Property Rights Regimes in Complex Fishery Management in Tonle Sap: Combining Choice Experiments and Agent-Based Simulations

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The candidate confirms that the work submitted is her own, except where work which has formed part of jointly-authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others.

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Abstract

Overexploitation, conflicts and inequality in resource use are common consequences of many fishery management systems such as those in the developing countries. A better understanding of the spatial dynamics of fisheries and the causes of past failures in management is needed in order to provide more effective management systems. The small-scale inland fisheries in Tonle Sap are used as a case study in this thesis, as they combine property rights and conservation in the form of distinct management zones (private, common and conservation zones) with access to private fishing grounds determined through allocation of licences through an auction system. This thesis uses a choice experiment approach to investigate how this allocation system affects different groups of fishermen. The results indicate that the auction system is likely to further the advantages of better-off fishermen irrespective of the characteristics of fishing lots. This suggests that it is unlikely that the design of fishing lots in itself would be an effective way of securing access to fishing resources for all types of fishermen. Agent-based modelling is then used to examine the links between conservation and private property rights, through an analysis of the spatial effects of property rights and conservation, using different management system designs and focusing on the interactions between heterogeneous fishermen, fish biomass and fishing regulations. Private property is found to promote better fish biomass conditions on its own, but does not necessary generate the best conservation or socio-economic outcomes for fishing communities when evaluating the entire fishery. Conservation zones perform better when the reserves are located in baseline quality fish habitats and the reserve size is large. The results show how positive effects on fishery sustainability can be achieved. Effective management for subsistence fisheries can be designed using property rights and conservation areas, combined with other fishery regulations and enforcement, in order to ensure biological and socio-economic sustainability.

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List of Abbreviation

ABM	Agent-based Modelling
CDRI	Cambodia Development Resource Institute
CE	Choice Experiments
CV	Contingent Valuation
CLM	Conditional Logit Model
CPUE	The Catch per Unit Effort
DoF	Department of Fisheries (now is FiA)
FAO	Food and Agriculture Organization
FiA	Fisheries Administration
FPAs	Freshwater Protected Areas
GIS	A geographic Information System
GMS	The Greater Mekong Sub Region
ITQs	Individual Transferable Quotas
LCM	Latent Class Model
MAFF	Ministry of Agriculture Forestry and Fisheries
MPAs	Marine Protected Areas
MW	Megawatt (one million watts)
NGOs	Non-governmental Organizations
NTZs	No-take zones
TAC	Total Allowable Catch
UNCED	United Nations Conference on Environment and Development
USD	United States dollar
WTA	The Willingness to Accept
WTP	The Willingness to Pay

Chapter 1

INTRODUCTION

The current situation in fisheries is a global concern because of declining fish species, degradation of fish habitats and decreasing natural fish populations (Hilborn *et al.*, 2003; Worm *et al.*, 2009; FAO, 2012). The fishery sector is important because it contributes to employment, trade, food security and nutrition, especially for the poor as it is often the cheapest source of animal protein (FAO, 2013a). The majority of fishery studies have focused mainly on marine fisheries leaving inland fisheries relatively understudied.

Fishery resources are a classic example of an open access resource (Gordon, 1954) where the market partly fails because it cannot exclude any users and avoid rent dissipation (Cheung, 1970). One solution to this problem is privatisation, which assigns individual ownership over resources with the expectation of an improvement in efficiency of resource use. According to the Coase theorem assumption, private property rights are understood to ensure efficiency in fisheries because it is assumed that there are no transaction costs, and the initial allocation of property rights does not affect the marginal valuation of resources (Grafton *et al.*, 2000).

This study investigates whether securing private property rights to fishery resources and establishing conservation reserves can discourage overcapitalization and encourage conservation in a developing country context. Tonle Sap inland fisheries in Cambodia are used as a case study, not only because of their importance to global fish catches but also because Tonle Sap demonstrates the complexity of wetland systems and mixed fishery management systems. Developing countries contributed approximately 90% of total inland fisheries output to the global fish caught in 1998 (Smith *et al.*, 2005).

Tonle Sap has been subjected to a combination of methods to regulate access to fishery resources. The Fishery Administration (FiA) assigned property rights and employed market-based approaches by privatising part of the wetlands using an auction system and then integrated this with zonal designation of protected areas. The wetlands were divided into conservation zones, fishing lots (private areas), and public areas (common areas) for fishing purposes. The zonal management was expected to avoid the collapse of fish biomass and improve viability of fish populations. The conservation zones were protected from all fishing activities with the expectation that this would lead to natural fish stock enhancement. Spillover effects were expected to lead to an increase in fish biomass, sizes and density (Russ and Alcala, 1996a; Wantiez *et al.*, 1997). The fishing lots were designated plots for commercial fishing during a defined fishing season and they were usually located in the most productive fishing grounds. Private concessionaires were able to bid for exclusive fishing licences. The public fishing zones were areas outside these two zones. This zone was open to everyone to fish at any time of the year.

