronger, but unfortunately, it would also increase drag on cage structures in floods and further reduce through-flows in low-flow periods.

The immediate observed effects of droughts or low flows are similar to floods, but explanations in this case seem most likely to be related to water quality, in particular, low dissolved oxygen levels. As water velocities drop to near zero conditions, cage culture become

more like those in ponds (Sriyasak *et al.*, 2013), but because of very high stocking densities, conditions may become even more severe. Farmers with aeration, mechanical mixers or pumps to circulate water, are sometimes able to reduce adverse impacts of low flow conditions. When depths are insufficient for cages, effective densities may increase greatly, producing stress in addition to water quality problems. Increased disease under these conditions is not surprising, but also deserves more detailed investigation to identify management options.

Evidence for a few longer-term impacts of high and low flow events were observed in this study; for example, increased likelihood of aquaculture-related debt, but it should be underlined, not increased difficulties of loan repayment. Moreover, a follow-up survey in late 2011 of 80 households farming fish in 2005 in the Upper Ping region, found that 5 had exited from fish farming as a result of the impacts of floods, and 2 because of droughts, in the intervening period (Chapter 3). This implies that most fish farms find ways of coping with extreme flow events.

Apart from flow-related disturbances, this study also found modest evidence of other weather and climate phenomenon that may be important to fish production. Farmers, for example, reported that sharp changes in temperature, as well as cold temperatures, reduce feeding, and thus growth rates. Comparisons of yields and profits of crops harvested in different seasons, however, did not confirm this claim.

4.2 Under future climate

Several published studies have considered the historical evidence for changes in climate and flow regimes, and the possible implications of future climate change on the hydrology of the Ping River basin. 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 (Lim *et al.*, 2012). Analyses using shorter-time series of 38 years, also suggest decreases in recent annual rainfall (Sharma and Babel, 2013), which was not apparent in the analyses of the longer dataset (Lim *et al.*, 2012).

Future projections of rainfall, for the mainland Southeast Asia region, are inconsistent among studies that vary in choice of climate models, downscaling procedures,

emission scenarios, geographical scales, and statistical techniques. In many cases, analyses fail to adequately separate multi-year variability from unidirectional trends, but overall, most studies suggest only very modest changes over land areas (Lacombe *et al.*, 2012).

If the frequency or severity of droughts or duration of low flow were to increase, the impacts on river-based aquaculture would be substantial. Growing fish could easily become impossible for several months of the year. One study focussed specifically on the Ping river basin, suggests decreasing trends in precipitation, especially for the wettest August-September-October period (Singhratna and Babel, 2011). Using a different general circulation model, another study projected similar declines in precipitation, which would translate into projected decreases in annual stream flow of 13-19% (Sharma and Babel, 2013). Seasonal shifts 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 (Sharma and Babel, 2013). This timing shift would moderate the effects of overall precipitation, and run-off declines, on the severity of low flow conditions in the river.

The impacts of a drier climate on water flows where fish are grown are complex, and basin specific. Water use, infrastructure, and allocation decisions, have a large impact on dry season stream flow. In the Upper Ping, upstream storage is modest. Small irrigation weirs in fish growing areas play a major role in regulating water depth in individual reaches in the dry season, making fish farming possible. Under drying climate, they would become even more important.

In the Nan River, fish farming takes place in a flow regime modified by dam operations geared to meet the needs of rice growers and hydropower generation. Following the 2011 Bangkok floods, operating rules and procedures for storage and release from dams in Northern Thailand, were further adjusted to give greater discretion to dealing with flood risks downstream. Inter-annual and seasonal variability in rainfall, interacts with management of water infrastructure – especially during and following more extreme events – with complex influences on flow regimes and thus risks faced by fish farmers in different locations. Modelling studies are needed to better understand the consequences of climate and water infrastructure interactions for in-stream aquaculture.

In many locations fish farmers need to consider both low- and high-flow related risks in making their stocking decision. Unfortunately, actions at river-basin level to reduce wet season flood risks tend to increase risks of serious impacts from low flows. The interaction between dry and wet season risks has not usually been considered in impact studies and assessment and should be in locations with highly seasonal climates (Lebel *et al.*, 2011). Farmers in Mozambique, for instance, are impacted strongly by droughts in upland fields and frequent floods in the lowlands if move activities closer to the highly seasonal and variable rivers (Brida *et al.*, 2013).

Under existing climate floods, farmers estimated the average annual risk of adverse impacts from floods at 0.30, and from low flows at 0.17 averaged across all regions. At these likelihoods and impacts (Table 11) fish farming already requires that substantial attention be given to risk management practices and the performance of loss and damage systems (c.f. Warner and Geest, 2013). Under some climate change scenarios, seasonal rainfall patterns could become more variable with higher risks from both extreme low flow and high flow periods. This scenario would be the most difficult situation for river-based cage aquaculture.

4.3 Implications for policy and practice

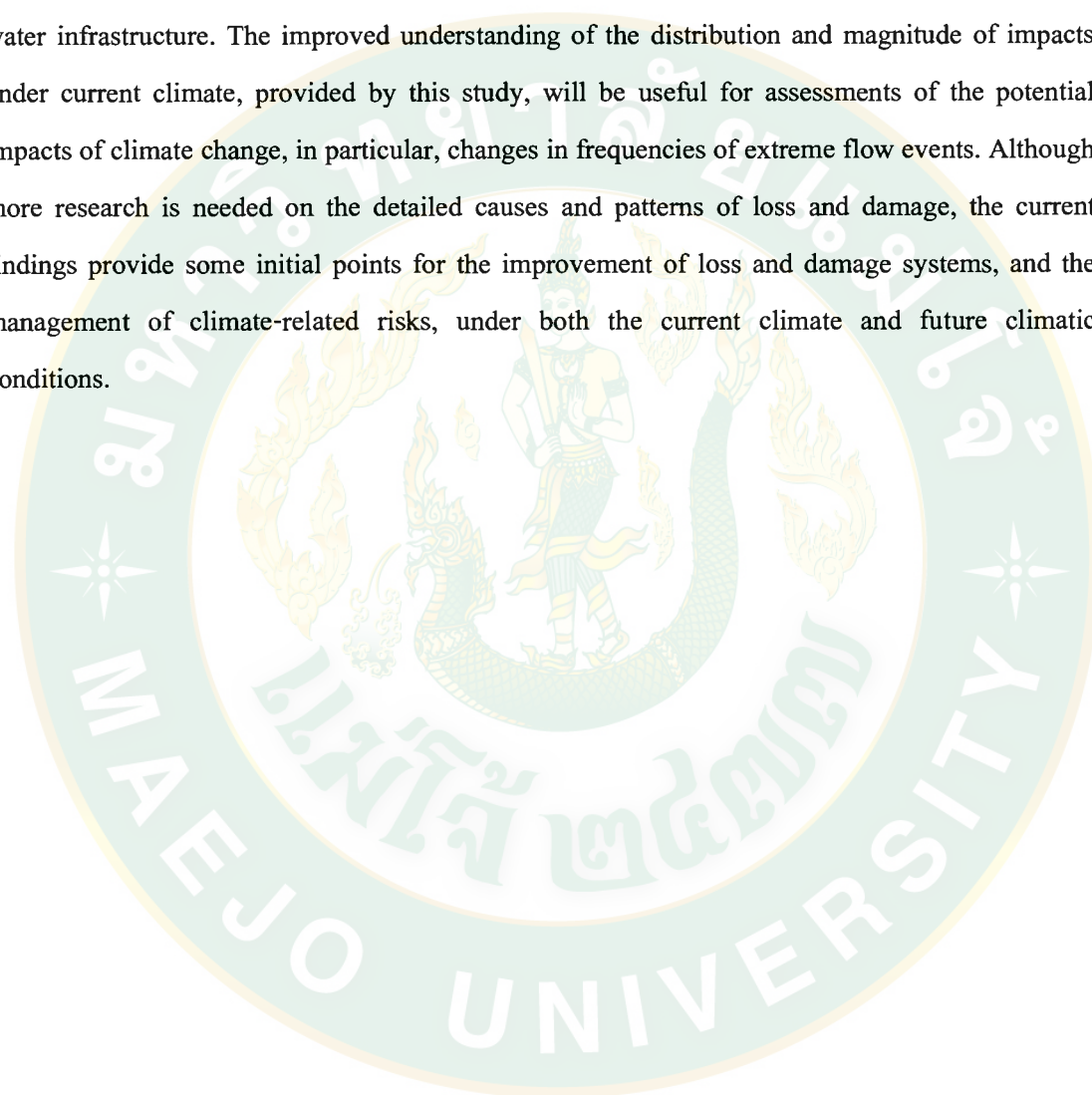
Under both current and future climate, the risk management practices of farmers on their own farms are important for dealing with low and high flows. How experienced impacts and observed broad patterns in climate and flow, fit with farmers' perceptions of risks, is important for identifying alternative options for risk management. Farmers, typically pay more attention to changes in sensitivity of farming system, then directly to meteorological evidence (Simelton *et al.*, 2013); that is, they judge changes in climate from their impacts or losses, rather than weather and climate variables more directly. In this study, farmers appeared to have a good understanding of seasonality in river flows, that they can directly observe and have immediate impacts on their production, but were less aware of the specific meteorological conditions, which lead to high risks of serious floods. Farmers also recognized the importance of inter-annual variability in severity of high and low floods, and thus may be open to seasonal forecasting information now being researched (Singhrattana *et al.*, 2012), if it was more widely accessible.

Risk management does not eliminate risks or impacts; systems may also be needed to deal with exceptional loss and damage. Compensation and assistance following floods is modest relative to losses, and coverage is incomplete (Table 11). Although many farms are in contract arrangements for feed inputs and sales of harvests, they do not receive much compensation, or other assistance, from the private sector to deal with losses and damages following extreme events. One alternative that deserves further policy research is weather-indexed insurance scheme. The patterns of losses observed in this study suggest that number of days above or below a threshold (Figure 16), or value of daily peak discharge, at well-monitored stations with long-time series – like Nawarat Bridge in Chiang Mai – could be used to develop an index. The findings of this research were based largely on farmers' recalling past events, and as such, have obvious limitations. More field measurements during high and low flow conditions are needed, in order to establish quantitative loss and damages models for fish farms, as well as refine thresholds that might be used as part of insurance indices.

Little is known about willingness to pay for insurance by fish farmers in the Thai context; studies in the US with trout growers, found that they were willing to pay premiums of 2-11%, for coverage levels 85-95% (Shaik *et al.*, 2008). Seasonal and inter-annual climate information could help farmers better manage risks, but providing that information at the right scale, and in easily accessible form, which can really support farmer decisions, is challenging (Goddard *et al.*, 2010). Informing risk management is a social process that depends on perceptions, values, goals, and how climate information is incorporated into agricultural practices (Crane *et al.*, 2010). This study in northern Thailand underlines that floods for fish farmers include periods with high velocity flows (or spates), that do not necessarily exceed bank or levee heights. Likewise, the notion of droughts for fish farmers relates to periods with low discharge, when flow velocities are low or water depths are shallow (Figure 14). Whether depth or velocity or both factors are important, is a function of micro-site characteristics and water quality. From the perspective of fish farmers recent years have included many low flow periods as well as one of the wettest (Figure 16). Fish farmers get a lot of their information about rearing practices from other fish farmers, the department of fisheries, and sellers of stock and feed (Chapter 3). More work is needed on how risks are perceived, communicated and managed by fish farmers.

5. Conclusions

This is one of the first papers to report in detail, how extreme events, unusual weather, and seasons, affect river-based cage aquaculture. Extreme events affect many farms by killing fish and reducing growth rates. Impacts on income are significant, and result in aquaculture-related debts. Impacts vary spatially and temporally, being affected by, for example, water infrastructure. The improved understanding of the distribution and magnitude of impacts under current climate, provided by this study, will be useful for assessments of the potential impacts of climate change, in particular, changes in frequencies of extreme flow events. Although more research is needed on the detailed causes and patterns of loss and damage, the current findings provide some initial points for the improvement of loss and damage systems, and the management of climate-related risks, under both the current climate and future climatic conditions.



CHAPTER 6

PERCEPTIONS OF CLIMATE-RELATED RISKS OF AND AWARENESS OF CLIMATE CHANGE OF FISH CAGE FARMERS IN NORTHERN THAILAND

1. Introduction

How climate uncertainties and climate change are understood and perceived by natural resource users is potentially important because it can influence their management practices. Farmers who believe climate in a place has particular characteristics make decisions about what crops to grow, when, and with what inputs, depending on that understanding. They may also adopt risk management strategies, for instance, staggering planting dates of different fields, or plant a mixture of varieties, or purchase crop insurance, to help deal with uncertainties. Farmers may also perceive that climate has changed already, or expect it will change in the future; such beliefs may affect longer-term adaptation strategies (Raymond and Spoehr, 2013) such as developing new varieties or supporting diversification into off-farm livelihoods within the household.

Several studies of climate risk perception have been carried out with farmers of field crops, perennials and livestock. These studies have shown that experience of losses in past events (Menapace *et al.*, 2013) as well as site (Tucker *et al.*, 2010; Manandhar *et al.*, 2011; Kost *et al.*, 2012) and individual (Barnes and Toma, 2012; Safi *et al.*, 2012; Regassa and Stoecker, 2014) characteristics are associated with differences in perceptions of climate-related risks and understanding of climate variability and change. Farmer perceptions and instrumental observations of changes in climate often roughly correspond, but not in all details or invariably so (Patt and Schröter, 2008; Rao *et al.*, 2011; Simelton *et al.*, 2013) underlining the importance of considering perceptions in risk management and climate change adaptation.

Findings from a broader area of scholarship underline that perceptions of risk are influenced by values, attitudes and culture (Leiserowitz, 2006). Gender, for instance, is often identified as an important factor in risk perception (Sundblad *et al.*, 2007; McCright, 2010; Weber, 2010; Safi *et al.*, 2012; Regassa and Stoecker, 2014). Perceived risk can be increased or

decreased through social relations, circumstances and experiences (Kasperson *et al.*, 2003; Duckett and Busby, 2013). Negative emotions, like fear or worry, and positive emotions, like interest in a hazard, influence risk perception (Sjöberg, 2007). In evaluating risks, people tend to pay more attention to recent events (Weber, 2010), negative impacts (Rao *et al.*, 2011) and tend to be more concerned about things over which they have some control (Weber, 2010; Kuruppu and Liverman, 2011).

An individual's assessment of the probability and severity of a risk should be distinguished from the evaluation of their own abilities to respond adaptively and the costs of doing so (Grothmann and Patt, 2005). Beliefs about one's own capabilities to respond may influence perceptions of risk as well as help understand differences between intentions and actions on adaptation. One constraint to changing practices in adaptation is that farmers are often highly risk averse (Ghadim *et al.*, 2005; Alpizar *et al.*, 2011a; Menapace *et al.*, 2013). Risk attitudes have been shown to vary with gender, age, education and measures of an individual's social capital (Nielsen *et al.*, 2013).

Individuals may not always have the necessary understanding, time or motivation to carefully evaluate risks themselves. In these situations trust in the information provided by others is important to risk perception (Visschers and Siegrist, 2008). The exchange of information between stakeholders about the existence, level, sources or acceptability of risks is influenced by many factors including perceived motivation of speakers (Rabinovich *et al.*, 2012) and language. Words and images may scare people or encourage them to act (Nerlich *et al.*, 2010). An important challenge in communicating the risks of climate change is that the largest, uncertain, changes are still in the future so their effects may not yet be visible (Moser, 2010a).

There have been relatively few studies that have considered the risks faced by inland freshwater aquaculture farms despite the large and growing importance of the sector and emerging concerns and hopes about the role it may play in adaptation (De Silva and Soto, 2009; Yazdi and Shakouri, 2010; Pickering *et al.*, 2011; Callaway *et al.*, 2012; Frost *et al.*, 2012). Most studies of aquaculture farmers have been for coastal systems and are not primarily interested in climate per se but rather in understanding more broadly risks to yields or profits (Le and Cheong, 2010; Ahsan, 2011). A study of a newly emerging blue mussel aquaculture industry in Norway, however, found that 'bad weather' was an important risk to production because it prevented

farmers from travelling to their culture sites (Ahsan and Roth, 2010). Another study comparing aquaculture of Tilapia in earthen ponds at different positions along an elevation gradient in Thailand found farmers had greater concern with cold weather in high elevation sites and more concern with hot weather in lower elevation sites (Pimolrat *et al.*, 2013). In the Mekong Delta of Vietnam duration and depth of seasonal flooding help explain the adoption of rice-fish integrated aquaculture (Bosma *et al.*, 2012). Similarly, prawn-fish-rice systems in southwest Bangladesh are extremely vulnerable to coastal flooding which result in escapes, and to droughts which curtail culture periods (Ahmed *et al.*, 2013).

In Thailand there is a diverse range of inland aquaculture systems varying in levels of intensity of inputs, degree of integration with other farm production activities, species reared, and the type of water body used – concrete tanks, earthen ponds, rice-paddies, public reservoirs, irrigation canals or rivers (Yi and Lin, 2001; Pant *et al.*, 2004a; Belton and Little, 2008). In northern Thailand some farmers rear fish, typically Nile tilapia or hybrid red tilapia, in floating cages suspended in rivers (Chaibu *et al.*, 2004). Cages are typically around 4m x 4m in area and 2m deep. Fish are first reared in tanks or ponds for 2-3 months before being used to stock cages at densities of around 40-50 fish⁻¹ m⁻³ (Chapter 3). Fish are then typically reared for a further 3-5 months using commercial pellet feed until they reach the market standard size of at least 500 g fish⁻¹. The river-based cage aquaculture system is sensitive to extreme weather events, such as flood or drought (Chapter 5). It is also sensitive to seasonal variation in water temperature, flow speed and water quality.

The purpose of this study was to improve understanding of how river-based cage fish farmers in northern Thailand perceive climate-related risks and understand climate change. Three specific research questions are considered: (1) Does knowledge of river flows, experience of past extreme weather events, individual or site characteristics influence on how climate-related risks are perceived? (2) Do farmers perceive that climate-related risks have changed, and if so, which factors are associated with these perceptions? (3) Are there any associations between how climate-related risks are perceived and beliefs towards or understanding of climate change?

2. Materials and methods

2.1 Interviews with fish farmers

A total of 662 fish farmers currently or recently having reared tilapia in cages in the rivers in northern region of Thailand were interviewed for this study. Not all who had recently stopped farming could be contacted. Local fisheries officials, community leaders and private sector feed and stock suppliers were asked to locate farmers.

Interviews were carried out using a structured questionnaire with farmers. The questionnaire covered individual, farm and site level characteristics as well as more detailed sections about impacts from past flood and drought events and patterns as well as perceptions of climate and understanding of climate change.

2.2 Measurement

The key outcome variables of interest were measures of how individual farmers perceived a range of climate-related risks. These were scored on a 5-point Likert scale based on level of concern or importance of impacts.

Most candidate predictor variables of interest could be used more or less directly in the analysis, for example, gender, level of education, age and so on. In three instances we derived a composite index based on responses to multiple questions. Knowledge of climate change impacts score was calculated based on the response to 11 questions on a 5-point Likert level of agreement scale. An extreme flow preparedness index was calculated on responses to questions about 6 dry season and 3 wet season practices. Scores for aggregated measures were standardised between 0-1.

Sites were grouped into four growing regions for analysis: Upper and Low Ping, and Upper and Lower Nan. Table 12 summarizes key features of climate and flow regime in the four regions. Climates were similar with Upper Ping being slightly cooler and drier. Flow regimes in all locations are affected by water infrastructure, in particular, in Uttaradit by operations of Sirikit dam upstream, and in Phitsanalok by irrigation diversions around Naresuan Dam (Chapter 5). The Upper Ping has the most extreme fluctuations in seasonal discharge – weirs playing a key role in maintaining water levels in some areas during the dry season.

Table 12 Climate and flow regimes in the four study regions. Province selected to illustrate precipitation and discharge data for the region is underlined (Source: Thai Meteorological Department and Royal Irrigation Department).

Conditions	Study region			
	Upper Ping River	Lower Ping River	Upper Nan River	Lower Nan River
Provinces	<u>Chiang Mai</u> Lamphun	<u>Kamphengphet</u> Tak Nakon-sawan	<u>Uttaradit</u>	<u>Phitsanulok</u> Pichit
Mean min. temp. (°C) in	14.9	18.5	17.8	18.6
Coldest month	(Jan)	(Jan)	(Jan)	(Dec)
Mean max. temp. (°C) in	36.5	37.3	37.9	37.2
Hottest month	(Apr)	(Apr)	(Apr)	(Apr)
Mean precipitation (mm) in	240	267	279	248
wettest month	(Sep)	(Sep)	(Aug)	(Aug)
Mean precipitation (mm) in	2	3.7	6.5	4.2
driest month	(Jan)	(Jan)	(Jan)	(Jan)
Average mean annual precipitation (mm)	1173	1306	1391	1320
Rainy days per year	108	118	115	115
Mean discharge (10^6 m^3) in	413	967	811	480
wettest month	(Sep)	(Oct)	(Mar)	(Sep)
Mean discharge (10^6 m^3) in	38	418	400	148
driest month	(Mar)	(Jan)	(Oct)	(Dec)
Mean annual discharge (10^6 m^3)	1800	7641	6952	2790

2.3 Data analysis

Two main multivariate statistical techniques were used to analyze associations between main outcome and candidate predictor variables of interest. For outcomes that could be considered continuous or taking multiple discrete ordinal values, general linear models were used. Only significant predictors were retained in final models. All statements about difference in this text were significant at $P < 0.05$ or better level; Tukey HSD tests were used post-hoc to separate means following detection of a significant main effect in ANOVA when 3 or more means.

For binary categorical outcomes logistic regression was used (Hosmer and Lemeshow, 2000). As above, only significant predictors were retained in final models and all statements about difference in text were statistically significant. Strengths of association were summarized using conventional odds ratios (OR) or the ratio between likelihood of having a particular exposure condition in the outcome group versus having that exposure in the non-outcome group. The significance of an OR is conventionally indicated by stating the 95% confidence interval (CI) – if that interval does not include 1 then it can be interpreted as statistically significant at $P < 0.05$. When a predictor variable has 3 or more levels one level must be designated as the reference group (as in a general linear model) with an OR set to 1 in tabulations of results.

2.4 Qualitative information

Qualitative, in-depth interviews were also carried out with 36 fish farmers using a pre-prepared guide of key questions, but allowing conversations to flow naturally. In this paper we focussed only on those parts of the interview where farmers explained their perceptions of climate-related risks and views on climate change. Interviews were also conducted with 32 other stakeholders such as fisheries department and company officials and academic experts, but these are only used sparingly and to emphasize contrasts as this analysis focussed on farmers' perspectives. All interviews were fully transcribed and formally coded using NVIVO software as an aid to content analysis.

3. Results

The findings of the study start with a brief description of the key characteristics of the surveyed fish farmers and their farms. This is followed by analyses of farmer perceptions of climate-related risks to profitability, including seasonal and imminent risks. The analysis then moves on to consider perceptions of change, first with respect to recent history of floods and droughts, then to understanding of climate change and its relationships with risk perception, and ending with perceptions of how climate is changing more broadly.

3.1 Characteristics of fish farmers

The main characteristics of fish farmers are summarized in Table 13. Fish farmers were mostly middle-aged, but a substantial fraction was over 60. About a third of fish farmers had more than primary school level of education. Fish farm households spanned a substantial range in average monthly income and years of experience with cage culture. The majority of farms had less than 16 cages. The largest farm had 500 cages. Most farms (86%) did not normally use external labour, and virtually all depended largely on family labor. Two-thirds of the farmers (68%) were in contract farming arrangements with firms that supplied feed on credit. Most farm households (92%) had income sources apart from fish cage farming like rice paddies, orchards; many (65%) had some non-agricultural income sources.

Experience or knowledge of local river flows ranged widely. On average fish farmers surveyed had monitored or closely observed river levels for 8.4 years and had practiced fish farming in river cages for 7.5 years. Based on years of farming experience the likelihood of experiencing a flood with significant negative impact was 0.30 and for drought 0.17 per year averaged across all sites.

Table 13 Selected demographic characteristics of fish farmers (n=662) in 2011-12

Characteristic	Percentage	Characteristic	Percentage
Age in years		Education	
< 30	4.7	No formal	4.5
30 – 39	14.0	Primary	60.4
40 – 49	33.1	Lower Secondary	10.4
50 – 59	29.8	Upper Secondary	17.2
60 +	18.4	University	7.4
Household average monthly income (Thai Baht)		Gender	
< 5000	6.5	Male	53.5
5000 – 9999	25.3	Female	46.5
10000 – 14999	20.6	Region	
15000 – 19999	13.8	Upper Ping	28.1
20000 – 29999	15.7	Lower Ping	21.3
30000 +	18.2	Upper Nan	40.0
		Lower Nan	10.6
Farm size (nos. cages)		Cage-culture experience (yrs)	
<= 6	28.1	<= 3	24.9
7 – 16	41.4	4 – 8	39.0
17 – 40	23.4	9 – 13	23.3
41 +	7.1	14 +	12.8

3.2 Perceptions of climate-related risks

Fish farmers were most concerned about risks to profitability from droughts or low flows in all regions (Figure 18). Heavy rainfall was of comparatively less concern than other climate-related risks in all regions.

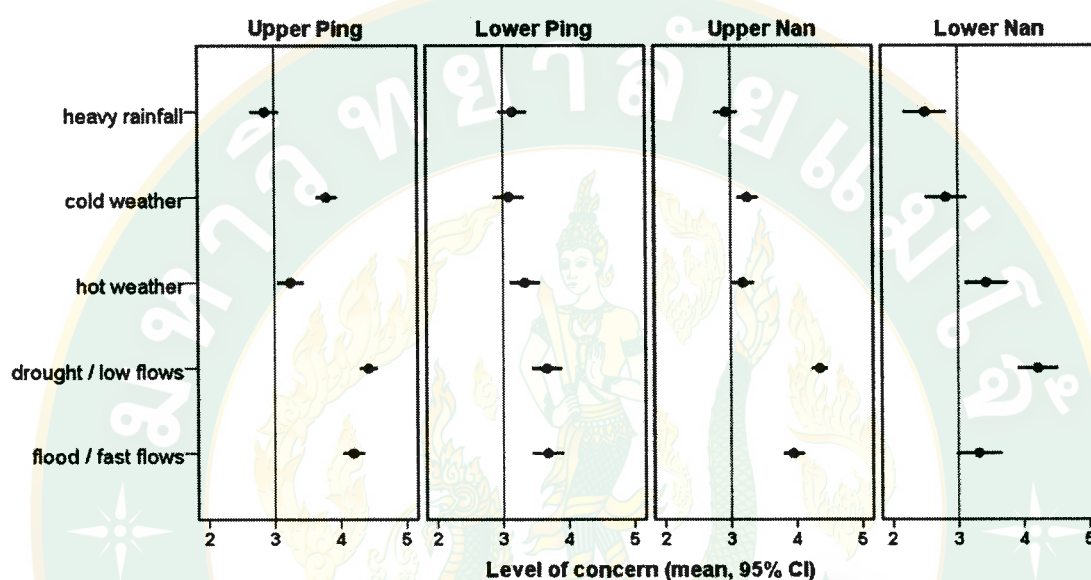


Figure 18 Level of concern of fish cage farmers over five types of climate-related risks in four regions in northern Thailand. Concern was scored on a scale of 1 (not concerned) to 5 (very concerned).

Concern with floods and cold weather was higher in the Upper Ping region than in the other two regions ($P < 0.05$, Tukey's HSD after ANOVA). Concern with drought was higher in the Upper Ping and Nan regions than in the Lower Ping. Concerns with hot weather and heavy rainfall did not differ significantly among regions.

Individual characteristics such as age, gender, education level, years of experience with cage culture, farm size and household income were also tested for each of the five climate-related risks (adjusting for region and other significant predictors where it was significant). For hot weather and high rainfall, women expressed greater concern than men.

Concern for droughts was higher in the largest farms compared to the two smallest classes. All other associations were not significant.

For both floods ($P < 0.01$) and droughts ($P < 0.001$) having experienced a recent impact from extreme high or low flow respectively, as might be expected, was associated with an increased level of concern.

Without prompting, in interviews farmers often compared the risks of floods and low flows. In Phitsanulok a farmer said *“I don’t fear floods, I fear low flow. Low flows are bad; there is no water. When it floods we can still move our floating cages”* and, similarly, in Lamphun: *“I fear drought more. With floods we still have change to prevent losses, but when there is no water we have no chance at all.”* Many other farmers also underlined their fear of droughts and low flows. In some locations, however, flow-related risks are low. Thus, a farmer in Nakhon Sawan in the Lower Ping argued that *“in this location nobody worries about choosing the right cropping periods. There are no problems with high or low flows. The river gives us no problems. People are just scared about rearing a lot of fish and then finding prices low. Nobody worries about natural conditions.”*

In a separate set of questions farmers were asked about the importance of impacts from other climate phenomena. Farmers identified sharp changes in temperature – both increases and decreases – as having the most important impacts on their fish farms (Figure 19). Rapid decrease in temperature and persistent cloud cover was more important in the Upper Ping than other regions.

Women considered rapid increases in temperature and late wet season as more important than men. Farmers with high education considered sharp decrease and increase in temperature more important than those without high education. There were no significant associations with farm size, age or experience. In in-depth interviews farmers often emphasized that rapid changes in conditions concerned them greatly: the onset of *“hot and cold weather is very fast. Factors change a lot, increasing risks we face.”* Rapid change is believed to be stressful to fish and slow growth rates or increase chances of disease.

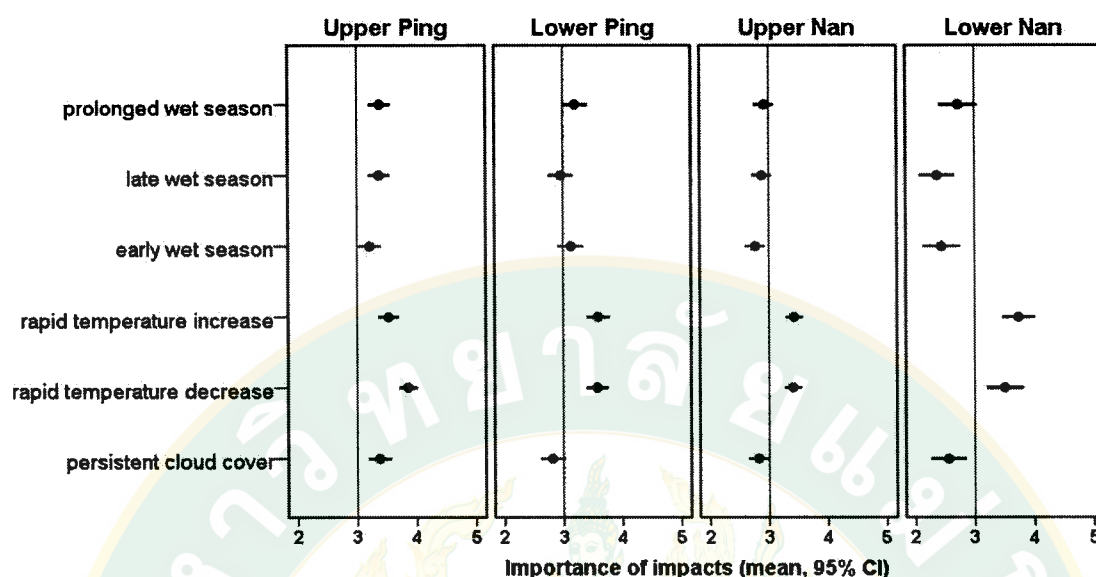


Figure 19 Level of importance fish farmers give to impacts from various climate phenomenon in three regions. Plotted symbols are means and bars 95% confidence intervals (CI) for those means. Importance of impacts scaled from 1=not important thru 3=somewhat important to 5=very important.

Northern Thailand has a seasonal climate (Table 12) implying risks should vary over the year. Farmers assessed that the months with highest risks of flood-related losses as being between August through October in all regions (Figure 20). The months with highest perceived risks from droughts or low flows, however, varied greatly among regions, reflecting the effects of river regulation. Thus, in the Upper Nan the month with highest risk from low flows is unexpectedly at the end of the wet season when Sirikit dam holds back water to allow harvests and irrigation later in the dry season. The pattern in the Lower Nan is more complex with two distinct periods of low flows depending on fish farm locations relative to Naresuan Dam and related irrigation withdrawals.

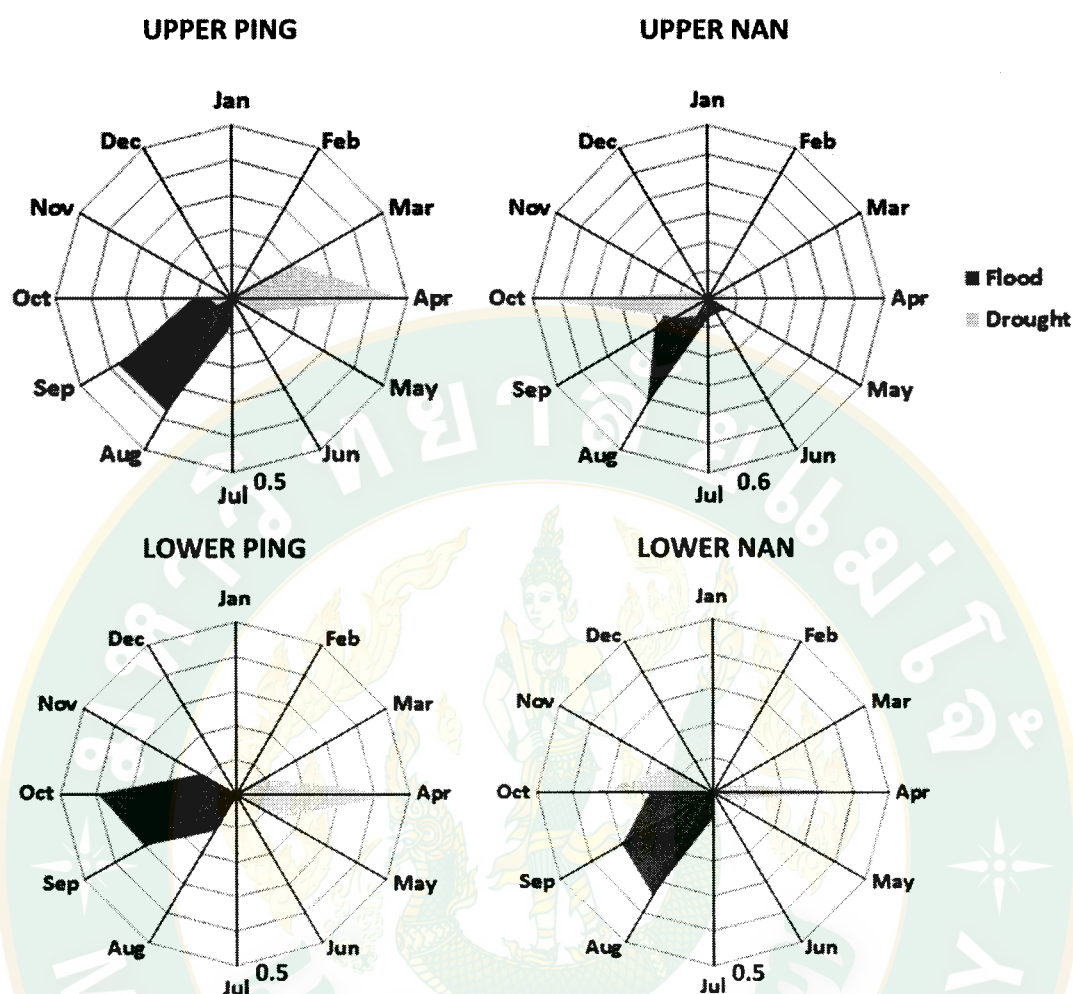


Figure 20 Months that farmers perceive pose the highest risk of flood (or high flow) and drought (or low flow) losses in four fish growing regions.

In-depth interviews gave a more detailed picture of how farmers see the river environment. An important underlying perspective of fish farmers is that rivers where they culture fish are open environments in which many factors cannot be controlled. These uncontrollable factors represent risks which cannot be avoided. Farmers understand that risk-taking is part of fish farming: *“If you want to succeed, to make a lot. Then, if only rear a little then it is not enough. You have to take risks”*. Moreover, during some periods of year with high risks of cold spells and low flows, supply is low and prices tend to be high. Farmers’ perceptions about the acceptability

of climate-related seasonal risks are modified by expectations of fish sale prices. Fisheries officials, invariably, said they would like fish farms to take fewer risks.

3.3 Imminent risks

Trust may play a role in risk perception. Some relevant evidence was available for the shorter-time frames around imminent risks. Of the 69% of fish farmers who received an early warning before the last major flood sources of information included: TV (88), community broadcasts (85), radio (72), other farmers (71), fisheries officials (62), company agents (33), other government agencies (10), and the internet (1).

Farmers were asked to indicate their overall level of trust or confidence in the warnings received on a five-point scale: 68% responded high or very high and just 4% none or low. The only source which was a useful predictor of level of trust or confidence in information was community broadcasts.

There was modest variation among regions in fraction of farmers receiving a warning: Upper Ping (78%), Lower Nan (79%), Upper Nan (68%) and Lower Ping (57%). These differences were paralleled by levels of trust if information was received. On a five point scale farmers in Upper Ping (4.22) and Lower Nan (4.24) had higher average levels of confidence in information received (if they got it) than in Lower Ping (3.85) while the Upper Nan (4.08) was intermediate and not significantly different from these two groups ($P < 0.05$, Tukey HSD after ANOVA).

Receipt of warnings, it should be noted, led to preparatory actions to reduce risks like tying up cages more firmly (96%) or moving cages towards river banks (91%), or less commonly, early harvest (35%) of their fish crop. The translation of information into perceptions, motivation and then actions underlines the significance given to early warning information by fish farmers.

3.4 Perceptions of change in floods and droughts

Farmers were asked whether there had been any noticeable changes in behaviour of floods and droughts since they started rearing fish cages. Many farmers perceived that droughts had become more frequent, intense and longer in duration than the opposite pattern

(Figure 21). Perceived changes with respect to floods were much less pronounced except in the case of flood water debris and sediments were widely seen to have increased. These patterns were evidence of changes in levels of perceived climate-related risks.