There were problems resulting from this management system including decreasing fish populations, habitat degradation (Nuorteva *et al.*, 2010), and conflicts of access to fishing grounds among lot owners and subsistence fishermen (Bonheur and Lane, 2002), which were caused by increased inequality in access to valuable fishing grounds. These problems led to the abolishment of fishing lots in 2012 for at least 3 years to reduce conflict over lot boundaries and to allow fish stock rehabilitation (Royal Government of Cambodia, 2012). All previous private fishing lots were converted into public fishing grounds. The management of the fishery is now being reconsidered and options need to be developed to develop a more sustainable management system. It is therefore important to understand why the previous management system failed. This research was established to investigate the situation for poorer and more vulnerable fishermen and evaluating the effects of the private property rights systems on them. The thesis focuses on small-scale fishermen because they are the largest group in Cambodian fisheries but they are also the most vulnerable because they have limited skills and budgets. In addition, information on small-scale fisheries is quite limited compared to commercial fisheries. This may have led to underestimates in past evaluations of the resource values used to set policies for small-scale fisheries (Worm *et al.*, 2009; Basurto *et al.*, 2012).

Few studies investigate the consequences of management on small-scale fisheries. There are several studies which investigate Tonle Sap fisheries but most of them focus on analyses of fish biology and/or ecosystem management (e.g., Kummu *et al.*, 2006; Lamberts, 2006; Baran *et al.*, 2007a; Lamberts and Koponen, 2008; Kummu and Sarkkula, 2009). Other studies (e.g., Navy *et al.*, 2006; Kimkong, 2007; Nuorteva *et al.*, 2010) emphasise socio-economic and livelihood issues in the Tonle Sap wetlands. The work of Navy *et al.* (2006) estimates the value of fishery resources to livelihoods surrounding Tonle Sap Lake using secondary data. They found that the lowest income group was small-scale fishermen who were highly reliant on the Tonle Sap wetlands. Thus, security of access to resources should be a priority for sustainable management that includes small-scale fishermen.

Some research has also aimed to understand and analyse the commercial fishery management system. For example, Allebone-webb and Clements (2009) studied a commercial fishery in one of the most productive fishing lots (fishing lot 2 in Battambang Province) in relation to conservation objectives. They found that there was an overlap between conservation areas and fishing lot “number 2” in practice even though, according to fishery regulations, commercial fishing and conservation areas should be separated. This overlapping area benefited both biodiversity and conservation objectives because the private property rights helped to protect wildlife and fish larvae, more than just the conservation area designation. Their research demonstrates the importance of understanding how property rights and zoning impacts fishery resources.

Other research has made use of models to understand wetland processes. Kummu *et al.* (2006) developed an integrated modelling system of water resource management in Tonle Sap by connecting a hydrodynamic model with socio-economic information (social, economic and political) to provide information about ecosystem processes. The model outputs included, for example, inflows, flooding characteristics and pollution dispersion. This information can be used to predict the impacts from development plans on the lakes’ ecosystem and riparian communities. A Bayesian model was also used to analyse different development policy scenarios for Tonle Sap (Varis and Keskinen, 2006). The objective of this Bayesian model was to evaluate risks to numerous components of the social and environment systems under different Mekong policy strategies. These two papers provide an understanding of the overall system of Tonle Sap and focus on physical and political aspects, however the fishery sub-system that includes the interactions of fishermen behaviours and dynamics of fisheries still remains unstudied. By focusing on the fishery sub-system, this thesis contributes to research on the interactions between fishing behaviour and the dynamics of fisheries to the research of others in order to build a holistic view of the Tonle Sap wetland. This thesis not only contributes to knowledge on Tonle Sap fisheries but also adds to literature on inland fisheries management.

1.1 RESEARCH AIM AND OBJECTIVES

This research aims to enhance understanding of fishery management systems and the implications for sustainable fisheries through the interactions of fishermen, governance systems, and fishery resources under different designs of property rights and conservation areas. Understanding the effects of interactions among these three main factors will lead to improved fishery sustainability, measured in terms of fish biomass and socio-economic conditions of small-scale fishing communities. This aim is achieved by tackling the following specific objectives:

1) To assess the implications of the distribution of fishing rights and benefits from Tonle Sap wetlands, and to explore the scope of widening participation by small-scale fishermen;

1.1) by studying how the allocation system for fishing rights affects small-scale fishermen;

1.2) by exploring whether different groupings of small-scale fishermen can be identified and characterised, measured in terms of differences in their valuation of attributes of fishing lots, and their behaviour in an auction market;

1.3) and by investigating the preferences of fishermen toward fishing lot characteristics.