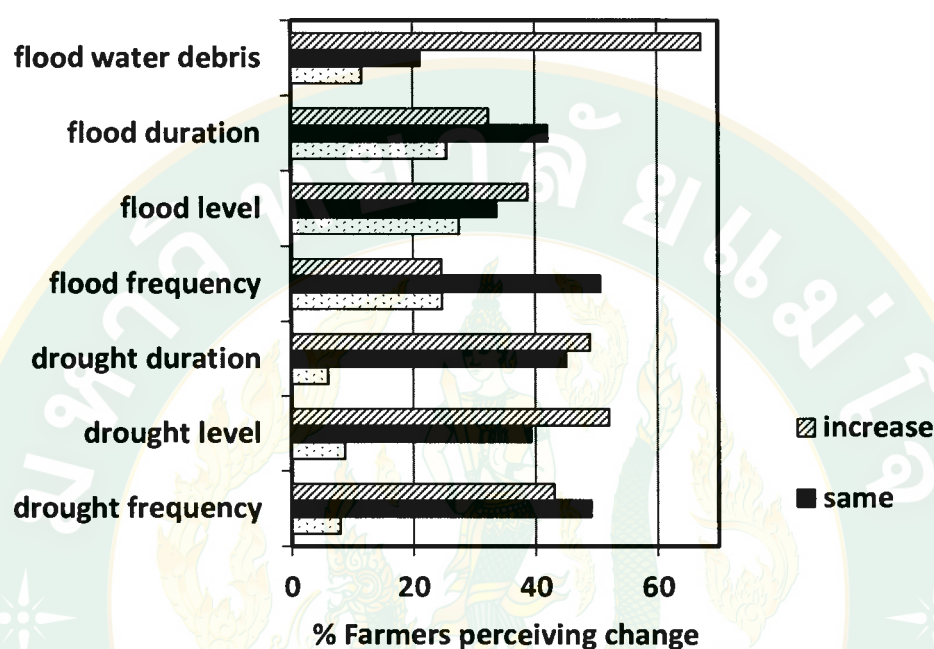


Figure 21 Perception of fish farmers on historical changes in patterns of floods and droughts across northern Thailand.

Perceiving droughts to have worsened was associated with having recently experienced negative drought impacts (OR=2.86; CI= 2.02-4.05). Farmers in the Lower Ping were less likely to perceive change than in other regions ($P<0.01$). There were no other significant associations with gender, age, education, experience, household income or farm size.

For association with perceived changes in floods, debris issues were considered separately from the other three which were combined as for droughts into a single response: worsening in any of the three dimensions. Perceiving floods to have worsened was associated with having recently experienced negative flood impacts (OR=1.82; CI=1.27-2.61) and was higher in the largest farm size group ($P<0.01$). Other associations tested were not significant.

3.5 Awareness and understanding of climate change

Most fish farmers (91.8%) had heard of global warming. Of those who have heard of global warming 87.2% agree it is already occurring and 7.1% are uncertain. Individual and site characteristics associated with awareness of climate change were explored using multivariate logistic regression (Table 14). Women (94.2%) were significantly more likely to have heard of global warming than men (89.8%). People aged over 50 years were less likely to have heard of global warming than those who were younger. Farmers in the Upper and Lower Nan were less likely to have heard of global warming than those in the Upper Ping (Table 14). Level of education was not associated with having heard of global warming. Among those who had heard about global warming knowledge came most frequently from TV (91%), radio (75%), newspapers (65%), meetings (49%) or, more rarely, the internet (26%).

Table 14 Associations of individual and site characteristics with having heard of global warming. Results of a logistic regression analysis with multiple predictors.

Predictor	Odds Ratio (95% confidence interval)
Female	2.06 (1.19, 3.77)
Older (age > 50)	0.47 (0.25, 0.86)
Region	
Upper Ping	1
Lower Ping	0.35 (0.11, 1.08)
Upper Nan	0.19 (0.07, 0.50)
Lower Nan	0.15 (1.12, 3.77)

Farmers were asked whether they agreed or not with a series of true and false statements about the impact of global warming (Table 15). Understanding of individual elements

was highest with respect to recognizing immediate issue such as agricultural impacts and less for more distant phenomena like melting of ice caps. Four false statements had lower average scores that in most cases correspond to being uncertain or disagreement – farmers could not be fooled suggesting that confirmatory bias was not large.

Table 15 Knowledge of fish farmers about impacts of climate change. Average scores on a 1-completely disagree through 3 uncertain to 5 fully agree scale. Statements with (-) indicate knowledge statements which are false.

Knowledge statements about the impact of global warming	Average score
Will have agricultural impacts	4.36
Increase climate variability	4.30
Rising temperature	4.19
More extreme floods	4.05
More severe drought	4.00
Melt polar ice-caps	3.63
Increase frequency of flooding	3.59
Reduce climate variability (-)	3.50
Decrease sea-level (-)	3.19
Increase biodiversity (-)	2.90
Reduce risks of disease (-)	2.65

Composite scores about knowledge of impacts of climate change increased significantly with level of education (Figure 22) but were not related to age, gender, income, farm size or region.

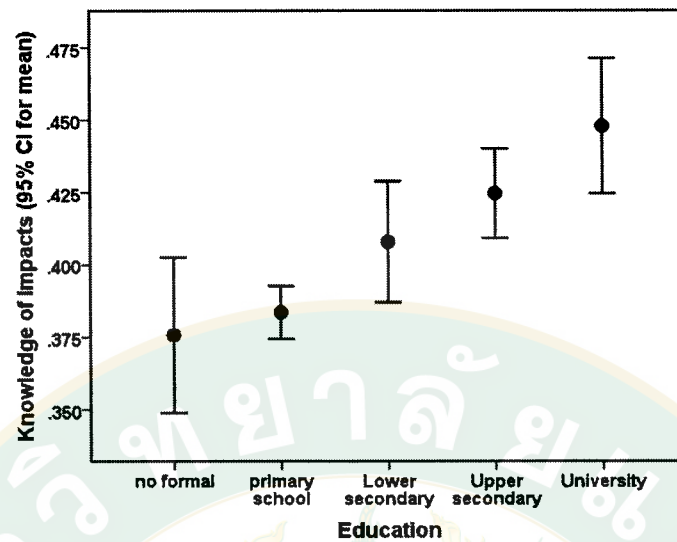


Figure 22 Association between scores on knowledge of impact scale and level of education.

Many researchers have speculated that recent negative experiences from climate extremes influence perceptions and perhaps seeking knowledge about climate change. Having been affected by floods or droughts (low flows) in the last 2 years was not associated with having heard of global warming or scores on knowledge of impact or cause scales.

3.6 Risk perceptions and climate change knowledge

Having heard of global warming or believing it has already occurred was not significantly associated with perceiving floods have worsened. Being concerned with climate change and having recently experienced negative impacts were associated with perceiving floods have worsened.

It should be noted that having perceived changes or not in flood or drought characteristics does not mean that farmers attribute differences to climate variability or change. Fish farmers who had heard of global warming but were undecided (7.1%) or disagreed it was occurring (5.7%) were considered climate change skeptics. Skeptics were not more or less likely to believe that the severity of floods or droughts has changed. In addition, there was no association between having heard of global warming, or among that sub-group a belief that global

warming had occurred already, and perceiving that droughts had become more severe on any dimension. However, individuals who were worried about climate change were also more likely to perceive that droughts had become more severe.

Farmers who overall give a high level of importance to climate-related impacts also tend to have better knowledge of climate change impacts ($r=0.18$) and causes ($r=0.15$) and are more worried about climate change ($r=0.18$, Spearman Rank Correlations, all $P<0.001$).

3.7 Perceptions of climate change and variability

As noted already, most (87%) farmers agree that global warming is occurring. Moreover, these farmers believe that global warming is increasing climate variability (97%), increasing adverse impacts on agriculture (96%) and making extreme floods more frequent (82%).

In in-depth, qualitative, interviews many farmers expressed their belief that climate and seasons have changed and have become more uncertain or variable. Increased climate variability means, overall, greater risks. A fish farmer in Chiang Mai province observed: *“It is not the same as before. Everything is warmer. Nature has changed a lot. Rain falls out of season. Cold weather comes at the wrong time. The seasons have changed.”* A farmer in Lamphun elaborated on the heat: *“The weather is not like before. Consider when it rains. Before we use to put on a sweater; now we turn on the fan or air-conditioner. It has been like this for 10 years.”* Another farmer in Phitsanulok province noted that: *“When it is hot it is very hot...In very hot weather, fish cannot survive. The change to cold weather happens very fast. When factors change a lot and quickly it increases our risks.”*

Specific patterns of change claimed by farmers and fisheries officials, however, varied substantially among individuals. In addition, it is noteworthy, that not all variability in weather is regarded as unusual or implying change: *“Sometimes the weather is hot, sometimes cold, and sometimes it rains all day. Farmers know fish won’t eat. This happens every year”*. Moreover, not all farmers were greatly concerned as this farmer in Uttaradit reflected: *“By nature if temperature gets hotter or colder or it rains. Fish can adapt. There are some losses, but not much. Farmers can adapt.”*

The need for collaboration to manage risks was emphasized by some farmers, like this one in Chiang Mai: *“If climate changes it has a lot of significant for us. We cannot fix it by ourselves. Maybe it gets hotter quickly. It is because of human activity. But cannot respond alone; everybody needs to do their bit.”*

4. Discussion

Several climate-related risks were perceived as very important by fish farmers, in particular, those which result in very high or low flows. These risks varied by seasons, among years and locations and were influenced by the operations of nearby water-related infrastructure. These findings extend and nuance findings from previous work carried out just in the Upper Ping region which identified floods and low flows as significant climate-related risks to profitability of fish farms (Chapter 3).

The direct impacts of water infrastructure on flow regimes helps explain some of the differences in findings between the current study of river-based cage culture and a related study on earthen ponds in the same general regions. Pimolrat *et al.* (2013) found that pond fish farmers in lower elevation sites were concerned more with impacts from floods and hot weather, whereas those at higher elevations were concerned more with droughts and cold weather.

Recent experience of past extreme floods or droughts, individual and site characteristics were associated with how climate-related risks are perceived. Having recently experienced negative drought or flood impacts raised the level of concern and stated importance of impacts. Impacts of floods in 2011 and drought in 2012 were large (Chapter 5).

For several individual climate risks, women were more concerned than men and more educated farmers were more concerned than less educated ones. The gender findings are consistent with a more detailed earlier study in the Upper Ping of gender-differences in division of labor and attitudes: women, for example, did relatively more feeding and taking-care of fish, whereas men did tasks requiring physical strength such as installing cages and harvesting (Lebel *et al.*, 2009). The emphasis on taking care of fish may help explain greater levels of concern about risks among women. Studies in other countries have also often found women perceive greater climate-related risks than men, for instance in Sweden (Sundblad *et al.*, 2007) and the US (McCright, 2010; Safi *et al.*, 2012).

Large farms were more concerned with drought and more likely to perceive that floods have worsened than small farms. One reason might be that a large farm implies a high concentration of cages and fish in the same area. During low flows this increases risks of water quality problems. During high flows this reduces the options for moving cages into areas with slower moving waters.

Differences among regions in how risk was perceived were common and make sense given actual river flow regimes and climates at different locations. For example, in the Upper Ping where upstream reservoirs are distant and modest in size, floods are of greater concern than in other regions with more highly regulated rivers (Figure 1). Likewise, low flows are also an important risk as discharge is extremely low towards the end of the dry season (Table 1). The Upper Ping is cooler so it was not surprising that farmers there were more concerned about sharp declines in temperature (Figure 2) and cold weather than in other regions. In the Lower Ping, where discharges are greatest and fluctuate least among seasons, fewer farmers perceived droughts to be worsening.

The perception that floods or droughts have become more severe was strongly associated with having recently experienced negative impacts from such flow-related changes. This is consistent with other research that emphasizes the importance of recent events in how people evaluate risks (Weber, 2010). To the extent that past impact reflects vulnerability, it also suggests that in this population vulnerability may be a determinant of risk perception – although such a pattern is far from universal finding (Safi *et al.*, 2012). These observations are also evidence that climate-related risks are perceived to be changing. It should be underlined that the 2011 flood, in particular, was an unusually large event.

The level of awareness of and concerns with climate change among fish farmers was high. Other recent studies have farming communities around the world in low and lower-middle income countries have made similar observations (Regassa and Stoecker, 2014). More highly educated farmers understood the consequences and impacts of climate change better, but most farmers had some basic understanding. Many farmers believed that droughts but not floods had worsened. Farmers who had perceived that droughts had worsened were also more worried about climate change. Having heard of global warming, or believing it had already occurred, however, was not associated with perceiving droughts to have worsened. This suggests

that fish farmers remain cautious about attributing flow changes solely to climate change; farmers also acknowledge, for example, the importance of dam operations and water management for flows. At the same time, evidence from in-depth interviews suggests many farmers believe they have observed significant changes in climate. This pattern is consistent with notion that farmers may be more skeptical about the implications of climate change for risks they face than whether or not climate change is occurring and attributable to human activities (Islam *et al.*, 2013).

The quantitative survey improved the understanding of how fish farmers perceive or evaluate affective risk (Sundblad *et al.*, 2007) or level of concern, but it did not adequately distinguish perceptions about the likelihood of a particular climate event from the severity of its impacts. The qualitative, in-depth, interviews helped understand how fish farmers perceive the overall risk environment, in particular, issues of lack of control – which suggest some risks cannot be avoided –and, at the same time, the market incentives to culture fish at risky times. Neither approach adequately explored the factors behind risk attitudes, such as feelings or emotions. Nor was much evidence gathered about how farmers expect climate-related risks to change in the future. Follow-up research should look more closely at these other dimensions of risk perception.

The core finding of this study is that climate-related risks are perceived as important by fish farmers. An acceptable risk is one that requires no further action; a tolerable risk is one for which further risk management is warranted (Renn and Klinke, 2012). Many of the climate-related risks identified in this study were considered very important or of serious concern to farmers, but that did not stop them from attempting to rear fish. These climate-related risks are thus still presumably at the tolerable level. Future work should focus on how farmers manage risks under current climate and how these practices may be improved. This paper focussed on climate-related risks, but in practice farmers must also deal with various financial, political and social risks. Studies of risk management in fish farms will therefore need to take into account interactions between different types of risks.

The findings of this study have implications for scholarship and practice beyond inland aquaculture in northern Thailand. First, they draw attention to climate-related risks and sensitivities in aquaculture more broadly – an agricultural activity that has often been assumed to be relatively less vulnerable to climate variability and change (De Silva and Soto,

2009). Second, the spatial and individual differences in how risks perceived and the diversity of knowledge sources used by farmers underline the need for improving how information about climate and climate-related risks is communicated (Moser, 2010a; Nerlich *et al.*, 2010). Third, in many ways household-based farms are like small firms; understanding how they perceive climate-related risks is important to developing more comprehensive effective farm risk management tools (Le *et al.*, 2012; Leppälä *et al.*, 2012). Finally, there is a need to develop approaches to study of risk perception and management which can systematically span the different time scales important for farm-firm decision-making: starting with imminent events, through dealing with seasonal varying risks of extreme conditions, to multi-year strategies to develop resilient farm enterprises.

5. Conclusion

Recent experience of past extreme flood or drought events, individual and site characteristics are associated with how climate-related risks are perceived. Having recently experienced negative drought or flood impacts raised the level of concern and stated importance of impacts. Differences among sites in how risk was perceived were common and fit well with understanding of actual river flow regimes and climates at the different locations. Level of awareness of climate change among fish farmers was reasonably high, but more highly educated farmers understand consequences and impacts of climate change better. The quantitative survey improved understanding of how fish farmers perceive specific risks; the in-depth interviews gave a more detailed picture of how farmers perceive the river environment. Climate-related risks were seen as important by fish farmers. Future work should focus on how farmers manage risks under current climate and how these practices may be improved to deal with current as well as uncertain and shifting risks arising from climate change.

CHAPTER 7

CLIMATE RISK MANAGEMENT IN RIVER-BASED TILAPIA CAGE CULTURE IN NORTHERN THAILAND

1. Introduction

Climate risk management usually refers to the short-term management of risks (and opportunities) associated with extreme weather and climatic events, seasons and inter-annual climate variability (Patt, 2013). Individuals, it is recognized, differ in their perceptions, tolerances and attitudes towards climate risks (Nielsen *et al.*, 2013). They also have different levels of experience with past extreme events and long-term observations of change in a particular place. Local capacities and knowledge about how to adapt may also differ (Lebel, 2013). All these factors can all influence risk management practices (Menapace *et al.*, 2013).

Moreover, climate risks are not experienced in isolation from other risks (O'Brien and Leichenko, 2000; Mubaya *et al.*, 2012). The impacts of a drought for example are much worse if it coincides with market conditions in which imported food and fuel prices were high. Thus, effective risk management often requires management practices that can deal simultaneously with several risks.

Learning how to better manage risks under current climate should also be helpful for adapting to a changing climate, but may not be sufficient. Risk management approaches for the longer-term management of risks associated with climate change must also deal with the significant uncertainties, for instance, about the likelihood of events of a specific magnitude or impacts if that event would occur (Kunreuther *et al.*, 2013). As climate change becomes more severe, more transformative responses may be needed (Howden *et al.*, 2007).

In commercial aquaculture farmers must manage a complex set of risks to profitability of their production systems. Salmon farmers in Norway rated the most important sources of risk as future prices, diseases and institutional changes (Bergfjord, 2009). Keeping costs low was seen as the most important risk management tool. Catfish farmers in Vietnam also perceive price and production risks as the most important, but focus their risk management strategies on production factors only (Le and Cheong, 2010). Shrimp farmers in Bangladesh

perceive the largest risks being disease, price, and availability of quality stock (Ahsan, 2011). In response, however, the only market-related strategy they considered was bypassing middlemen. Mussel farmers in Denmark were worried most about future prices and government regulations (Ahsan and Roth, 2010); their prioritized risk management practices focussed on reducing production costs, cooperative marketing and maintaining good relations with government which corresponds well to the risks actually faced.

Climate-related risks have been investigated much less than financial and market-related risks to aquaculture businesses. Flood- and drought-related risks were noted in the catfish study in Vietnam, but scored very low compared to other risks (Le and Cheong, 2010). Mussel farmers mention bad weather as important risk because it interrupts work or makes it unsafe. Extreme weather, like flooding, droughts, and storms adversely effects catfish farms in the US, but to a lesser extent than losses caused by diseases (Hanson *et al.*, 2008).

Farmers in northern Thailand rear Tilapia and other species in open-top mesh cages on floating platforms in rivers. The cages are typically around 4mx4m in areas and 2m deep (Chapter 3). Fish that have been reared in tanks or ponds for 2-3 months are released into river cages to be reared for a further 3-5 months until they reach the market standard size of at least 500 g fish⁻¹. Fish farmers face a complex set of risks to the profitability of their production system. Floods and low flows, in some years, have particularly large impacts (Chapter 5). Climate-related risks are perceived as important by farmers and are affected by experience of past events, site and individual characteristics (Chapter 6). The purpose of this paper is to analyse how fish farmers manage climate-related risks and explore possible ways to strengthen risk management under current and future climate. It is one of the first papers to report in detail on how fish farms in rivers manage climate-related risks.

2. Materials and methods

2.1 Study region

This study was carried out in two rivers in northern Thailand where river-based cage aquaculture is common. Sites were grouped by provinces into three growing regions (Figure 23) for analysis: Upper Ping (Chiang Mai and Lamphun), Nan (Uttaradit, Phitsanalok and Pichit) and Lower Ping (Kamphengphet, Tak, and Nakon-sawan).

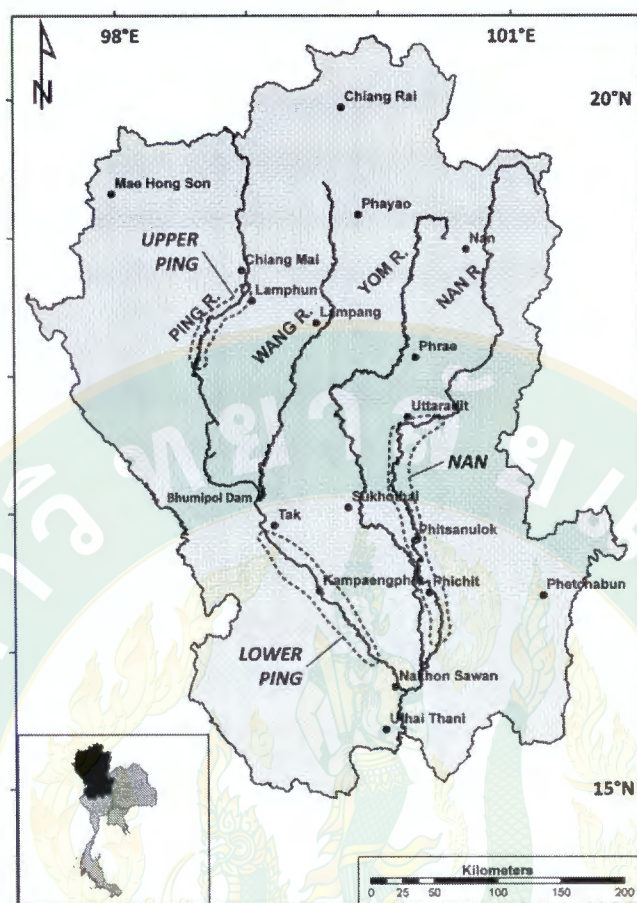


Figure 23 Map of northern Thailand showing fish farming regions considered in this paper.

The climate of these three regions differs modestly, providing insights into the possible consequences of future climate shifts. The rivers have contrasting flow regimes as a result of dam regulation which provides another natural experiment for understanding potential flow-related climate changes (Chapter 5). Fish farming regions in the Nan River are downstream from the very large Sirikit Dam which results inversion of natural peak-low flow regime providing a sharp contrast to the Upper Ping River which has much smaller weirs and dams upstream that have very modest influences on flows where fish farms are situated (Figure 24). Sites in the lower part of the river system have many tributary influences that again tend to even out and shifted seasonally by a month or two from those further north (Chapter 5).



Figure 24 Climate risk management practices: (A) Moving cages into deeper, dredged channels in the Nan River; (B) Interviewing fish farmers about management of climate-related risks; (C) Use of paddle-wheels to improve water circulation and increase dissolved oxygen levels during low flows; (D) Early harvest of fish impacted by extreme flow conditions.

2.2 Interview

A total of 662 fish farmers currently or recently having reared tilapia (red hybrid or black Nile) in cages in the rivers in the northern region of Thailand were interviewed between 9 October 2012 and 21 March 2013. Just over half (54%) were male and two-thirds (65%) had only completed primary school level education. In all cases the informant was the owner, investor or caretaker and in most had all three roles. The structured questionnaire covered individual, farm and site level characteristics as well as more detailed sections about risks to the profitability of their fish farm enterprise and ways such risks could be managed. Questions about

types of risks and their management were initially identified through in-depth interviews and refined following pre-testing of the survey instrument.

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

In-depth interviews around more open-ended questions were carried out with fish farmers (36), company officials (2), department of fisheries officials (18), officials from other departments (3), local government (4) and university academics (5). Informants were purposively selected to provide a diversity of views on the issues being investigated and thus included men and women, small and larger farms, and officials working in sites with different water and fish farming conditions. The interviews were used to help cross-validate findings from the quantitative survey as well as identify less common practices and improve understanding of the reasoning of stakeholders around risk management issues. All interviews were taped, fully transcribed and coded in NVIVO software prior to analysis. The analysis in this paper focuses on statements related to the management of risks.

2.3 Data analysis

Average scores for levels of concern for different risk factors were compared among farm sizes and regions using ANOVA followed by Tukey's HSD. All statements about differences among places or farm size made in the results section were significant at $P < 0.05$; details from ANOVA statistics, however, are only shown in a few instances so as not to disrupt readability. Farm sizes were classified by number of cages into 4 groups: small (≤ 6), medium

(7-16), large (17-40), and very large (41+). Regions were defined as explained above in section 2.1.

Canonical correlation analysis approach was chosen because it fitted the problem structure of understanding associations between four sets of variables: climate-related risks, non-climate related risks, farm level risk management practices, and river and watershed level management practices. The list of variables used in the analysis is given in Appendix A. Non-linear canonical correlation analysis was chosen over conventional canonical correlation analysis because all variables were measured on 5-point ordinal Likert scales and because assumptions of interval scale or multivariate normality were unlikely to be upheld. The main product of the analysis is to identify a set of canonical functions that maximizes the correlation between the four sets of variable. The analysis was carried out using the OVERALS procedure in the statistical software SPSS (Meulman and Heiser, 2011).

3. Results

3.1 Sources of risk

Farmers identified disease outbreaks as the overall most worrisome risk to profitability (Figure 25). Prices of feed and fish as well as quality of stock and feed were other risks of high concern. Farmers were relatively unconcerned about financial risks such as interest rates or repaying loans and market risks like demand or finding buyers. Among climate-related risks droughts or low flows were ranked highest followed by floods or fast flows.

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

Levels of risks also varied among regions. There were two main patterns. First, farmers in the Upper Ping region were more concerned than those in Nan or Lower Ping about floods/fast flows, polluted water, cold weather, persistent cloud cover, rapid temperature decreases, late wet season, and low fish prices. Second, farmers in the Lower Ping were less concerned than those in Nan or Upper Ping about repaying loans, interest rates, government regulation or drought.

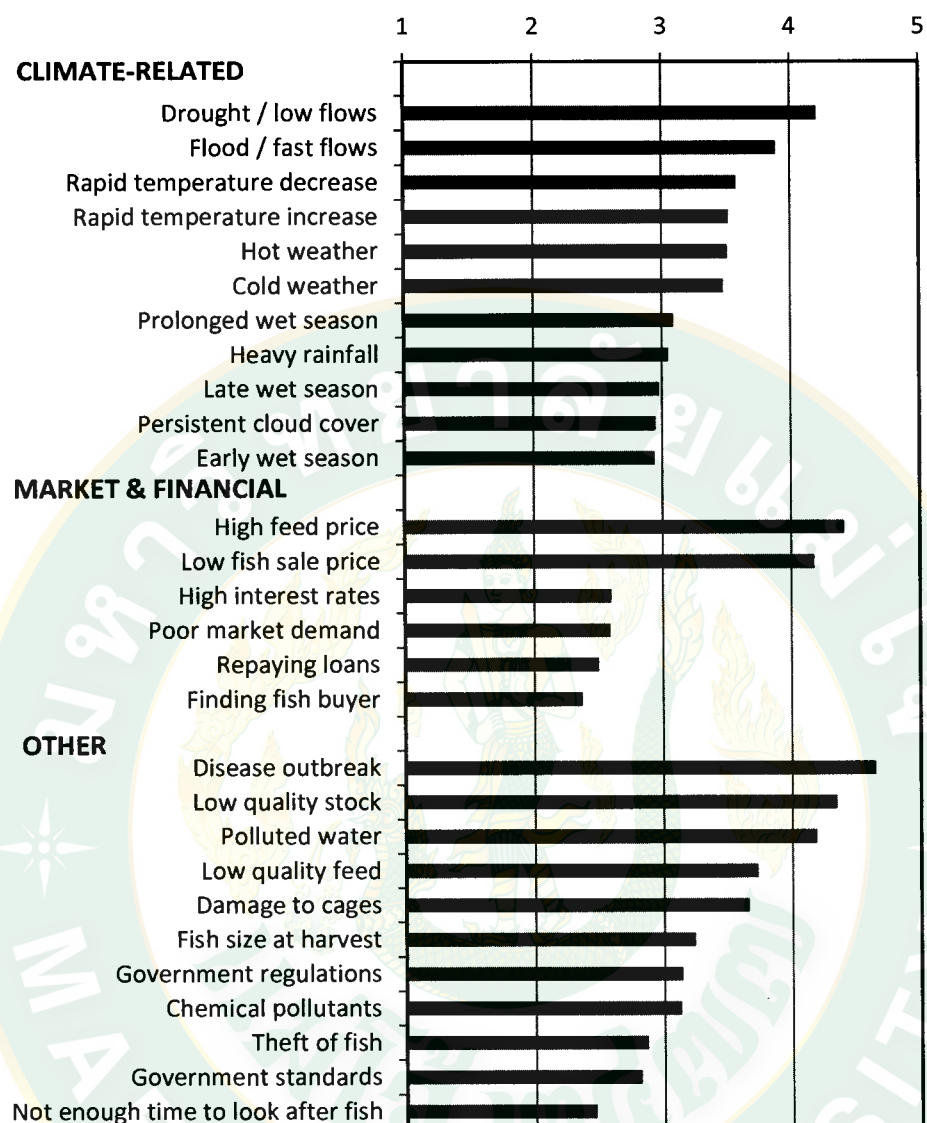


Figure 25 Level of concern about different types of risks to farm profitability. Averages scores of 662 fish farmers on a scale of 1 (unconcerned) to 5 (very concerned).

3.2 Farm-level management of climate-related risks

Farmers gave high importance to a mixture of technical, business and social risk management practices (Figure 26). High scoring technical practices included choice of stock, quality of feed and cage site selection. Important business practices included keeping money in

reserve, reducing expenses. Three of the top six practices were related to maintaining good social relations: with neighbours, fisheries staff or local government officials. Many other practices also were thought of as being of intermediate importance. Collaboration with other farmers to borrow money, purchase inputs, or sell harvest was among the lowest ranks, underlining the individual enterprise basis of this industry.

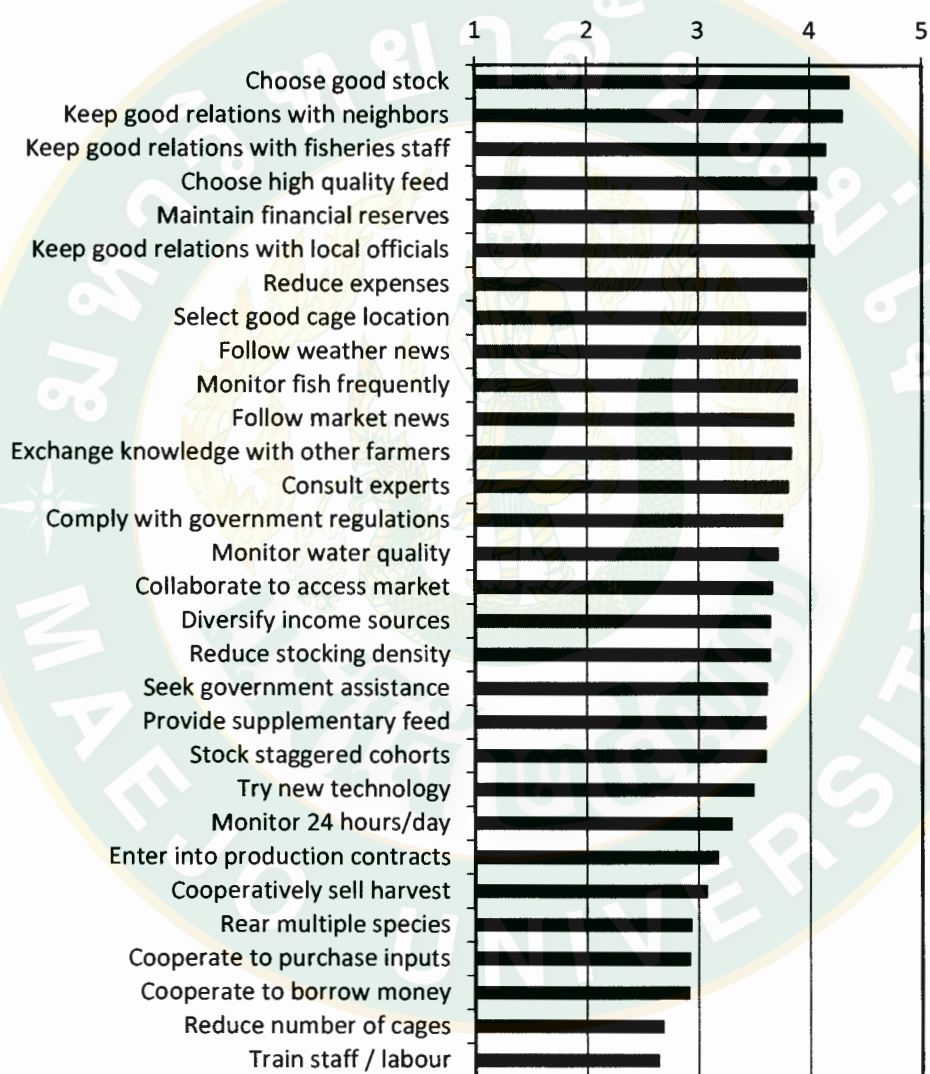


Figure 26 Level of importance given to different farm level risk management practices. Averages scores of 662 fish farmers on a scale of 1 (unimportant) to 5 (very important).

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

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

Active management or 'taking care' of fish was emphasized by many farmers as key to dealing with change and uncertainty: *"Farmers need to have their own management system because everything seems to change. Nothing is the same. Sooner or later the flood waters come; this year a lot or less rainfall. Either way you have to take good care."* Moreover, *"if we take good care – I mean really good care to look after and protect them that will help a lot."* And: *"It is all about taking care – there is being industrious and being lazy."*

A few farmers have tried switching species as a way to manage climate-related risks. Most shifted to catfish species which could tolerate low dissolved oxygen levels and less susceptible to scale damage in higher flows. The channel catfish is popular but has the constraint that it takes 18-24 months to rear and as production increased prices have fallen.

Initial choice of site for cages is an important element of risk management (Figure 26). Farmers look for a site where there is good circulation but current is not too strong. Farmers note that river bends are favourable as they allow moving cages out of strong currents during flood periods: *"strong or fast flows, if we choose a good site, then a lot of risks can be reduced."* River depth should be sufficient that water may flow freely under bottom of cages – ideally at least 2.5-3m. Position relative to dams and weirs are thus important considerations. In practice farmers may have relatively few options near where they live and given existing water and river uses: *"if a site is good, there are few problems. But our chances to select a good site are limited. Water around here is stagnant. We have no choice because available sites are limited."* A few farmers moved to sites at new locations after experiencing difficulties.

Timing of crops is an important decision. Risk-averse farmers in the Upper and Lower Ping, for instance, avoid having fish in the river during August-September when flows are strongest and around April when flows are lowest (Chapter 5). River and site differences, however, are substantial: thus, in some places concerns are higher for floods than low flows and in others the opposite. In interviews farmers and fisheries officials explained that some farmers are willing to grow fish at time when risks from weather and climate are relatively high because these are also the times when market supplies compared to demand are low and prices for fish are high. Others, however, emphasize the lack of alternatives.

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

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

3.3 River basin management

At the river reach and basin level farmers identified the storage and release of water from dams as the most important risk management practices (Figure 27). These were more important in the Nan than in the Upper Ping Region. Operation of weirs and sluice gets, on the

other hand, were more important in the Upper Ping than Nan region. Very large farms gave greater importance to dam water release and storage than small farms. Average levels of importance given to river basin level risks (Figure 4) were comparable to those for individual farms (Figure 26).

Interactions among water users, irrigation water use, urban-industrial water use, and participation in water management were all considered more important in the Upper Ping than in the Lower Ping. Management of run-off from farms, orchards and livestock rearing was also emphasized more in the Upper Ping than in other regions. Piggeries were identified as a particularly important source of pollution by farmers and experts in in-depth interviews. Concerns with boating were relatively low everywhere (Figure 27).

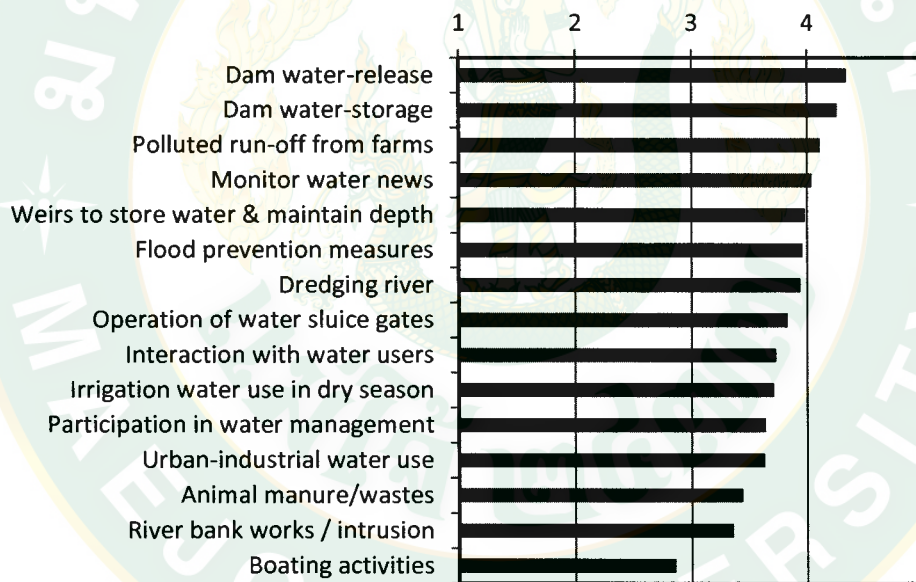


Figure 27 Level of importance given to different river reach or basin level risk management practices. Averages scores of 662 fish farmers on a scale of 1 (unimportant) to 5 (very important).

Farmers recognize that many risks influencing their farms profitability lay beyond their direct control in the sense of actions they can take in their own set of cages. In lieu of such challenges farmers give substantial weight to both watershed and river management as

ways to manage risks to fish farms. The operations of dams, weirs and sluice gates all have significant implications for fish farms. For the most part the Irrigation Department, however, does not see fish cage culture as either part of the river ecosystem or an agricultural activity.

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

Small, local check dams or weirs are under community or local irrigation office control. These are particularly important in the Upper Ping sites studied as they help maintain depths during periods of low flows where fish are grown. Exchange of information within communities about water management is important to risk management, for instance, about the schedule for opening and closing water gates. The high-level of importance given to maintaining good relations (Figure 26) while important for individual farm-oriented practices is also useful to addressing reach and watershed level management issues.

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

3.4 Early warning, event preparation and compensation

Farmers were slightly more likely to receive flood early warnings in the Upper Ping (78%) than in Nan (70%) or Lower Ping (57%) region. Farmers received warning

information from multiple sources, the most common being: TV (88%), community broadcasts (85%), radio (72%), other farmers (71%), and fisheries officials (62%). Two-thirds of farmers indicated they had high trust in the warnings and only 4% had little or no trust. Early warning triggered additional preparations. Farmers moved cages towards banks (91%) and into slower flowing areas (83%) and tied up cages more firmly (96%). Virtually all increased their monitoring activities (97%). Over a third (35%) harvested fish earlier than they initially had planned. In 7% of cases farmers moved fish from cages to a pond. About a third of fish cage farmers in Nan and Lower Ping regions also had fish ponds.

Seeking compensation was one of the few post-event strategies this study (with its focus on ex-ante risk reduction) explored. Farmers in the Upper Ping (20%) were less likely to have received assistance after floods than those in the Nan (64%) and Lower Ping (62%) regions. Assistance was usually in the form of cash (88%), and more rarely as fish stock (22%) or feed (12%). Farmers estimated the average value of this assistance at 19,450 Baht representing a quarter to one third of the average value of reported losses (Chapter 5). The most common source of assistance was the Department of Fisheries (85%) followed by local government or Sub-district Administrative Organizations (19%). According to regulation of the DOF, only farmers who have registered their fish farms with the DOF and did not stock their fish during the flood and drought warning period can get assistance. Officials from the department of fisheries issue warnings that farmers should not rear fish in low flow risk period in the dry season (March-April) as well as flood risk period in the wet season (August-September). It was not entirely clear if this 'no eligibility' periods were strictly enforced or varied according to differences in local flow regimes. Financial assistance, according to interviews with a Fishery Department official was provided at rate of around 270 baht per square metre.