2) To investigate the spatial consequences of property rights systems and whether the application of private property rights encourages sustainability in fisheries management;

2.1) by developing a spatial fishery model for assessing various policy options;

2.2) by exploring the spatial dynamics of fishing intensity and fish biomass conditions under different policy scenarios;

2.3) and by investigating the sustainability of fishermen's livelihoods.

3) To examine the spatial effects of inland conservation reserves through the interactions of harvesting intensities and fish stock conditions under different management zones (private, common, and conservation zones).

3.1) by investigating the effects of proportion (size) of reserved areas in inland fisheries;

3.2) by examining the effects of habitat quality on fishery sustainability;

3.3) and by exploring the effects of different patterns of reserve distribution.

1.2 THESIS ORGANIZATION AND CHAPTER OVERVIEW

This thesis comprises eight chapters. Following this first introductory chapter, the second chapter provides a literature review and a description of the case study while the third chapter outlines the theoretical framework. There are three empirical chapters and each empirical chapter is presented as a journal paper with literature review, methods, results and discussion. The first empirical chapter, Chapter 4, presents an analysis of fishermen behaviours using a Choice Experiment approach. Chapter 5 provides an explanation of the agent-based model specification for the next two empirical chapters. Chapters 6 and 7 demonstrate different versions of the agent-based model, which has been used for spatial analyses of the fishery management system. The last chapter discusses the main findings of the thesis, draws together its conclusions, considers some of its limitations and makes recommendations for future research. A more detailed outline of each chapter follows:

Chapter two: This chapter reviews the relevant fishery literature and describes the Tonle Sap wetlands. It starts with an introduction to inland fisheries, followed by a brief overview of management approaches that have been used for fisheries. Then, the chapter reviews the literature related to social simulation approaches that have been used as research tools in fishery management research. The Tonle Sap Wetlands are then introduced as a case study, outlining the biophysical environment, relevant livelihoods, and setting it in the context of historical and contemporary management of Cambodian fisheries. Tonle Sap is important because it is the biggest floodplain lake and one of the most productive fisheries in Southeast Asia. It has both local and transnational importance because it supports agriculture over a large area and is the main fish nursing ground for the Mekong watershed. Zonal management was established in Tonle Sap to ensure fishery sustainability. However, fish degradation, conflicts among users, illegal fishing activities, and limits on access to valuable fishing grounds for small-scale fisheries are problematic, leading to a need for research to support improvements in fishery management.

Chapter three: This chapter elicits a thesis framework focusing on research methodology. The chapter begins with the thesis motivation, which is derived from the fishery problems in Tonle Sap, and is followed by an analysis of theoretical concepts underpinning fishery management approaches. Then, it provides a framework for how problems can be addressed by understanding key components of the fishery system, and how the methodology as outlined can be used to improve the understanding of the management system. The interactions between fishermen, fishing regulations and fish biomass are key to the analysis approach taken in this thesis. The methodological framework presents choice experiment approach and agent-based simulation techniques, which are applied to examine fishery management. Choice experiments are used to simulate fishermen behaviour in an auction market and identify different characteristics of small-scale fishermen in Tonle Sap. Spatial analysis of fishery dynamics is undertaken using agent based modelling. This approach is used to analyse the consequences of property rights and conservation approaches. The combination of choice experiments and agent based modelling helps improve the understanding of past management and current fishery dynamics.

Chapter four: The first empirical chapter investigates how the auction-based fishery management system affects different groups of small-scale fishermen by using a Choice Experiment. The management of the Tonle Sap wetlands in Cambodia has previously been divided into three different management zones; conservation, open access fishing, and private fishing. Rights to the private fishing zone involved auctions for exclusive rights to temporarily designated fishing lots. The main concerns have been an observed degradation of fish biomass and limited access to rich fishing grounds for small-scale fishermen. As a result, the system has been abolished and new fishery regulations are currently being considered. This chapter aims to explore the auction-based system by investigating how it affects different groups of small scale fishermen and how different characteristics of the fishing lots affect the bidding. The choice experiment approach was used to model fishermen’s choices in a hypothetical auction market by offering fishermen two options; purchase or non-purchase of potential fishing lots. The second option means fishing only in the communal fishing grounds. The preferred latent class model with two segments of fishermen showed that the bidding behaviour of the more privileged group out-competes the other group irrespective of the fishing lot characteristics. This result suggests that it is unlikely that the redesign of the auction system itself would be an effective way of securing access to fishing resources for the two observed groups of fishermen. This implies that open access fishing grounds and/or other regulations may also be needed in future management as they serve an important role for the poorer segments of the fishing community.

Chapter five: The chapter introduces the general concepts of social simulation and agent-based simulation approaches and presents the model settings and protocols for the spatial analyses in the following chapters (Chapters 6 and 7). This approach deals with the complexity of fisheries involving multiple users, different gear regulations, seasonal closures, and fishing zones. The spatial models address the gap identified in Chapter 4 concerning the importance of spatial distribution of rights and resources. The model is set for small-scale fisheries by adapting past management experiences of fisheries (both small-scale and commercial) in Tonle Sap. The main components of the model consist of the dynamics of fish biomass, fishing regulations, and heterogeneous and autonomous fishermen.

Chapter six: This chapter aims to develop a spatial model to examine whether private property rights encourage fishery sustainability by investigating the spatial effects of a property rights system in terms of socio-economic and biological aspects, using agent-based modelling. A model has been used to explore the consequences of spatial interactions between fishermen and fish biomass in two fishing zones: common and private fishing zones. The results show that private property rights over private fishing zones provide better fish stock conditions and fishing profits compared to common property rights in common zones. This implies that private property rights may help to improve both economic efficiency and fish biology. In addition, different combinations of private and common fishing grounds were simulated. These results show that when common fishing grounds dominate, higher fish biomass and fishing profits are achieved compared to when private property rights dominate. This may be because there is less competition between fishermen when common areas are more dominant.

Chapter seven: This chapter also uses agent-based modelling to analyse spatial effects, this time focused on different arrangements of conservation reserves. Conservation reserves have been used as part of fishery management tools with the expectation of improvement in fishery sustainability, as they reduce harvesting pressure at least within the conservation zones themselves, and spillover effects may benefit fishing grounds as well. Three different management zones consisting of private, common, and reserve zones were included in the model. The spatial effects of reserve sizes, patterns and locations (habitat quality) were evaluated using fish biomass and socio-economics as indicators of fishery sustainability. The model results show that larger reserve sizes, square patterns and location in areas of normal habitat lead to more sustainable fisheries. However, conservation zones need to be used along with other management tools, such as restrictions on fishing effort, in order to maximise their benefits.

Chapter eight: The final chapter outlines the main thesis findings and suggests opportunities for future work. The results presented in this thesis contribute to debates about property rights and conservation. Although private ownership and/or conservation zones have the potential to promote fishery sustainability, future management should not focus only on either private rights or conservation. The combination of private, common and conservation areas can be an option to improve biological and socio-economic sustainability and generate greater benefits for fishing communities. How the combination of property rights and conservation is designed is more important, as is the need to implement these management designs with other fishery regulations/laws. Auction-based methods for exclusive fishing licences do not distribute access equally between small-scale fishery households so mechanisms for the distribution of private property rights need to be carefully designed. Finally, Chapter 8 concludes by outlining how this research contributes a new methodological approach using choice experiments and agent-based modelling to better understand and manage small-scale inland fisheries.

Chapter 2
UNDERSTANDING INLAND FISHERIES AND THE TONLE SAP CASE STUDY

Fisheries are important because they provide food security and create employment for households in wetland areas (FAO, 2005). Although, small-scale fisheries in many countries (e.g., Indonesia and Vietnam) are important for national economies (Béné *et al.*, 2010), they often get limited research attention (Béné and Friend, 2011). This thesis aims to enhance understanding of small-scale inland fisheries through the interactions of fishermen, governance systems, and fishery resources under different designs of property rights and conservation areas. Understanding the effects of interactions among these three main factors will lead to improved fishery sustainability. This chapter provides an overview of the literature related to inland fisheries and identifies the research gap that has motivated this research. This is followed by a description of the case study; the Tonle Sap wetlands in Cambodia. The first section presents a synopsis of the key characteristics of inland fisheries to identify factors influencing the common challenges, such as degradation of fish stocks and habitats. Different fishery management tools are evaluated and different simulation approaches are assessed. The second section presents the case study, outlining physical characteristics, livelihoods, fisheries, and the problems related to fishery management focusing on small-scale fisheries.

2.1 INLAND FISHERIES

Inland fisheries have been important for human sustenance since the pre-historic era. They contribute enormously to food security, especially for low income households in rural areas because they provide cheap and numerous animal protein supplies (FAO, 2013b). Protein from fish was calculated as contributing 15.3% of total animal protein consumption in 2000 (FAO, 2003b) and approximately one billion people were dependent on this protein as their primary source of animal protein (Allan *et al.*, 2005). The income from fisheries contributes to gross domestic product (GDP) in many countries, especially from the large-scale fisheries. Inland water resources have also been used for other purposes such as recreation, water quality, and flood control (Welcomme, 2001). Inland fisheries are crucial to livelihoods worldwide, nevertheless, they have received less attention as discussions have been more focused on marine fisheries (Hilborn *et al.*, 2003; Allan *et al.*, 2005).