3.5 Risks and management practices

Associations between four sets of variables describing different climate-related risks (n=11), non-climate risks (n=17), farm-level risk management (n=32), and reach or basin level risk management practices (n=15) were studied using nonlinear canonical correlations analysis. A model with six dimensions was chosen after also considering models with 4 or 5 which proved much more difficult to interpret because of unusual variable combinations.

Eigenvalues for each dimension were: 0.68, 0.60, 0.52, 0.48, 0.47, 0.44. The overall fit, estimated from sum of six eigenvalues was 2.8/6 or 47% which is reasonable given type of data involved, but also underlines that a lot of variation remains unexplained.

The results of the analysis are summarized by identifying the most significant correlations (or loadings) between original variables and the canonical functions and then offering interpretations for these combinations of co-varying variables or the canonical functions (see Appendix A). This will be done function-by-function.

Canonical function 1 describes overall concern with risks and attention given to risk management practices: all variables show correlations in same direction. All of the climate-related risk loadings were high; many of the non-climate related risks and management practices were also high. The implication is that some fish farmers worry more about risks and take steps to deal with those risks, whereas others are less concerned and therefore do less to manage risks.

The second canonical function describes risks associated with the approach of the wet season or pre-monsoon transition: climate conditions with cold weather, rapid temperature increases and late start of the wet season are contrasted with heavy rainfall or the wet season. Stocking management practices were associated with these climate risks including: choosing good stock, stocking staggered cohorts, and rearing multiple species. Farmers also tended to try new technology. Management of risks at the basin level included dam water storage, weirs to store water, water gate operations, urban-industrial water use, and river bank works. A non-climate risk was government regulations on river user. In response farmers comply with regulations, and maintain good relations with neighbours, local officials and fisheries staff. They also train staff. Risks from government practice standards and finding a fish buyer were associated with reducing number of cages.

The third canonical function describes a specific set of conditions which can arise early in wet season when flows are low but temperatures are high and contrasts this with when wet season is early. Under the former conditions there are risks of poor water quality from wastewater and chemical use. This is an example of interacting climatic and non-climatic risk. The favoured responses to manage these risks are to monitor water quality, control polluted run-off from farms, adjust operations of sluice gates, and interact with water user groups. The early

wet season risk was associated with following market news, keeping good relations with local officials and fisheries staff and flood prevention measures.

The fourth canonical function corresponds to flood or high flow conditions. This was associated with non-climatic risk of low quality stock. The associated risk management practices included: choose good stock, reduce stocking density, exchange knowledge with other farmers, reduce investment costs, manage weirs to maintain depth, and flood prevention measures.

The fifth canonical function relates to periods with drought or low flow conditions and is contrasted to conditions when have early wet season. Disease outbreaks were associated with low flow risks, while risks from chemical use and small size at harvest with early wet season. The risk management practices were to reduce expenses and dredge the river.

The sixth canonical function captures the end of wet season when temperatures decrease quickly and is contrasted with low flow conditions when farmers are worried will not have enough time to look after fish. Risks associated with temperature drops are managed by following weather news and exchanging knowledge with other farmers. The low flow conditions are best managed through dam water storage and release.

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

3.6 Risk management and adaptation

Fish farmers were asked in surveys and in-depth interviews whether they agreed with various ways to adapt to a changing climate. Farmers showed relatively uniformly high levels of agreement with a set of 8 statements about adapting fish farming to climate change (Figure 28). There were no differences among regions. Very large farms agreed more strongly than smaller farms on need to plan for the future, know future climate, know impacts of climate

change, and cope with current climate. They tended to be less likely to agree on the need to diversify livelihoods, whereas small farms emphasized this strategy more.

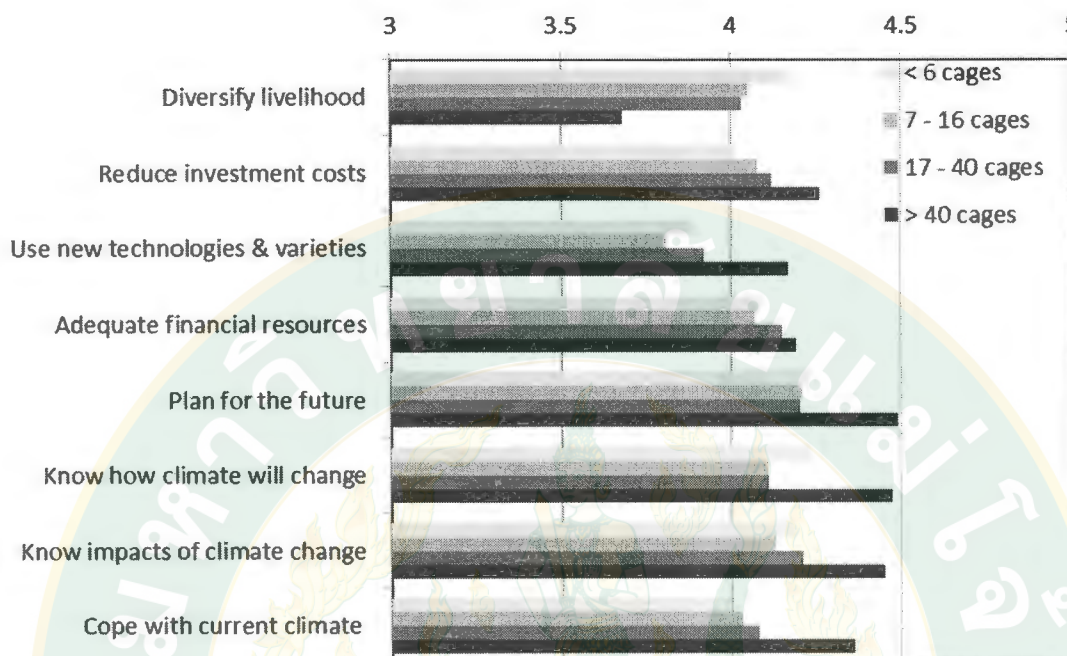


Figure 28 Level of agreement with various statements about adapting fish farming to climate change. Averages scores of 662 fish farmers on a scale of 1 (disagree completely) to 5 (fully agree).

To explore the association between climate risk management practices and adaptation attitudes, three aggregate variables with average score were created for farm-level practices ($n=32$ variables, Figure 26), river-level practices ($n=15$, Figure 27), and adaptation attitudes ($n=8$, Figure 28). Adaptation attitude scores were then regressed against the farm- and river-level risk management practice variables with a few other selected predictors. Region was included in the model as a possible confounding variable given risks vary geographically; farm size was considered, but dropped because it was not significant. Measures of knowledge of impacts and causes were also included because they are important to how climate change related risks are perceived (Chapter 6). All variables were significant in the final model. A high attention

to farm- and river-level risk management practices was strongly positively associated with agreeing on multiple adaptation strategies (ANOVA; d.f.=6, 599; $F=44.8$, $P<0.001$).

4. Discussion

At the individual farm level farmers gave high importance to a mixture of technical, business and social risk management practices. Climate- and weather-related risks are managed alongside other risks. An important finding of this study was that individual risks are addressed by multiple practices and particular practices contribute to management of multiple risks. Supporting evidence come from the patterns of association revealed in non-linear multivariate canonical correlation. Qualitative data provided some additional support when farmers explained how they managed multiple risks at the same time. Farmers also recognize that risks interact: the effect of climate on profitability depends on things like interest rates and market prices for harvested fish. Reducing risks may need to take into account more than one source of risk.

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

Farmers focus on managing those risk which can be managed. The persistence of fish farmers in the face of occasional losses improves understanding of how farmers think about acceptable risk, in particular, for those sources of risk for which they have only modest or no control. Compensation for loss and damages arising from extreme events represents an important type of post-event risk management that complements the many ex-ante strategies explored in more detail in this study.

In this study some expert and government stakeholders believe that the objective should be to minimize risks from extreme flows and climate by avoiding rearing fish at

high risk times. This is incomplete reasoning, as farmers' are quick to point out as this may also be times when prices are highest. Up to a threshold level risks may be acceptable; risk management and adaptation is needed when those levels are likely to be exceeded (Jones, 2001). Risk management should not be equated to risk avoidance or elimination.

Previous studies on the management of risks in aquaculture have often not considered climate-related risks in much detail. This is likely to change given increasing concerns with climate changes and its influence on water resources. The findings of this study strongly suggest that even in the absence of climate change, climate-related risks are an important set of considerations to aquaculture, and, in particular, flow-related disturbances, for culture systems in rivers.

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

Despite these limitations, this study shows that understanding of climate-risk management practices under current climate provides some important insights for developing longer-term strategies to adapt to a changing climate in the aquaculture sector. First, our findings underline the need to think of strategies at multiple scales: spatially, from farm through reach or local community to the whole of watershed or river basin; and temporally, from within season, among season and inter-annual phenomena (Table 16). There is a need to go beyond the conventional focus on early warning, site selection, farming techniques and avoiding risky times. Greater attention needs to be given to the aquaculture stake in river basin management.

Table 16 Time and space scales of risk management practices relevant to adaptation.

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

Maintaining reasonable water quality and flow conditions and thus viable freshwater ecosystems is very much in the interests of aquaculture farms sensitive to flow and quality. Building resilience of aquaculture through more sustainable farm level practices and improving river ecosystem health would have multiple benefits for adaptation to climate change. This is a multi-scale response.

Second, our findings emphasize the value of simultaneously considering multiple risks. Fish farmers do not manage climate-related risks in isolation from supply, financial or institutional ones. Information is important to making good risk decisions, for example, about stocking calendar, given patterns in fish prices and likelihoods of climatic and flow risks. Different kinds of risks need to be evaluated jointly. At the moment there is very little decision-support available for farmers apart from their social networks. Diseases and how to manage them are not very well understood. Insurance, perhaps weather or flow-indexed, should be investigated to help deal with unavoidable losses following particularly extreme events, without penalizing farmers who adopt better practices or creating incentives for unwise risk-taking. Trustworthy information could help farmers make better stocking calendar decisions. Early warning systems with respect to floods, for instance, are already largely in place and make a valuable contribution to reducing losses. Much less effort so far has been given to anticipating the severity of dry season and thus low flow conditions.

Third, our findings underline the relevance of a climate risk management approach. Farmers strongly agreed that reducing risks under current climate was an important strategy for dealing with climate change (Figure 28). This is an important foundation from which to deal more explicitly with challenges created by a changing and uncertain climate. Fish farmers have a reasonably good understanding of climate change (Chapter 6). It is noteworthy that fish farmers already place a high priority on monitoring activities, following-up information sources and social relations. These are important pre-requisites for learning about change. Fish farmers also emphasize the need to know how climate will change and what impacts it will have (Figure 28) but it was less clear that the high levels of uncertainty around future climate change are fully appreciated. More engagement with farmers and other stakeholders is needed to communicate these uncertainties and address the challenges which arise for practice and policy with more severe climate change.

5. Conclusion

This is one of the first papers to report in detail on how inland fish farmers manage climate-related risks. It shows that they use a combination of adjustments to rearing practices, cropping calendars, as well as financial and social measures to manage those risks which they perceive as being manageable. Some other risks are tolerated or understood to require longer-term and indirect actions to influence water and watershed management at higher spatial levels. Many risks are both season and river- or place-specific meaning that the risk profiles of individual farms can vary substantially. A key finding of this study is that individual risks are often addressed through multiple practices and strategies and that a particular practice can have a bearing on several different risks. This is significant for considering adaptation as it underlines the need to consider multiple spatial and temporal scales as well as fact that farmers do not manage individual climate-related risk in isolation from other risks.

CHAPTER 8

LEARNING ABOUT CLIMATE-RELATED RISKS: DECISIONS OF FISH FARMERS IN A ROLE-PLAYING SIMULATION GAME

1. Introduction

Farmers must often make decisions about their crops with only limited information about the probability and consequences of particular types of extreme weather events, seasonal patterns or change in climate (Crane *et al.*, 2010; Wood *et al.*, 2014). Under these conditions farmers may learn about risks through experience or description, that is, information provided by others (Dutt and Gonzalez, 2012a). Risk refers to uncertainty about the likelihood and consequences of an event with respect to something humans value (Aven and Renn, 2009). Perceptions of climate-related risks are affected by personal experiences of weather and observations of impacts and thus often differ regionally (Manandhar *et al.*, 2011; Higginbotham *et al.*, 2014).

In practice, learning from experience is a dynamic task as key decision conditions change as a result of both external factors and past decisions (Lejarraga *et al.*, 2010). Learning from experience, individuals may be able to improve their decisions with time, for example, by getting a better understanding of likelihoods or outcomes (Erev *et al.*, 2010). Many studies suggest that people are often more strongly influenced by what they learn from experience than from descriptions that require analysis and cognitive effort (Weber, 2010; Dutt and Gonzalez, 2012b). There are also important limitations from learning from experience. People tend to overestimate likelihoods of conspicuous and recent events, but also deny extremely negative outcomes (Ogurtsov *et al.*, 2008). Uncertainty influences what can be known about risks. Farmers often are highly sensitive to ambiguity in risks, in addition to generally being risk averse (Alpizar *et al.*, 2011b; Engle-Warnick *et al.*, 2011).

Risk decisions are influenced by an individual's risk knowledge, and the situation in which a decision is made (Figure 29). Risk taking may also depend, for example, on whether or not a farmer is already in debt or they have just suffered a major loss or have accumulated profits (Jakobsen, 2013). For example, Italian apple growers who have experienced

greater losses to weather events in past seasons perceive risks for current growing season to be higher (Menapace *et al.*, 2013). Perceptions and subjective beliefs are also likely to influence evaluation of probabilities of adverse events, and, more broadly, attitudes towards risk, and thus decisions (Breakwell, 2010). Gender and other traits are often associated with risk attitudes, perceptions and decisions (Figner and Weber, 2011). Women, typically, are found to be more concerned with risks, at least in part because they are also more vulnerable (Breakwell, 2010). Emotions, such as fear or dread, have also been shown to play a significant role in decisions about risk (Slovic *et al.*, 2004; Sjöberg, 2007).

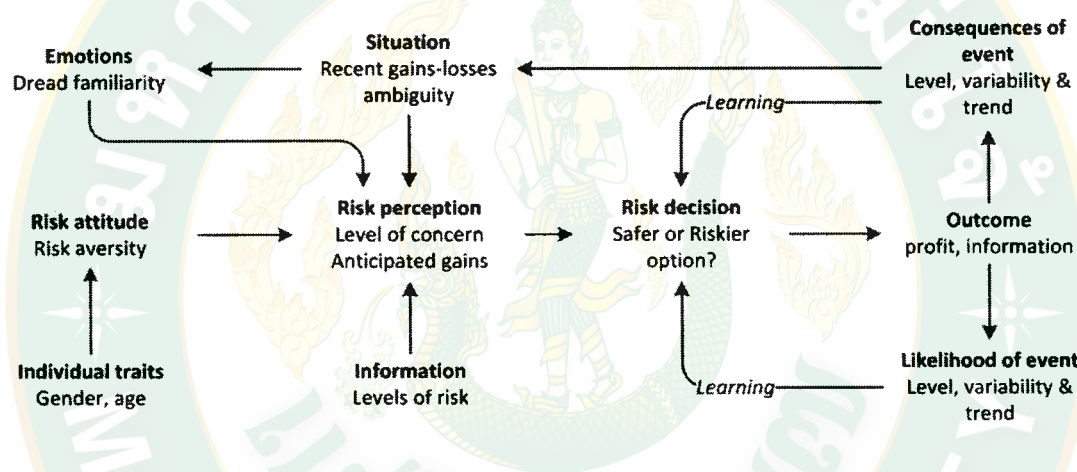


Figure 29 Conceptual framework for learning about climate-related risks and making decisions.

Only a few studies have looked closely at risk perceptions and decisions in aquaculture. Salmon farmers in Norway rated the most important sources of risk as future prices, diseases and institutional changes (Bergfjord, 2009). Similarly, mussel farmers in Denmark were most concerned about risks related to prices and government regulations (Ahsan and Roth, 2010). Catfish farmers in Vietnam (Le and Cheong, 2010) and the US (Hanson *et al.*, 2008), perceive price and production risks, from disease as more important than those related to weather. Tilapia farmers in the central region of Thailand rate risks of disease outbreaks and water pollution highest and noted these risks appear to vary seasonally (Belton *et al.*, 2009). A modeling study showed that profits from rearing shrimp in Mexico can be increased by adjusting stocking

densities to match differences in risks related to uncertainty in temperatures in different seasons (Villanueva *et al.*, 2013). Thus, while there is increasing understanding of which risks are perceived as important in aquaculture, less attention has been given to risk decisions.

The purpose of this study was to improve understanding of how fish farmers in northern Thailand make cage stocking decisions when faced with risks that are imperfectly known and which may be changing. River-based cage aquaculture involves dealing with a number of climate- and weather-related risks. Fish farmers, for example, make decisions about when to stock fish into cages and at what density. In making these decisions they must take into consideration the likelihood of losses due to floods or low flows as well as seasonal differences in temperature which influence growth rates and likely prices at time of harvest and other factors. Information about future conditions is imperfect and farmers vary in how much prior past experience they have which they can draw upon on to evaluate likelihoods and consequences of adverse events like floods (Chapter 5). When farmers move cages to a new location, for instance, they have much less specific experience about possible conditions than for site they have used for a decade or more. Differences in location, both at regional and more local scales, influence exposure and contribute to differences in perceptions about the importance of various climate and non-climate related risks (Chapter 6).

A role-playing simulation game was created to capture some of the key features of the decision-making context and explored with farmers in the field. Role playing games have been used for teaching and helping stakeholders understanding water and land management challenges (Worrapimphong *et al.*, 2010; Hoekstra, 2012). Simple, interactive, games improve understanding of risks (Ancker *et al.*, 2011) and in the case of climate change were more effective than just providing descriptive material (Dutt and Gonzalez, 2012a). To keep things simple in this study the focus was just on one key decision – initial stocking density – which farmers widely report is a factor which they manipulate to manage risks from floods and is closely related to level of investment in a particular crop.

The specific research questions addressed in this study were as follows: (1) How do farmers evaluate levels of risk, including likelihoods and impacts, when these are fixed or varying, to make decisions? (2) How does information, investments in adaptation and

insurance or compensation influence risk decisions? (3) How do recent losses influence the next risk decision?

2. Methods

2.1 Study area

This study was carried out with fish farmers in northern Thailand that rear Tilapia in open-top mesh cages suspended on floating platforms in major rivers. Four growing regions are distinguished (Figure 30). The climate and river flow regimes of these four regions differ providing insights into the importance of past experience on decisions as well as potential impacts under climate change (Chapter 5).

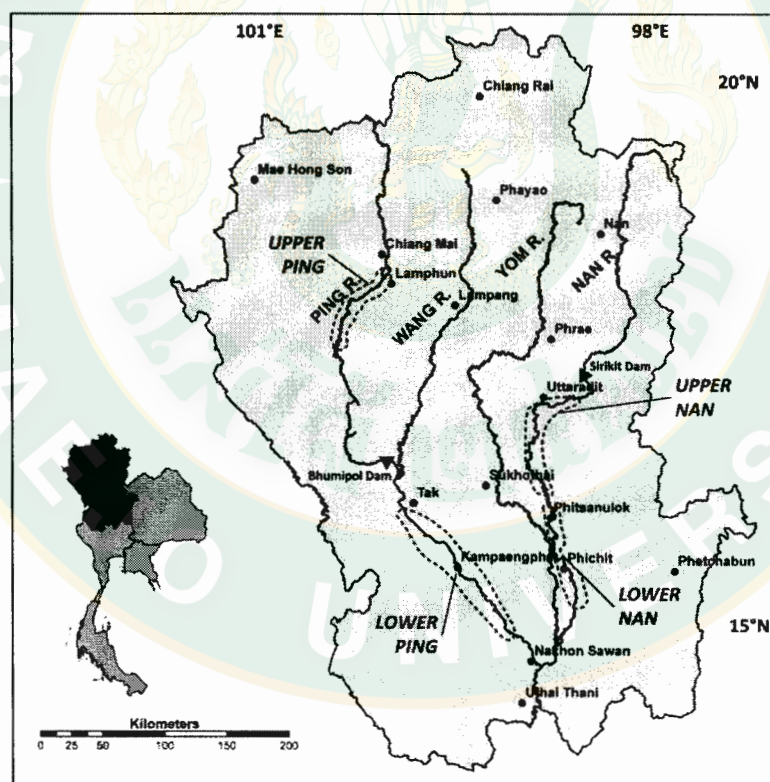


Figure 30 Map of river-based cage culture regions in northern Thailand studied in this paper.

1.1 Flood risk pay-off matrix model

A simple model for flood-related losses from fish farms was constructed based on empirical survey findings (see Appendix B). The model simplifies reality treating stocking level or density as a proxy variable for level of investment, and thus the riskiness of a cropping decision. The model was used to derive the pay-off matrix shown in Figure 31. The graph shows the expected pay-offs for each fixed level stocking strategy across a range of flood probabilities. From graph in Figure 31 it is clear that with this payoff structure the optimal stocking density varies from high density at low probabilities of floods (0.1) through middle density at intermediate probabilities (0.3) to low density at high probabilities (0.5).

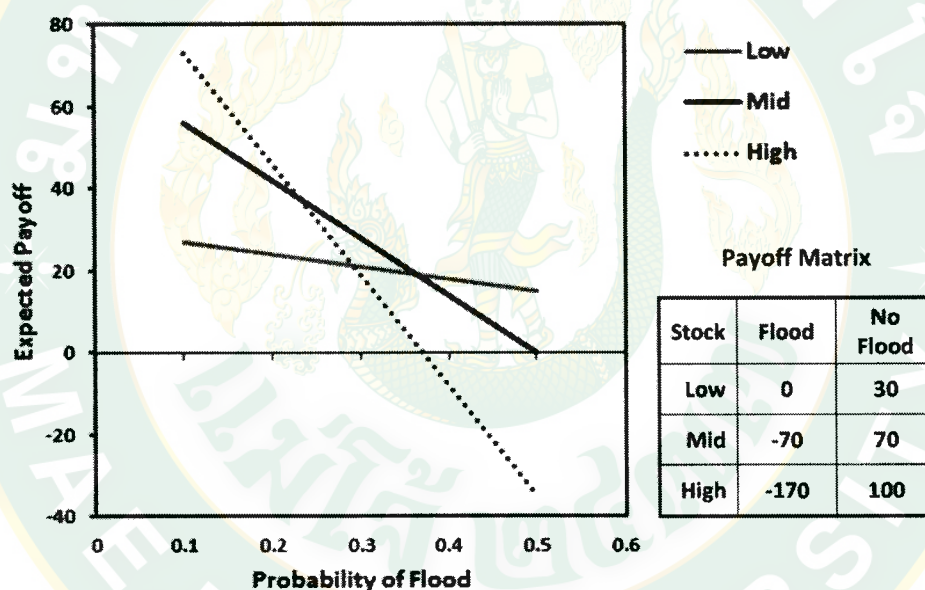


Figure 31 Expected pay-offs from adopting single stocking strategy.

2.2 The simulation game

The flood risk model was turned into a simulation game as an Android application. In the role playing game farmers play a person like themselves, that is, a fish farmer. The game is played on a touchscreen hand-held tablet. The main idea of the game is to maximize cumulative profit by choosing among three options: low, medium, high stocking density. After selecting an option the game responds with a harvest graphic, payoff value and cumulative total (Figure 32). In case of flood there is a corresponding animation.

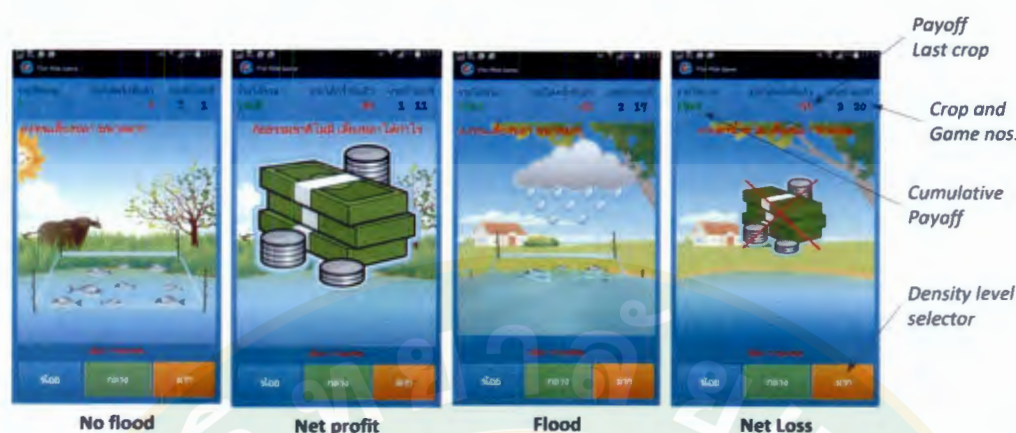


Figure 32 Stills from tablet game screens.

A session with a farmer started with very brief explanation of how to use the hand-held tablet device to make stocking decisions in each round. Farmers were told that if there was no flood then a higher stocking density means more profit; but if a flood occurs then lower stocking density means less loss. Farmers were not told the level of risk of a flood or specific payoffs. Each game lasted 20 rounds or crops, that is, required 20 stocking decisions.

Farmers played 7 games corresponding to different treatments. In pre-tests with students and farmers we learnt that attention begins to fade after around 10 games, whereas with 7, players maintained concentration. On average each game took about 3.5 minutes to play. The order in which games were played was randomized to minimize order effects. Each time they began a new game farmers were told to imagine starting farming in a new location where risks and consequences may be different from earlier games. In 9 cases problems with tablets meant the farmer played only 6 recorded games, rather than 7. All decisions made by farmers and the payoffs were recorded automatically in a database in the tablet for later analysis. Across all crop decisions farmers chose: low (27.1%), mid (40.2%), and high (37.7%).

We considered paying players depending on how high they scored in game, but because of different treatments they played this would not be fair. Moreover, additional discussions with farm leaders suggested that they would take task seriously even without such an

incentive and that they would prefer that all players received the same small allowance intended to cover local travel costs and their time, which is what we did.

In the end, a total of 224 fish farmers played the risk game: 54% men, and 46% women. The distribution of player ages was: <30 (7%); 30-39 (17%); 40-49 (29%); 50-59 (29%); and, 60+ (18%). Approximately equal numbers were drawn from four growing regions: Upper Ping, Lower Ping, Upper Nan, and Lower Nan (Chapter 5). All fish farmers included had recently reared tilapia, but in 7 cases were currently rearing only other species.

2.3 Experimental treatments

Each game was an experimental treatment which in various combinations would allow comparisons that could address the specific hypotheses posed. The set of all treatments used is summarized in Table 17. As a consequence of a programming error treatment 8 was same as 1 and 9 same as 5 so findings for these were pooled. A priori, planned, contrasts used to test each hypothesis are given in the tables in the results section of the paper.

Table 17 Experimental treatments (or game types). Standard payoffs are as in Table 1. Full details of payoffs are given in Appendix B.

Treatments	Probability of a flood	Payoff Matrix
T1 –T5	0.1 – 0.5	Standard
T6, T7	0.3	Impact increased or reduced
T19, T20	0.1	Impact increased
T10, T11	0.3	Impact less or more variable
T12 – T14	0.1 0.3 0.5	Likelihood known
T15 – T17	0.1 0.3 0.5	Adaptation investment reduces impact
T18	0.3	Fixed fee for fixed compensation or index insurance

2.4 Measurement of risk decision variables

Six indicator variables were derived from the simulation game runs to describe different aspects of decisions made by players. First, were two measures of overall performance: cumulative profit (CP) and random standardized profit (RSP, Table 18). Second, was a measure

Table 18 Measurement of key risk decision indicator variables

Variable	Definition
Cumulative profit	Sum of pay-offs from 20 rounds of a game $CP = \sum_{i=1}^{20} P_i$
Random Standardized profit	Difference between sum of pay-offs and expected score if chose randomly $RSP = \sum_{i=1}^{20} (P_i - P_{rand}) = CP - (\sum_{i=1}^{20} P_{rand})$
Mean Density Level	Mean density level chosen $MDL = (\sum_{i=1}^{20} (d_i)) / 20$ where $d_i = 1$ if low, 2 if mid, 3 if high
Optimum decision intensity	Proportion of times chose optimum density for that game. $xODI = (\sum_{i=1}^{20} (P_i = P_{max})) / 20$
Risk learning rate	Difference in pay-off in second 10 crops compared to first 10 crops. $RLR = (\sum_{i=11}^{20} P_i - \sum_{i=1}^{10} P_i) / 10$
Random standardized risk learning rate	Risk learning rate standardized against expected if played randomly. $RSRLR = \left(\sum_{i=11}^{20} (P_i - P_{rand}) - \sum_{i=1}^{10} (P_i - P_{rand}) \right) / 10$ where P_{rand} is based on number of flood events in that time period

2.5 Qualitative information

Most participants were interviewed in-depth after they had completed the game. The short (15min) discussions covered: strategies used in the game to increase profits; similarities and differences between game and reality; and, what games they like and how they felt about making risk decisions. Interviews were taped, transcribed, and coded using NVIVO.

2.6 Data analysis

Specific hypothesis were tested by using a priori contrasts within an ANOVA framework in line with the logical structure of the treatments. In preliminary analysis game number was included as a predictor to adjust for possible learning across games but as it was not significant it was dropped. In the analysis games were treated as independent and the blocking with respect to farmers ignored. The primary purpose of using incomplete, partial, blocks was to ensure reasonable interspersal of treatments among farmers.

To explore in more detail decision-making from crop-to-crop within a game, nominal or polytomous regression was used. In these analysis, stocking density, a categorical with three levels, was the outcome variable.

3. Results

3.1 Likelihood of event

The first set of hypotheses explored how the likelihood of flood events influences risk decisions, specifically:

- H1a. The greater the likelihood of a flood the lower the profit.
- H1b. The greater the likelihood of a flood the lower the density chosen.
- H1c. Farmers find it's harder to learn rare than common risks

The first two hypotheses follow directly from game goal of maximizing profits and information provided on payoffs at start. The third hypothesis is based on the logic that when

event happens more often it is easier to get information about likelihoods and outcomes than if it rarely happens.

When floods were more frequent farmers raw profit (CP) declined (Table 19) as would expect from pay-offs in treatments. After adjustment for expected pay-offs, however, there was no significant difference (RSP) implying that increased floor risk and thus losses did not affect decision-making performance once took into account differences in expected payoffs. Hypothesis H1a was thus only supported in the obvious case.

Table 19 Effects of likelihood of flood event. Treatment means for 5 decision and outcome measures and result of hypothesis tests using a priori planned contrasts. Abbreviations are as in Table 18

Treatment	Flood risk	CP	RSP	MDL	ODI	RLR	RSRLR
T1	0.1	1090	50.2	2.11	.36	56.7	3.30
T2	0.2	806	59.7	2.10	.35	45.8	1.63
T3	0.3	452	-2.2	1.99	.38	16.9	-0.70
T4	0.4	131	-28.5	2.04	.27	10.7	-1.33
T5	0.5	-104	29	1.99	.30	-8.2	-1.56
Hypothesis test [‡]		+ H1a	- H1a	+ H1b	# H1c	# H1c	- H1c
		.01	ns	.01	.01	.001	ns

[‡] Conclusion from hypothesis test: + hypothesis supported; - hypothesis rejected; # support for opposite relation

Farmers, on average, reduced their stocking densities (MDL) when faced with higher flood risks as predicted under hypothesis H1b, but the difference was primarily between first two lower levels of risk and the latter three treatments. There was a significant trend towards fewer optimal decisions with higher level of flood risk (ODI, Table 19). Again, contrary to initial hypothesis (H1c), farmers appeared to learn better when flood risks were low than when they

were high (RLR), but after adjustment for actual flood events experienced in each half of the game (RSRLR) the difference was no longer significant.

Farmers found the game similar to real-life decisions. There is a risk of losses due to water conditions in each season. If invest to a little, take too small a risk, then gains on investment are not worth the time spent. When water and climate conditions look good farmers invest fully, but if conditions are poor then they are more cautious. The key point is that in the game, as in real life, the risks are imperfectly known: *“It is like rearing fish for real. When we rear fish we don’t know future risks or what will happen in the future. This year: will there be a shortage of water? Will it flood? Will the river be dry? When we invest we know there will be risks, but not how big they will be.”*

There is always a chance it will flood and will lose, but if invest a lot, take a larger risk, you can make a lot, but you may also lose a lot as well: *“It is about investing, investing in fish farming. If you stock a lot the risk is high, if encounter bad conditions you lose a lot; if you stock a little and encounter bad conditions you lose a little.”* Fish farmers told us the game *“is like the real-life situation. You can make a profit or a loss. It depends on natural disasters. Rearing fish is risky: There are risks every crop if we rear fish.”* And another: *“It is very similar to rearing fish in reality, because in reality when rear fish it is like this. When it rains a lot, if it is me I will not increase investments, not stock high. I won’t stock much, will reduce densities.”* These findings suggest the payoff matrix was, at least in general terms, understood. Post-game many farmers identified low probability of flood games as the most enjoyable. They argued they were happiest when there were few floods and could make a lot of profit: *“I liked the game where it only flooded two times; it was easy to adapt to the conditions and invest a lot in each round.”* In recalling the last game played farmers tended to over-estimate number of floods when rare ($P=0.1$) and under-estimate them otherwise (Figure 33).

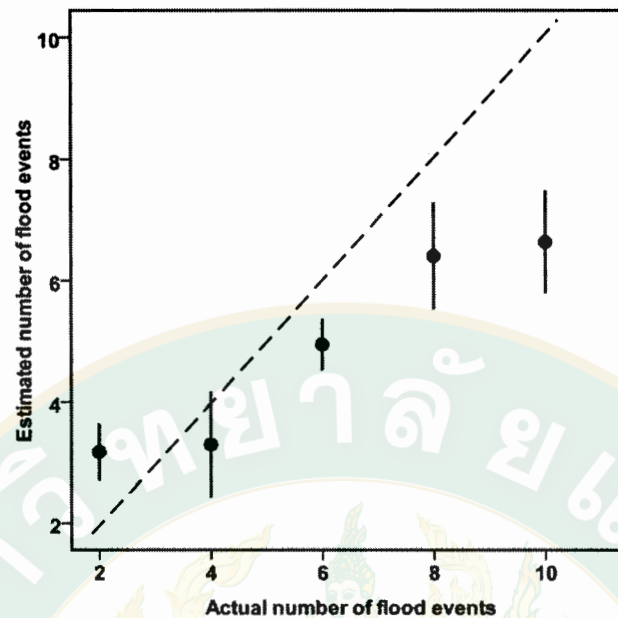


Figure 33 Recall of recently experienced flood risks. Diagonal indicates equivalence between estimated and actual number of events. Means and 95% confidence intervals (n=215).

3.2 Magnitude of consequences

The second set of hypotheses explored how the magnitude of flood impacts influences risk decisions, specifically:

- H2a. The larger the magnitude of flood impacts the lower the profit.
- H2b. The larger the magnitude of flood impacts the lower the density chosen.
- H2c. Farmers find it harder to learn from low than large magnitude events.

When floods had larger impact farmers raw profit (CP) declined (Table 20) as would expect from pay-offs in treatments. After adjustment for expected pay-offs a similar trend was present, however, there was only some significant differences (RSP) when floods were unlikely.

Table 20 Effects of magnitude of flood impact. Treatment means for 5 decision and outcome measures and result of hypothesis tests using a priori planned contrasts. Magnitude of impact is ratio of payoff loss in event of flood for the treatment related to standard payoff (see: Appendix B).

Treat- ment	Likeli- hood of flood	Magni- tude of impact	CP	RSP	MDL	ODI	RLR	RSRLR
T7	0.3	0.5	715a	20.8	2.09	.348a	35.2a	0.37
T3	0.3	1	452b	-2.2	1.99	.381a	16.9b	-0.70
T6	0.3	2.1	-108c	-28.3	2.10	.240b	-13.8c	-2.84
Hypothesis tests [†]			+ H2a	- H2a	- H2b	# H2c	# H2c	- H2c
T1	0.1	1	1090a	50.3a	2.12	.357a	56.7a	3.30a
T19	0.1	2.4	820b	5.9ab	2.05	.329a	37.9b	-3.27b
T20	0.1	8	-129c	-48.7b	2.12	.217b	-32.4c	-12.8c
Hypothesis tests			+ H2a	+ H2a	- H2b	# H2c	# H2c	# H2C

[†] Conclusion from hypothesis test: + hypothesis supported; - hypothesis rejected; # support for opposite relation

Hypothesis H2a was partly supported. Farmers did not reduce their stocking densities (MDL) when faced with higher impacts from floods as predicted under hypothesis H2b (Table 20). Again, as above, and contrary to initial hypothesis (H2c), farmers appeared to learn better when flood impacts were low than when they were high (RLR). Similarly they were more likely to select optimal densities when impacts were low (ODI) although means were not as easy to separate as in case RLR measure.

3.3 Variable likelihood

The third set of hypotheses explored how changes in the likelihood of flood events influences risk decisions, specifically:

- H3a. When likelihood of a flood changes profits are lower.
- H3b. When likelihood of a flood changes more likely to choose lower densities.
- H3c. Farmers find it harder to learn risks when they are changing.

The idea behind these three hypothesis is that uncertainty makes evaluating risks more difficult (H3c) making it harder to succeed (H3a), and in response become more cautious (H3b). To explore these three hypotheses we classified games into three types based on a difference of 2 or more floods in first versus second 10 crops: increasing, unchanged, decreasing. There was no support for any of the three hypotheses and in some cases support for opposite or other patterns (Table 21). Farmers chose riskier options (MDL) when likelihoods varied in either direction. When likelihoods were changing raw profits (CP) were higher, but analysis of standardized scores (RSP) suggests this just reflected differences in payoffs. The pattern for RLR was what would expect given classification of games. Even after standardization for expected payoffs, however, rates of learning (RSRLR) were highest in games with decreasing risks and lowest with increasing risks.

Table 21 Effects of variation in likelihoods of floods. Treatment means for 6 decision and outcome measures and result of hypothesis tests using post-hoc comparisons across all original treatments.

Likelihood change	n	CP	RSP	MDL	ODI	RLR	RSRLR
Decreasing	196	610b	33.5	2.12	0.36	58.5a	6.08a
No change	1166	413a	22.4	2.04	0.33	18.8b	-0.77b
Increasing	197	541b	-5.3	2.12	0.35	-0.21c	-6.51c
F-ratio		17.1	1.2	4.5	1.5	98.4	10.2
p-value		.001	.30	.01	.22	.001	.001
Test [‡]		#H3a	-H3a	-H3b	-H3b	-H3c	#H3c

[‡] Conclusion from hypothesis test: + hypothesis supported; - hypothesis rejected; # support for opposite relation

3.4 Variable consequences

The fourth, and final set of hypotheses under research question 1, explored how variability in the magnitude of flood impacts influences risk decisions, specifically:

- H4a. The more variable the magnitude of flood impacts the lower the profit.
- H4b. The more variable the magnitude of flood impacts the lower the density chosen.
- H4c. Farmers find it harder to learn when consequences are more variable.