2.1.1 Fish catches and difficulties in inland fisheries

The annual yield of inland capture fisheries, including from aquaculture, is reported to be over 10 million tonnes (Welcomme *et al.*, 2010; FAO, 2013a), although these figures are considered to be perhaps 2 or 3 times lower than the real catches (FAO, 2013a). Catches from subsistence fisheries, recreation fisheries, and agriculture-related sources such as rice-field fisheries were mostly excluded from the report. The amount of inland capture has increased almost linearly since the early 1950s (Welcomme, 2011). There are also numerous species of inland fish that are not usually reported in capture statistics. Around 41% of all fish species (approximately 11,500 fish species) are exclusive to inland fisheries and around 1% are diadromous (when fish migrate between the sea and fresh water) (FAO, 2013b). From FAO's statistics in 2010, the Asian continent made the biggest contribution (more than 50%) to world captures, particularly China, followed by Africa.

However, inland fisheries have been under threat for a considerable period of time. First and foremost overexploitation has been identified as a key factor, especially in tropical fisheries. Fish stocks and biological diversity of fish species have been continuously decreasing (Arlinghaus *et al.*, 2002; Allan *et al.*, 2005) and this is mainly attributed to overfishing. Vertebrate species, such as fish, are mainly affected by overfishing, while invertebrate species, microbes and megafauna are more disturbed by other threats such as habitat degradation (e.g., eutrophication, removal of vegetation, sedimentation), pollution from industrial and domestic point sources, and modification of water channels through dams and irrigation (Dudgeon *et al.*, 2006). However, most inland captures depend on recruitment from fish populations that are affected by habitat loss and environmental degradation too. Failure to fully account for inland captures is another threat to improvement of inland fisheries. These threats reduce the opportunity for fisheries management to improve food security, and increase the social and economic advantages from inland resources (FAO, 2013b).

Apart from biological and environmental threats, social conflicts also impact on inland fisheries. The water resources that supply fisheries are also subject to other uses such as domestic use of water, agriculture, wildlife conservation, power generation, flood control, navigation and industry. Conflicts among users are common, especially in tropical countries (Welcomme, 2001; FAO, 2013b). FAO (2003a) have suggested that policy and institutional management frameworks are important to reduce conflicts between fisheries and other sectors, by coordinating management plans of shared resources. So, fishery management needs to be implemented in the context of other uses in order to tackle the key threats identified and maintain fishery resources for future generations.

In addition, there is an important relationship between poverty and small-scale fisheries where poverty is inversely related to fishery resources and catch levels (Béné *et al.*, 2010), i.e., as availability of fishery resources and catch levels in communally accessed fisheries decrease poverty increases. If many fishermen compete for few fish stocks, only small profits will be generated. In addition, aspects of poverty, such as food insecurity and low income, can be key drivers of environmental degradation as they force people to over exploit fishery resources (Cowx and Portocarrero Aya, 2011). In these cases, the actions of a dominant group of small-scale fishermen can affect the condition and functioning of inland fisheries overall.

2.1.2 Fishery management

The management of Inland fisheries has a long history. In the Middle Ages in Europe, fishermen were split into guilds and were charged for exploitation and resource management. Landings were controlled in seventeenth century in France and local traditional regulations were reinforced, mostly by religious sanctions, in other parts of the world (Welcomme, 2001). This shows that limited fishery resources have been a concern since ancient times, when the first recorded control measures were introduced.

There are three main objectives for fishery management, which have emerged from the UNCED process, the Convention on Biological Diversity and FAO Code of Conduct for Responsible Fisheries: 1) preservation of the diversity of living aquatic resources, 2) fishery sustainability, and 3) fair distribution of fishery and ecosystem benefits (FAO, 1995; Welcomme, 2001). Fisheries management is defined as "the integrated process of information gathering, analysis, planning, consultation, decision-making, allocation of resources and formulation and implementation, with enforcement as necessary, of regulations or rules which govern fisheries activities in order to ensure the continued productivity of the resources and accomplishment of other fisheries objectives." (FAO, 1997, p. 7). The methods of fishery management are frequently based on science in order to protect fishery resources and to provide evidence for the level of sustainable extraction. The focus for objectives in inland fishery management differs for developed and developing countries. Developed countries focus more on recreation and conservation, while developing countries have their focus on food security (Arlinghaus *et al.*, 2002).

Conventional approaches to fishery management are usually regulated by national governments and focus on regulations that control the types of gear that can be used, catch amounts and limited fishing seasons (Welcomme, 2001). Regulations directly or indirectly control either input access or outputs and are biological or technical in nature. These sets of rules are implemented through monitoring and surveillance. Examples include ownership systems (such as fishing licences[1] and quotas), closed seasons, conservation areas, gear restrictions, and a limitation on the number of fishing vessels. Fishing methods in inland fisheries are dissimilar from marine fisheries because there is greater variability. For example fishermen in inland fisheries use a wide variety of fishing gear that includes hooks, nooses, bait holders, barriers, traps, nets, seines and trawls. As a result of this greater variability, the biological and technical fixes used for marine resources may not always apply in inland fisheries.

When the classic biological and technical approaches to fishery management have failed solutions have been drawn from other disciplines, namely economics and sociology. For example, economists focus on improving economic efficiency by promoting transferable quotas (Grafton and McIlgorm, 2009). The quota system

[1] Fishing licences are normally issued by government and ideally their numbers are limited by scientific calculation of CPUE and fishing effort. In this sense, it is almost impossible to impose a licence system on small-scale fisheries, especially in flood plain systems, because it involves many fishermen fishing for subsistence over a very wide geographical area (Welcomme, 2001).

contributes to decreases in excess capacity but does not deal with inequality in the distribution of access or with ecosystem protection. Sociologists meanwhile, have addressed fishery problems using participatory management approaches (Wilson *et al.*, 1999). These also focus on access control or defining ownership, as in more conventional approaches, but power is shared between government and local communities. In particular, community-based or co-management strategies (e.g., Pomeroy, 1995; Bruckmeier and Höj Larsen, 2008) have been designed to improve distributional equity. However, these do not promise economic efficiency or conservation.

It is clear that there are strengths and weaknesses to each approach. Historically, these approaches have been applied to inland fisheries and adapted to local contexts individually. However, if the complex, diverse and dynamic inland fishery problems are to be addressed then the single perspective and approach might not be sufficient; hence there is a need for a mixed approach or integrated techniques for research and governance in order to successfully achieve the goals of sustainable fishery management.

Biologists and ecologists widely use conservation, or zonal, management in research on fisheries (Roberts *et al.*, 2005). Conservation management involves creating protected areas, providing stock enhancement, regulating fishing activities, and restoration and rehabilitation (Cowx and Portocarrero Aya, 2011). Conservation areas are portions of environment that are reserved to reduce disturbance from fishing activities so as to allow natural processes to replenish fish populations (Suski and Cooke, 2007). Conservation can not only enhance ecosystem protection by reducing fishing on spawning stocks, but also can improve recruitment and so fish abundance. It is also expected that the benefits in conservation areas will spill over into neighbouring areas, increasing fish populations in areas surrounding conservation zones and so increasing fish captures. While conservation can help to preserve local biodiversity and fish habitats it is not designed to lead to improvement in harvesting efficiency or equity. Marine protected areas (MPAs) have been well established, while there are fewer freshwater protected areas (FPAs), which have also been slower to establish (Herbert *et al.*, 2010). This may be because of poor scientific knowledge about the conditions of freshwater fish (status and disturbances). Ecosystem based approaches are also considered promising for sustainable fisheries (e.g., Pikitch *et al.*, 2004; Smith *et al.*, 2007). These approaches emphasise ecosystem components and interactions in order to maintain a healthy ecosystem. Healthy fish stocks and ecosystems are thought to ultimately lead to a healthy society in terms of food, income and jobs (Branch *et al.*, 2006).

Not only have conservation approaches been used in fishery management but ownership systems have also been considered as a management tool to promote fishery sustainability (Welcomme, 2001). The implications of common property resources or open access resources have been broadly claimed as the major cause of fishery depletion. In economic theory, lack of property right leads to a race among fishermen to exploit fishery resources (Dewees, 1998) because fishermen consider short-term profits over long-term profits. Ownership systems create incentives for fishermen to protect the fishery resource as an asset (Sumaila, 2010) and reduces the race to over fish in the long-term. FAO (2003a) have pointed out that where fishing rights are granted for a long period, fishermen have greater interest in managing fisheries sustainably. In contrast, research has shown that fishermen might attempt to generate a quick profit by intensively fishing if fishing rights are assigned only for a short time (Yandle, 2007). In both these contexts implementation of access policies, such as gear limitations, together with the ownership system can help control fishing intensity (Grafton *et al.*, 2006). Ownership system approaches have been applied to fishery management for a long time. For example, traditional methods for inland fishery management in Africa has been dominated by a common property approach (GmbH, 2002). Property rights over resources were given to groups or communities through social consent. To compliment with other prevailing norms, this approach offered incentives to invest and preserve fishery resources. Whereas, private property rights are very uncommon for inland fishery management in Africa they are more common in Asia e.g., in Cambodia.