All planned contrasts were not significant so no support for any of these hypotheses. As no significant findings table is not shown.

3.5 Information

The fifth set of hypotheses, under research question 2, explored how prior information on the likelihood of floods influences risk decisions, specifically:

- H5a. Knowing likelihood of floods beforehand increases the profit.
- H5b. Knowing likelihood of floods is high beforehand lowers the density chosen, and if low then raises the density chosen
- H5c. Farmers find it easier to learn when likelihoods of floods are known beforehand.

The third hypothesis reflects the idea that when only need to understand consequences as likelihoods are already known is easier when must estimate both. With better understanding would expect better choices (H5b) and thus overall performance (H5a). All planned contrasts in this set of hypothesis were not significant so no support for any of these hypotheses. As there were no significant differences a table of summary means for each treatment is not shown.

Although, on average, farmers did not do better with information, when asked what game they liked to play most, some farmers identified these treatments. Several said they liked when they were given information about the number of floods to expect as this allowed to make more strategic decisions: *"I liked the game that told us it would flood once in 10 times. I could decide to invest a lot and only lose once in ten times."* Some farmers liked the latter games more than early ones because by then they felt they could understand how to play and make better

decisions. *“The last game, I made a profit. At the start did not know what effect floods would have. After playing a while I felt I knew how to play.”*

3.6 Adaptation

The sixth set of hypotheses, under research question 2, explored how investment in adaptation influences risk decisions, specifically:

- H6a. If invest in adaptation or insurance then more likely to gain higher profit when floods are frequent than when rare.
- H6b. If invest in adaptation or insurance then more likely to choose a higher density.
- H6c. Farmers find it easier to learn when have invested in adaptation.

The first hypothesis follows directly from reduced impact of floods. The second is more speculative but is based on idea that these investments reduce perceived risks. The last hypothesis is based on the argument that farmers would learn that having invested in adaptation, losses when it floods will be reduced, and thus payoffs last variable.

The first hypothesis, H6a, was supported in the obvious case (Table 22). The significant difference in CP reflects difference in expected pay-offs as move to higher probabilities of floods – a difference which disappears when standardize (RSP). There was no evidence that adaptation investments led to higher risk taking (MDL, H6b, Table 22). Farmers appear to learn more when invest in adaptation only when flood risks are high (RLR, ODI, H6c) but after standardization (RSRLR) the effect disappears. One difference farmers noted was that in the game there was no warning or opportunity to prepare for individual flood events as there is in real life; this particular set of treatments helped understand that option when it was used.

Investing in a fixed-compensation insurance – like index-based scheme rather than one that depends on actual losses – led to better decisions (ODI) than one which reduces flood impacts by 50% and for which expected payoffs (Appendix B) were identical (ODI: T16 vs. T18). Post-game some farmers noted they liked the games with *“insurance as even though there was a risk, when it flooded there was some help.”*

Table 22 Effects of investments in adaptation and insurance. Treatment means for 5 decision and outcome measures and result of hypothesis tests using a priori planned contrasts (***) $P < 0.001$; ** $P < 0.01$; * $P < 0.05$).

	Prob.	CP	RSP	MDL	ODI	RLR	RSRLR
Contrast	<i>Flood</i>						
T1 vs. T15	0.1	+***	Ns	Ns	ns	+ **	ns
T3 vs. T16	0.3	ns	Ns	Ns	+ **	Ns	ns
T5 vs. T17	0.5	- ***	Ns	Ns	- **	- ***	ns
Hypothesis Tests [‡]		+ H6a	- H6a	-H6b	+ H6c	+ H6c	
T16 vs. T18	0.3	ns	Ns	Ns	- **	Ns	ns
T3 vs. T18	0.3	ns	ns	Ns	ns	ns	ns

[‡] Conclusion from hypothesis test: + hypothesis supported; - hypothesis rejected; # support for opposite relation

3.7 Learning strategies within a game

We next looked more closely at decisions within a game and what learning strategies farmers might be using by analyzing sequences of decisions within a game, in particular, following floods. To investigate the effects of a flood event on subsequent stocking density decisions separate nominal (or polytomous) regressions models were estimated for situations in which the last stocking decision was low, medium and high (Table 23). In each model the outcome variable was 'stocking density' chosen this crop (which also has three possible values). The reference category was set to no change in density for each model. Overall, the tendency, was to repeat the last decision, and increasingly so as density increased: low (46%), mid (49%), and high (54%). In each model the candidate predictors were: flood last crop, gender, age group, late round (crop number > 15) and region. The findings with respect to floods will be discussed first and in most detail.

Table 23 Factors associated with changes in stocking decisions. Summary of three separate nominal regression models based on density chosen at last crop. Odds ratios and 95% confidence intervals shown only for significant predictors.

Model	Density this crop			
Density	Predictor	Low	Mid	High
Last crop				
High	Last Flood	1.25 (1.10,1.43)	1.62 (1.46,1.79)	1
	Women	ns	1.25 (1.14,1.37)	1
	Late round	ns	0.88 (0.79,0.98)	1
	Region			1
	<i>Lower Ping</i>	0.39 (0.33,0.46)	0.67 (0.59,0.76)	
	<i>Upper Ping</i>	0.53 (0.45,0.62)	0.69 (0.60,0.79)	
	<i>Lower Nan</i>	0.58 (0.49,0.68)	0.74 (0.65,0.85)	
	<i>Upper Nan</i>	1	1	
	Age			1
	<i>Young</i>	ns	ns	
	<i>Old</i>	0.83 (0.70,0.97)	ns	
	<i>Mid (40-60)</i>	1	1	
Mid	Last Flood	1.96 (1.77, 2.17)	1	1.51 (1.37, 1.66)
	Women	ns	1	ns
	Late round	ns	1	ns
	Region		1	
	<i>Lower Ping</i>	0.59 (0.52,0.68)		0.71 (0.62,0.80)
	<i>Upper Ping</i>	0.60 (0.53,0.69)		0.77 (0.68,0.88)
	<i>Lower Nan</i>	0.66 (0.58,0.75)		0.70 (0.62,0.78)
	<i>Upper Nan</i>	1		1

Table 8.7 (continued)

Model		Density this crop		
Density	Predictor	Low	Mid	High
Last crop				
	Age		1	
	<i>Young</i>	ns		ns
	<i>Old</i>	ns		ns
	<i>Mid (40-60)</i>	1		1
Low	Last Flood	1	ns	1.60 (1.40, 1.83)
	Women	1	0.78 (0.71,0.87)	0.70 (0.61,0.80)
	Late round	1	0.86 (0.77,0.96)	Ns
	Region	1		
	<i>Lower Ping</i>		0.77 (0.67,0.88)	Ns
	<i>Upper Ping</i>		0.74 (0.65,0.85)	0.70 (0.58,0.84)
	<i>Lower Nan</i>		ns	0.74 (0.62,0.89)
	<i>Upper Nan</i>		1	1
	Age	1		
	<i>Young</i>		0.70 (0.62,0.79)	0.68 (0.58,0.80)
	<i>Old</i>		ns	0.79 (0.66,0.95)
	<i>Mid (40-60)</i>		1	1

The effects of a flood in previous crop on the next stocking decision depended on the density, and thus payoff outcome, in previous crop (Figure 34). If the last stocking density was high and a flood occurred farmers were more likely to reduce stocking densities in the next round (rightmost panel, Figure 34). If density chosen in last crop was low, however, farmers were more likely to make the riskiest choice if they had just experienced a flood (leftmost panel). At low densities it should be noted flood effects were modest. If the density chosen for last crop was intermediate, farmers responded to a flood by changing density taking both lower and higher

densities more often than continuing to choose the mid option but reducing more than increasing (central panel).

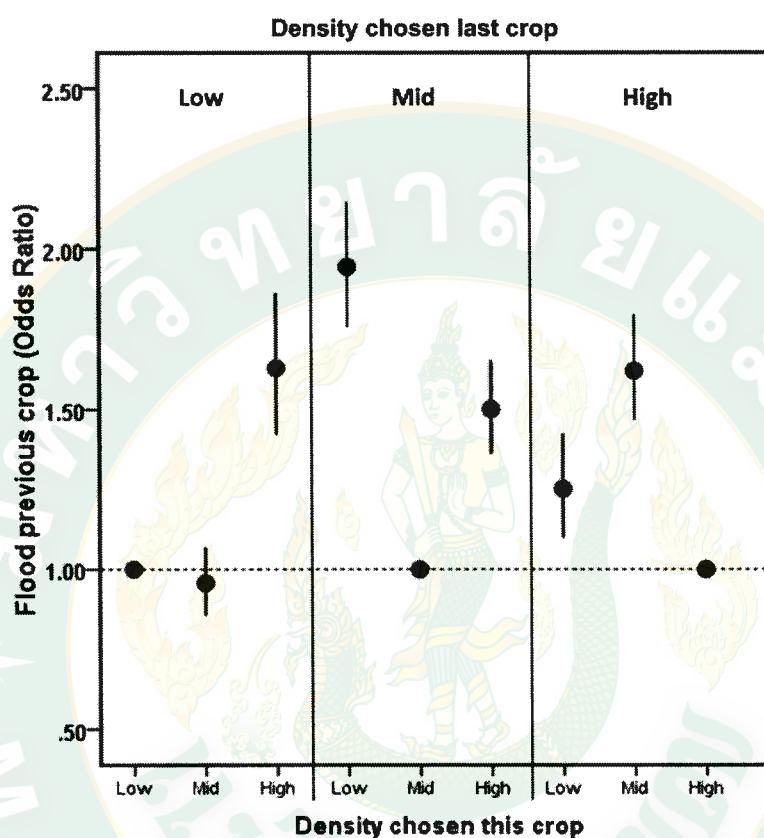


Figure 34 Effects of a flood in previous crop on subsequent stocking decisions. Odds ratios and 95% confidence intervals from nominal regression model with multiple predictors.

The key findings for other predictors apart from floods in Table 23 will now be briefly considered. It should be underlined that these associations are after mutual adjustment for other factors in the model. Women responded to floods more cautiously than men. Women were more likely than men to reduce densities by one step (H->M) following a flood; they were also less likely to increase densities from a low level following a flood (L->M or L->H, odds ratios < 1.0). Young and old farmers tended to maintain same density more than middle-aged farmers, being less likely to make a big reduction (H->L) or increase (L->H). In late rounds farmers were

less likely to move to intermediate densities following a flood ($H \rightarrow M$ or $L \rightarrow M$) suggesting that by then they were clear on appropriate level of risk to take. Regional differences in response to floods were strong and consistent. Farmers from the Upper Nan region were more likely to change density after a flood event than those in the other three regions (odds ratios < 1.0).

Fish farmers said they understood the game as being about making decisions in situations where you do not know in advance what will happen: *“a situation in which cannot predict when fish will die, when it will flood.”* Or as another put it: *“Each time you stock fish it is like an experiment. You cannot predict what will happen. It is practice in analyzing investments: which option would be good to choose next?”* They also acknowledged that different places have different risks so when start in a new place they initially start with small investments, that is, less risky decisions. The game *“makes us think when we invest: In this new situation should we invest a little or a lot? Do we dare to take a risk? In a new place who would take the high risk? In a new place you need to take less risk.”*

4. Discussion

In this game selecting low stocking was a relatively certain bet compared to high stocking where differences in payoffs if it flooded or not were large. As would expect more frequent or larger impact floods reduced cumulative profits (Table 19 and Table 20). Farmers slightly reduced their stocking densities when playing in games with high likelihood of floods but did not do so as expected when impacts were larger. Contrary to initial expectations farmers found it harder to learn – choose most optimal density or improve score within a game – when floods were common or had large impacts. Most laboratory studies on learning from experience suggest participants underweight rare events (Erev *et al.*, 2010). In the context of climate-related risks and a role-playing game situation, the findings suggest there may also be an emotional rather than purely analytical response to losses (Slovic *et al.*, 2004). Players, for instance, may sometimes seek to recover lost investment as quickly as possible from a recent major loss and take more risks, or, alternatively, feel overwhelmed by a large impact event or repeated losses, lose sense of control over risks and become overly risk averse.

Apart from evidence about effects of likelihood and consequence we also explored several other situational factors which might influence risk decisions following the

conceptual framework presented earlier (Figure 29). Uncertainty in risks as variation in likelihoods produced some unexpected effects. Raw profits were higher in games with change than those with unchanging risks (Table 21). Again contrary to initial hypothesis farmers appeared to learn about risks better when they were decreasing, and do worst when they were increasing. This latter finding has particular significance when consider potential adverse impacts of climate change, for which, many key risks are increasing, but perceptions of policy or planners lack urgency (Moser, 2010b; Runhaar *et al.*, 2012). In this study, however, uncertainty in risks, as greater variation in outcomes, did not significantly reduce profits, result in lower densities being chosen or reduce rates at which learning takes place, as might be expected. One explanation is that learning from experience in the role-playing game was already challenging under conditions of fixed risks.

Farmers concentrated hard when they played the game, but it was not easy to play. Many did not do much better than would expect with random choices. This is a telling finding, because the game was designed to reflect the series of decisions a fish farmer must make based on accumulation of experience. Moreover, farmers validated that the game matched reality in key features around investment decisions. Against a background of variation in pay-offs the likelihood and consequences of adverse events like floods are hard to estimate with much precision and thus use as a guide for subsequent decisions.

This study also suggests that many farmers did not know what to do with likelihood information when they got it. Providing information about likelihoods prior to a game also had no impact on performance or decisions. One explanation for these findings is that many farmers did not understand or translate a statement like chance of “1 in 10 times” or “1 in 2 times” into meaningful information to use in the game. At the same time some farmers did perform well in these types of games, and in interviews stated that knowing likelihoods was very helpful in making decisions in those games. Many studies have shown that people have difficulties in understanding and using ratios, proportions and probabilities (Reyna and Brainerd, 2008). Another possible explanation for lack of hypothesized effect of information might be probability matching where decision-makers focus on matching choice probabilities with their selections rather than making selections based on the most likely outcome – a strategy that would maximize their cumulative payoffs (James and Koehler, 2011).

In games with compulsory insurance farmers did better when floods were more frequent as would expect based on payoffs but not better than that. There was no evidence that adaptation investments led to higher risk taking (Table 22). Farmers play significantly improved within a game when they had invested in adaptation but only when flood risks were high. This may relate to feelings of confidence when losses are reduced (Weber, 2010). Investing in a fixed amount compensation insurance – like an index-based scheme rather than one that depends on actual losses – led to better decisions than one which reduces flood impacts by 50% and for which expected payoffs were identical. This suggests farmers appreciate reduced ambiguity with respect to outcomes. A study of Coffee farmers in Costa Rica, and another of mixed field crop farmers in Peru, both found that ambiguity made it even less likely for farmers to change practices, for instance, invest in new adaptation options.

Place-related factors, like region of origin, were significant for some of the associations with learning about risks. Regional differences in immediate responses to floods (Table 23), for example, might be explained by differences in experiences, as in the Upper Nan River flow modification as a result of dam operations has large consequence for seasonal risks of extreme flows (Chapter 5). We suggest that farmers entered the role-playing game with set of expectations about likelihoods and consequences based on their own personal experiences and then updated these, or their mental model, as a result of playing the game. Different groups of expert stakeholders appear to have distinct mental models for adaptation to climate change (Otto-Banaszak *et al.*, 2011). Further, in-depth, investigations of farmers' perceptions and attitudes towards climate-related risks is needed to more completely understand how beliefs and concepts influence risk management decisions and support for various adaptation actions.

The above findings help, in several ways, improve understanding of how fish farmers make stocking decisions in the face of risks that are imperfectly known and may be changing (Figure 29). The findings caution against placing unrealistically optimistic assumptions about how fast individuals can learn about risks from monitoring and experience. Learning from experience is not easy as there is often a tendency to repeat last decision despite outcome or a problem of inertia (Dutt and Gonzalez, 2012b). Farmers who switch densities frequently, on the other hand, especially after negative events, may be searching for information that could inform alternative strategies (Weber and Johnson, 2009). At the same time, the findings of this study

also caution against assuming information about likelihoods of extreme events has high values: such information may be difficult to communicate in a way that is easily understood and related to decisions which must be taken.

The findings suggest that decision-support systems for aquaculture need to take into account how recent experiences and other factors influence risk perceptions and decisions. An extensive review of experiences with DSS for farmers in Australia noted that DSS should not aim to optimize recommendations but rather help farmers explore options and understand their own intuitions about problems and solutions (Hochman and Carberry, 2011). An example of such an approach is the prototype decision-support system developed for catfish farmers in Vietnam (Le *et al.*, 2012). To develop a useful system for inland tilapia aquaculture it would be important to also consider key non-climate related risks such as costs of fish fry and feed, and risks of disease (Belton *et al.*, 2009).

This study also had some important limitations that suggest areas for further research. First, the sequence of stocking decisions made and outcomes experienced in the simulation game were seconds apart whereas those in the real world are separated by several months. Second, as no cash transactions were involved it is likely that the emotional elements of the decision, including things like fear of losing investment, dread of extreme floods and their impacts on farmer's households, would not be fully replicated in the role-playing game. Third, the games were played by individuals, whereas in the real world farmers talk to each other and learn about risk levels from others and not just their own experiences. Finally, decision-making in the real world involves considering multiple risks and trade-offs or interactions among them. Future studies using the game, or related techniques, could consider testing the effects of recall aids, incentives or penalties, a pair of risks rather than single risk, giving farmers the option within games to invest in adaptation in the next crop, and comparing performance when playing in groups against playing alone. The findings of such investigations could be explored using decision models. Relatively simple and stylized models based on instance-based learning theory, for instance, are known to perform reasonably well on a wide range of tasks including probability learning and making repeated choices (Erev *et al.*, 2010; Lejarraga *et al.*, 2010).

5. Conclusion

Taken together the methods and findings of this study have significant implications for future work on climate risk management, especially in aquaculture, but maybe also in some other agricultural decision-making settings. The combination of experimental, role-playing and qualitative methods was novel and proved helpful to obtaining a deeper understanding of decision behavior in a specific setting. The experimental tests imply that some common, or otherwise reasonable, assumptions about how farmers evaluate risks based on experience need to be revisited. In particular, it is difficult to learn with much precision from a relatively short series of decisions about the likelihoods or consequences of an adverse climate event, especially if those risks are increasing. Past experiences in different locations also matters to risk-taking behavior implying the need to adjust risk information by site. These insights from a role playing game, combined with other work on risk perceptions and experience of impacts, should be useful for design of future risk communication activities and decision-support to improve climate risk management and, ultimately, developing realistic strategies for enabling climate change adaptation.

CHAPTER 9

CONCLUSIONS

This thesis is one of the first in-depth analyses of the climate-related risks faced by farmers who culture fish in river-based cages. The findings show clearly that climate-related risks are an important factor in production decisions, and that the losses associated with impacts of extreme flow events can be large. The study also shows that fish farmers manage multiple climate-related and other risks simultaneously, with an emphasis on actions at the level of the farm, while also acknowledging the importance of actions at the river scale. Fish farmers learn about levels of risk in particular locations through experience and consider shorter- and longer-term, as well as generic and systemic, adaptation responses. Although the empirical focus of this thesis was on managing risks under current climate, the findings support the general notion that improving climate risk management is a useful, initial, climate change adaptation strategy. This final chapter of the thesis is organized as follows. The next three parts reflect on the three initial project objectives and their associated specific research questions as posed in Chapter 1 (Table 1). This is followed by a short analysis of some of the key limitations of the study and suggestions for further research.

1. Climate-related risks

The first objective of this thesis was to assess the risks from floods, low flows and other weather and climate-related phenomenon to river-based tilapia cage culture in northern Thailand.

Extreme floods and droughts have major impacts on the profits of river-based fish cage culture across Thailand (Chapter 2). Detailed surveys across Northern Thailand, with information from different major events, show that extreme high and low flows adversely impact a substantial fraction of farms, causing damage to cages, fish deaths, slow growth and disease problems (Chapters 3 and 5). When fish die or grow slowly or must be harvested at smaller-than-standard size, profits are reduced. Economic losses are significant and result in financial debt.

The probability of extreme flows and impacts vary among locations, are highly seasonal, and vary inter-annually (Chapter 5). In most locations monsoon-driven differences between wet and dry seasons dominate levels of risk to fish farms. In areas downstream from large multipurpose dams, however, risks of high and low flows, while reduced overall, can show seasonal patterns completely reversed from what expect from seasonal rainfall and run-off. Smaller weirs also can have major local influences on river depths modifying risks at another scale. Water infrastructure modifies climate-related effects on water flows and thus temporal and spatial patterns of climate risks.

Even so, there can be substantial differences in risks among farm sites within a river. This raises the issue of access or how households gain access to river cage sites to farm fish. A case-control study in the Upper Ping suggests that households with good access to farming sites, financial capital, and social networks are more likely to farm fish (Chapter 4). Proximity to the river front was a very important factor and operated at a micro-level within villages with river borders. Land and vehicle assets were also associated with fish farming – more so than monthly income levels – probably because they reflect access to credit.

The findings of this thesis show that floods, low flows, and a few other weather and climate-related phenomenon, have major impacts on the profitability of river-based tilapia cage culture in northern Thailand. Impacts and risks, however, vary among rivers and sites as well as among seasons.

2. Perception and management of risks

The second objective of this thesis was to assess how farmers perceive and manage climate-related risks.

How climate risks are understood and perceived by farmers is important, because it can influence their management practices (Chapter 6). The perceived importance of climate-related risks, such as floods and droughts, vary by seasons, among years and locations, and are modified by water infrastructure. While perceptions often reflect actual seasonal patterns in climate and water flow conditions, the match is not perfect. Recent experience of negative impacts increases levels of concern about risks. Farmer's perceive that risks from droughts have significantly worsened over the last decade, whereas those from floods have not changed. The

overall level of awareness of climate change among fish farmers is high suggesting future work should focus on building on how farmers manage risks under current climate to then take into account climate change.

Farmers use a combination of adjustments to rearing practices, cropping calendars, as well as financial and social measures to manage those risks which they perceive as being manageable (Chapter 7). Many risks are season, river and place-specific meaning that the risk profiles of individual farms can vary substantially. Individual risks are often addressed through multiple practices and strategies; conversely, a particular management practice can have a bearing on several different risks. Farmers recognize that risks must be managed at farm and higher spatial and administrative scales. These findings underline the need to consider multiple spatial and temporal scales in climate risk management.

Climate and non-climate related risks can interact and so may need to be managed jointly. For instance, fish farmers in the Upper Ping River rear Hybrid red and black Nile tilapias (*Oreochromis niloticus* L) for 4-5 months in cages at mean stocking densities around 50 fish m⁻³ (Chapter 3). During extreme flow or high risk periods stocking densities and feeding rates may be reduced. Input costs, it should be remembered are dominated by feed and stock. To succeed fish farmers must always manage a combination of market, climate and environmental-related risks.

Findings from a role-playing simulation game strongly suggest that as losses associated with impacts of extreme flow events can be large, climate-related risks are an important factor in production decisions (Chapter 8). Fish farmers learn about levels of risk in particular locations from experience. As hypothesized more frequent or larger impact floods reduced cumulative profits in the simulation game. Farmers slightly reduced their stocking densities when playing in games with high likelihood of floods but did not do so as expected when impacts were larger. Contrary to initial expectations farmers found it's harder to learn – choose most optimal density or improve score within a game – when floods were common or had large impacts. Farmers learnt most when risks were decreasing and least when they were increasing. Providing information about likelihoods prior to a game had no impact on performance or decisions

Taken together the findings of this thesis improve understanding of how farmers perceive and manage climate-related risks.

3. Reducing risks and adaptation to a changing climate

The third objective of this thesis was to identify practical ways through which climate-related risks to fish farms can be reduced.

The findings of this study suggest that farmers can reduce climate-related risks at the farm level by a combination of following some of the better practices that already exist within the fish cage farming community, and by continuing to explore new technologies and practices. Examples of good practices include adjusting cropping calendar and stocking densities or providing supplementary aeration during critical low flow periods. Innovations being considered include using baffles upstream and strengthening cages with frames to prevent deformation of netting during periods of fast flows.

At the community, river reach or basin level farmers could reduce climate-related risks through collective action. Fish cage farmers have not traditionally formed very strong growers' clubs or associations as is found in Thailand for shrimp farmers, or in some locations in northern Thailand, for earthen pond farms. A next, obvious step is for fish farmers as a group, to get involved in, or influence, watershed and river basin management activities and committees – to ensure that the fish farming stake is at least acknowledged in watershed management and infrastructure decisions.

A key idea from this study is that improving climate risk management is a good, first step, in developing longer-term adaptation strategies. On-going monitoring and information sharing should also be encouraged to help farmers learn about levels of risks and whether these are changing or not. At the same time there is also a need to take a long-term view on investments in research and development, breeding programs, and institutional development (e.g. weather-indexed insurance, Chapter 5). The Department of Fisheries has an important role in these longer-term and strategic responses.

4. Limitations and future research

This study had several limitations. First, the quality of interview-based evidence can be affected by recall bias. Farmers, for example, are likely to remember, and recall accurately, more recent events than things which happened longer ago. They may also pay more attention to extreme events that are discrete (like a 2 day flood) than those which are prolonged (like the slow build-up of a 3 month drought). The timing of the surveys analyzed in this thesis, both in 2005-7 and 2011-13, were soon after major flood or drought events, so some of these difficulties may have been less than usual. On the other hand, this proximity to major events may limit the generalizability of some of the findings to other less extreme years.

Second, there were some ambiguities in our survey questions about climate risk management practices (Chapter 7) that meant it was not always clear whether a particular practice was already being undertaken, or the practice was something a farmer would like or intended to do, under particular circumstances, but had not yet done. We also did not get much information that would allow direct evaluation of the effectiveness of different risk management practices.

Third, while the surveys (Chapter 6) improved the understanding of how fish farmers perceive or evaluate affective risk or level of concern, they did not adequately distinguish perceptions about the likelihood of a particular climate event from the severity of its impacts. This distinction was addressed, in part, in the role-playing game (Chapter 8) but needs further clarification as it is a key element of risk perception in decision-making.

Fourth, while information was gathered about perceptions of past changes in climate and flow regimes, as well as general concerns about climate change, not much detailed evidence was gathered about how farmers expect climate-related risks to change in the future. Our lack of understanding of risk expectations is important because it could help better understand constraints and opportunities for developing longer-term adaptation strategies with farmers.

Fifth, most evidence gathered in this study related to the risks of high and low-flows. Much less information was collected about other weather phenomenon that vary seasonally or annually and which may be affected by climate change. The initial findings of this study suggest further work on cold spells, heat waves, periods with prolonged cloud cover, and intense rainfall events that trigger polluted run-off into rivers.

The findings and limitations of this study raise several issues for further research. First, the factors behind risk attitudes, such as feelings or emotions remained largely unexplored outside some basic insights from the role-playing game (Chapter 8). More work is needed on how risk attitudes, feelings and emotions influence risk decisions and actual risk management practices. One way to approach this would be to study decisions on stocking, with a focus, on availability of fry, the size and density of fry stocked and expected conditions up to harvest time.

Second, detailed investigations of how biophysical risks vary among rivers with different flow variability and among potential cage sites within rivers, and the mechanisms by which fish are stressed, injured and die is needed. This will require direct measurement of conditions in and around cages during extreme high and low flow events as well as around mass mortality events with other causes. Farmers' and experts have many reasonable hypotheses about the causes of fish deaths but few have been systematically investigated.

Third, it is clear that many fish farmers are part of local groups and networks (Chapter 4), whereas others work more independently. How these groups help farmers collaboratively deal with water management, disease and other access issues deserves further study. Such research could help improve understanding of social learning in adaptation more broadly.

Fourth, additional studies on the economic sustainability of fish cage farms (Chapter 3) are also needed. This should aim to better understand how climate, disease and other more business-related risks are managed jointly. This research should pay careful attention to the entry, exit and movement of fish farms and to ways in which losses and damages are dealt with financially.

Fifth, studies of impacts, risk perception, and risk management need better methods with which to systematically span the different spatial and time scales important for reducing climate-related risks to aquaculture production. More detailed, follow-up, with farmers is needed to understand how decisions are made about risk management practices on different time and space scales and which strategies are pursued in practice (Chapter 7). This means, for instance on the time scale, starting with imminent events, through dealing with seasonal varying risks of extreme conditions, to multiyear strategies to develop resilient farm enterprises.

Sixth, this study emphasized ex-ante risk management; in practice, coping strategies after events occur are also important for recovery and longer-term engagement in aquaculture (Chapter 7). Post-event strategies also deserve further study as these some may complement, or even undermine, ex-ante risk management practices.

This thesis, through a detailed exploration of a cage-based aquaculture system in northern Thailand, significantly expands the knowledge-base for evaluating the impacts of extreme events, and thus, climate change on aquaculture. The study also suggests that a focus on strengthening the management of climate-related risks can be a practical way to build capacities to adapt to future climate change.



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APPENDIX A

NON-LINEAR CANONICAL CORRELATION ANALYSIS

Appendix A1 Summary of non-linear canonical correlation analysis between risks and risk management practices. Values are the loadings or correlations between original variables in the 4 variable sets and the 6 canonical functions (C1-C6). Loadings > 0.3 on 1st dimension and >0.25 on all other dimensions are shown in bold.

Set		Dimension					
		1	2	3	4	5	6
Climate-related Risks	Flood / fast flows	.40	-.22	-.11	.28	.15	-.15
	Drought / low flows	.46	.12	.23	.03	.39	-.28
	Hot weather	.37	-.01	.29	.23	-.14	-.01
	Cold weather	.36	.30	-.06	.02	-.14	.01
	Heavy rainfall	.42	-.38	-.18	.02	-.16	-.09
	Cloud cover	.38	.07	.25	.15	-.20	.05
	Rapid temperature decrease	.51	.08	-.18	-.01	.15	.42
	Rapid temperature increase	.31	.38	-.10	.07	-.14	-.02
	Early wet season	.46	-.20	-.29	-.05	-.25	.12
	Late wet season	.39	.40	-.07	-.19	-.13	-.01
	Prolonged wet season	.48	-.24	.00	-.12	-.15	-.03
Non-climate related risks	Low quality stock	.32	-.06	-.18	.27	.23	-.15
	Low quality feed	.26	.23	-.10	.15	-.02	-.08
	Disease outbreak	.26	-.07	-.01	.16	.26	-.12
	Not enough time to look after fish	.26	-.17	-.04	-.18	-.19	-.33
	Theft of fish	.42	-.11	.06	-.14	-.01	-.06
	High feed price	.22	-.10	.10	.20	.00	-.04
	Chemical use	.29	-.07	.29	.19	-.32	.00
	Cages damaged	.39	-.19	.22	-.11	-.13	.06
	Low fish price	.28	-.03	-.14	.20	-.06	.19
	Small size at harvest	.28	-.11	-.04	.15	-.34	-.14

Set		Dimension					
		1	2	3	4	5	6
	Finding fish buyer	.37	-.29	-.22	-.01	-.17	-.17
	Low market demand	.48	.04	-.08	-.23	-.20	-.07
	Wastewater	.39	.03	.51	.09	.09	-.15
	High interest rates	.43	-.08	.12	-.14	-.02	-.19
	Repaying loans	.41	.16	.14	.10	-.24	-.16
	Government standards on practices	.47	-.34	-.02	-.06	-.16	.19
	Government regulations on river use	.50	.33	-.02	-.18	-.08	.08
Farm level risk management practices	Choose good stock	.12	.39	-.17	.27	-.02	-.12
	Reduce stocking density	.26	.17	.04	.28	-.14	-.09
	Choose high quality feed	.37	.21	-.18	.10	-.01	.01
	Monitoring fish frequently	.13	-.13	-.20	.15	-.09	-.08
	Monitor water quality	.37	-.02	.29	.18	.02	.03
	Reduce number of cages	.33	-.27	-.07	.06	-.13	-.05
	Select good cage location	.32	-.16	-.04	.06	.18	-.00
	Train staff/labor	.11	.30	-.22	.20	.06	-.01
	Monitoring 24 hours per day	.30	-.12	-.06	.18	-.09	-.17
	Provide supplementary feed	.17	.12	.24	.03	-.24	.02
	Consult experts	.36	.02	-.11	.18	.14	-.10
	Reduce expenses	.46	-.08	.03	.10	.33	.16
	Maintain financial reserves	.28	-.22	-.11	.06	.24	.18
	Follow market news	.36	-.20	-.26	.03	.04	.07
	Follow weather news	.24	-.08	-.13	.13	.09	.31
	Diversify income sources	.38	-.14	.25	.05	-.07	.14
	Seek government assistance	.33	-.24	-.20	.02	-.08	.07

Set		Dimension					
		1	2	3	4	5	6
	Keep good relations with neighbours	.32	.31	-.20	.12	.10	.12
	Collaborate to access market	.39	-.20	-.05	-.27	-.09	-.08
	Collaborate to borrow money	.46	.05	-.08	-.19	-.17	-.18
	Comply with government regulations	.41	.29	-.11	-.28	-.01	.09
	Cooperate to purchase inputs	.36	-.18	-.16	-.12	.05	.00
	Cooperatively sell harvest	.41	.04	-.07	-.11	.06	-.05
	Exchange knowledge with other farmers	.24	.04	.05	.28	-.06	.31
	Keep good relations with local officials	.27	.39	-.28	.13	-.17	.08
	Keep good relations with fisheries staff	.28	.26	-.28	.07	.01	-.03
	Try new technology	.32	.30	-.20	.20	-.11	-.06
	Reduce investment costs	.41	.21	.01	.25	.12	.08
	Work aside from fish farming	.40	.15	.14	-.11	-.02	.13
	Enter into production contracts	.42	-.03	.22	-.04	-.07	.22
	Stock staggered cohorts	.24	.32	-.14	-.17	-.13	.11
	Rear multiple species	.33	.26	-.07	-.25	.01	-.14
Reach and river basin	Dam water-release	.28	-.01	-.16	.19	.18	-.32
	Dam water-storage	.27	.34	-.23	.12	.11	-.32

Set		Dimension					
		1	2	3	4	5	6
risk management practices	Weirs to store water & maintain depth	.32	.37	.05	.26	-.14	-.07
	Irrigation water use in dry season	.40	-.21	.04	-.22	-.06	.07
	Urban and industrial water use	.32	.47	.03	-.16	-.03	-.04
	Flood prevention measures	.54	.03	-.26	.27	-.08	.01
	Dredging river	.45	.06	.08	.14	.32	.01
	River bank works	.48	.35	-.17	-.15	-.11	.06
	Boating activities	.29	-.04	.20	.03	-.19	-.03
	Control polluted run-off from farms	.47	-.02	.39	-.14	.08	-.20
	Animal manure/wastes	.49	-.28	.11	-.21	-.08	-.06
	Operation of water sluice gates	.44	.31	.27	.04	-.04	.10
	Participate in water management	.51	-.22	.04	.21	.10	.19
	Interact with water user groups	.51	-.11	.31	.02	.14	.21
	Follow water news	.52	.10	-.12	-.09	.20	.13



APPENDIX B

MODEL FOR FLOOD-RELATED LOSSES USED IN SIMULATION GAME

A simple model for flood-related losses from fish farms was constructed based on empirical survey findings. The model greatly simplifies reality by treating stocking level or density as a proxy variable for level of investment, and thus the riskiness of a cropping decision. The model was used to derive a pay-off matrix that could be into a fish farming simulation game. The assumptions of the flood risk model will now be described.

Value of harvest (H_d) at stocking density d is assumed to be directly proportional to, and double, the input costs (C_d):

$$H_d = 2C_d$$

In this system variable costs (for stock, feed, medication and labor or labor-opportunity) dominate costs (Chapter 3) so fixed costs were, in this simple model, assumed to be zero or spread over several crops.

Profit from a crop (P_d) if no flood ($f=0$) is then just equal to input cost or

$$P_{d,0} = C_d \text{ if } f=0$$

Profits from a crop if a flood ($f=1$) occurs is adjusted for reduced value of harvest ($1-L_d$) and non-harvest related loss (k), for example, to cages or equipment, assumed to be proportional to cost:

$$P_{d,1} = 2 C_d (1-L_d) - k C_d \text{ if } f=1$$

The fraction of harvest lost for flood was set at following values for three stocking densities (low, medium, high): $L_{lo}=0.15$, $L_{md}=0.65$, $L_{hi}=1$. The non-harvested costs was set at constant $k = 1.7$.

The expected pay-offs for probability of flood α are then:

$$E(P_d) = \alpha P_{d,1} + (1-\alpha) P_{d,0}$$

The pay-off matrix for this model was calculated using above assumptions and is shown in the table in Figure 31 in the main text along with the expected pay-offs for each fixed stocking strategy across a range of flood probabilities. The values used in the actual game were

derived from the standardized matrix where high stock, no flood, has a value of 1 by multiplying all entries by 100 – interpreted with farmers in units of a thousand Baht. The average expected payoff in this game with random strategies for range of probabilities from 0.1 to 0.5 is 19 (thousand) close to the observed median profit for a last harvested crop of 20 (thousand) baht.

Appendix B1 Payoff matrix settings for game treatments.

Game	Flood		Flood Payoffs				No Flood Payoffs				Random Payoff Mean
	Likelihood	Impact	Low	Mid	High	SD	Low	Mid	High	SD	
1	0.1	1	0	-70	-170	15	30	70	100	5	52.0
2	0.2	1	0	-70	-170	15	30	70	100	5	37.3
3	0.3	1	0	-70	-170	15	30	70	100	5	22.7
4	0.4	1	0	-70	-170	15	30	70	100	5	8.0
5	0.5	1	0	-70	-170	15	30	70	100	5	-6.7
6	0.3	2.111	0	-147.8	-358.87	15	30	70	100	5	-4.0
7	0.3	0.5	0	-35	-85	15	30	70	100	5	34.7
10	0.3	1	0	-70	-170	5	30	70	100	5	22.7
11	0.3	1	0	-70	-170	45	30	70	100	5	22.7
12	0.1	1	0	-70	-170	15	30	70	100	5	52.0
13	0.3	1	0	-70	-170	15	30	70	100	5	22.7
14	0.5	1	0	-70	-170	15	30	70	100	5	-6.7
15	0.1	1	-7	-22	-57	15	8	48	78	5	37.3
16	0.3	1	-7	-22	-57	15	8	48	78	5	22.7
17	0.5	1	-7	-22	-57	15	8	48	78	5	8.0
18	0.3	1	51.3	-18.7	-118.7	15	8	48	78	5	22.7
19	0.1	2.416	0	-169.1	-410.7	15	30.0	70	100	5	40.67
20	0.1	8	0	-560.0	-1360.0	15	30.0	70	100	5	-4.00



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