One popular and classic example of using property rights for fishery management is individual transferable quotas (ITQs), which has been used in state regulation of marine fisheries (Grafton *et al.*, 2000). ITQs are catch share quotas providing exclusive use and transfer rights to concessionaires, as a means to raise fishing efficiency and returns to the concessionaires. Principally, ITQs are given as a proportion or percentage of total allowable catch (TAC[2]) of fish (Dewees, 1998)

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[2] As ITQs are based on catch quotas, the abundance of fish stocks needs to be estimated precisely, however these estimates are sometimes subject to uncertainty and political interference (Sumaila, 2010). Then, if

and can be transferred by trading in an open market or through an auction system. Dewees (1998) revealed that the operation of ITQs did indeed improve economic efficiency. However, when the right holders do not have full property rights[3], they may not be motivated to conserve the resource in the long term (Hannesson, 1996; Bromley, 2009). This can result in high-grading, discarding, and misreporting. Consequently, individual fishermen will gain the benefits of these illegal activities in the short-term only; whereas the long-term costs will accrue to all participants. Property right allocation through an ITQ system covers only the flow of fishery resources but not the fish stocks and their environment. Controversy, the quotas may end up in the hands of a few large business enterprises due to their economic and political power. Recommendations to improve the quota system include the use of stock assessments, strong arms-length monitoring and control, and integration with an ecosystem based approach (Sumaila, 2010).

The allocation of quotas or fishing rights can be distributed by different alternatives, such as administrative decision, lottery or auction (Morgan, 1995). Administration is generally centralised, depending on each case. Entry to fishing grounds can be limited through grandfather clauses to fishermen who receive grandfather rights (Karpoff, 1989; Libecap, 2007) while lottery allocations might lead to mismatches between quotas and fishing capacity (Morgan, 1995). Auction systems are market-based mechanisms used in order to enhance the transparency of quota allocation and to divert resource rent to the national budget. Auctions provide economic efficiency by identifying market demand and appropriate prices for the quotas. Potential resource users are identified through the auction as the bidders with the highest use-values for the fishery (Milgrom, 1985; Morgan, 1995). Theoretically, the willingness to pay (WTP) of the successful bidder would be equal to the maximum resource rent but there is a chance of paying less. Over bidding can happen if bidders under estimate the cost of policing their rights. The concession fee, the transaction cost (i.e., the cost of participating in the market) and enforcement costs are all additional costs (Smith and Panayotou, 1992).

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significant factors have not been addressed suitably, overestimates of resource stocks can lead to stock collapse.

[3] The holders of full property rights are provided with 1) a complete security, 2) exclusivity and 3) unrestrained transferability.

There are advantages and disadvantages to the auction system. The auction system was considered a fair distribution system in Estonia (Peipsi-Pihkva Lake) and in the Russian Far East (Anferova *et al.*, 2005; Sumaila, 2010). It has also contributed to the state budget in Cambodia and the Russian Far East (Tana and Todd, 2001; Anferova *et al.*, 2005). Although the auctions supplied more income for Russian federal budgets than expected, the additional cost e.g., debt (Vetemaa *et al.*, 2002; Anferova *et al.*, 2005) encouraged many business enterprises to harvest more than the quota allowance, particularly as the monitoring and enforcement system was not strong (Anferova *et al.*, 2005). The auction in Estonia provided an opportunity for local inhabitants and new small enterprises to access fishing resources and the number of small enterprises grew as a result. These were mainly attractive to the most efficient users (Vetemaa *et al.*, 2002). Even though the advantages of auctioning property rights were identified, the system in Estonia is no longer operational. Fishing rights over Peipsi-Pihkva Lake were first auctioned in 2001 and the system was terminated in 2003 on political grounds, as the political parties were concerned that they would not gain the votes of auction opponents in the next election. Similarly in the Russian Far East, the auction mechanism was introduced in 2000 and was cancelled in 2003 because of depletion of fish stocks and the effects on the economic performance of the fishery sector. Both of these cases illustrate that the auction system needs to be well designed to achieve both economic efficiency and conservation (Morgan, 1995). There is a need for holistic auction designs, which should be considered case by case, taking into consideration factors such as the ability of fishermen to participate in the auction and political influences.

Fishery management also links with social issues as it influences equity and socio-economic conditions in fishing communities. For example, good fishery management can assist in reducing poverty because fisheries act as a source of income and employment (Cochrane and Garcia, 2009). People who benefit from fisheries are not only fishermen but also fish traders, processed fish makers, fishing gear makers and boat manufacturers (Welcomme, 2001). However, there are also conflicts between groups of fishermen and non-fishery interests, such as tourists, who use the same space for different purposes. For example, fishing gear from subsistence fisheries can be destroyed by tourist motorized boats (International Centre for Environmental Management, 2003), conflicts over the use of water can arise between farmers and commercial fishermen (Degen *et al.*, 2000), and there can be conflicts over access to certain areas between small-scale fishermen and commercial fishermen (Keskinen *et al.*, 2007). Hence, conflict reduction is another important objective in fishery management.

The mixed fishery management system (combining property rights, conservation, and auction-based approaches) in Tonle Sap is an interesting case to be evaluated. Ownership is not only assigned over flow of fishery resources through ITQs but also over a fish stock in particular wetland areas. As a result understanding fishermen behaviour towards regulations and their interactions with the dynamics of fish stocks is of key importance. Most fishery management studies, conducted predominantly in marine fisheries, emphasise a balance of fish stocks and optimum harvesting levels (e.g., Ransom and Mertz, 1998; Ami *et al.*, 2005; Armstrong, 2007; Beddington *et al.*, 2007). Research on fishermen behaviour (e.g., Branch *et al.*, 2006; Hilborn, 2007; Fulton *et al.*, 2011; Andersen *et al.*, 2012) has developed since the early 1990s and focuses particularly on allocation of fishing effort (Branch *et al.*, 2006). No research has focused on simulating the consequences of interactions between fishermen behaviour and fishery dynamics under property rights and conservation management approaches.

2.1.3 Modelling fishermen behaviour

Suitable methods for modelling fishermen behaviour depends on the hypothesis, data, sample, and the decision which is to be modelled. The Choice Experiments (CE) approach is used to model behaviour of fishermen in this thesis. This is because it can analyse behaviour of heterogeneous fishermen and identify different characteristics for groups of fishermen. The model is based on utility maximisation or optimisation and applies consumer theory in order to investigate human decisions (Simon, 1959).

This microeconomic theory focuses on human preference as the main factor influencing behaviour and has been widely used in marketing and business (e.g., Simon, 1979). Many studies have used CE for valuation purposes through measurement of WTP/WTA (e.g., Hanley *et al.*, 1998; Hanley *et al.*, 2006). However, CE can go beyond valuing benefits of resources. For fishery resources, for example, Wattage *et al.* (2005) investigated stakeholders' responses to different combinations of fishery objectives (reduce conflict within the fishery, improve fishery socio-economic structure, conserve fishery and marine environments) using a case study of UK fisheries in the English Channel. The greatest preference was for a combination of an increase in sustainable yields, promotion of regional employment and a decrease in conflict between towed and fixed gear. Many CE studies (e.g., Bockstael and Opaluch, 1983; Eales and Wilen, 1986; Wilen *et al.*, 2002; Andersen *et al.*, 2006) have focused on allocations of fishing effort and choice of location. Smith (2005) used a combination of tools in a mixed logit and state dependence model, to study choices of fishing location for commercial sea urchin in California. In this system, individuals may have heterogeneous preferences over fishing ground characteristics because most of them have different information on the quality of fishing grounds depending on personal experiences. For instance, seemingly similar individuals regularly select different locations even if they start from the same fishing port and go on the same day (Smith, 2005). CE has also been used for modelling/analysing fishermen behaviour. For example Hutton *et al.* (2004) used the approach to understand behaviour in the English beam-trawl fleet in the North sea, while Andersen *et al.* (2006) conducted a similar study on the Danish North Sea Gillnet fleet. Although, there are many papers using stated preference methods for fishery studies, none of them so far, have analysed fishermen behaviour in context of auction markets.

2.1.4 Fishery simulation approaches

Simulation has been applied as a tool in resource management in order to better understand the resource system. A model represents a simplification of real world situations or systems. The model can be either static, examining how inputs and outputs correspond at a certain point in time, or dynamic, where the outputs in one period influence outputs at a later point in time. Static models can be used to identify indicators which might be useful for predicting impacts, sensitivities or vulnerabilities, while dynamic models go beyond those by assessing future quantifiable impacts and assessing different management or development scenarios (Castle and Crooks, 2006). Many types of simulations have been used in fishery studies such as discrete models, mathematical models, econometric models, and agent-based models. Most of the studies on fishermen behaviour have focused on fishing effort, choice of fishing locations or targeted species (e.g., Bockstael and Opaluch, 1983; Jules Dreyfus-León, 1999; Babcock and Pikitch, 2000; Wilen *et al.*, 2002; Millischer and Gascuel, 2006). However, this thesis emphasises the interactions between fishermen behaviour and the dynamics of fishery resources under different types of wetland management and property rights. This provides a framework for understanding the bigger picture related to inland fishery management including economic, ecological and regulatory aspects.

Simulations have also been used for fishery management analysis. Early simulations relied on biological aspects, such as surplus-production and yield-per-recruit models (e.g., Pikitch, 1987). However, bio-economic models have been the favoured approach for policy analysis (Carothers and Grant, 1987). These models combine biology and economic aspects. The models, for example, explore how various parameters (e.g., fishing effort) affect fish stocks. They intend to determine the optimal level of socio-economic activities that the biological system can sustain. The bio-economic concept in fishery studies was initially developed by Canadian economists Scott Gordon (1954) and Anthony Scott (1955), although the fishery model was primarily applied by Schaefer (1957). The basic bio-economic model for fisheries comprises of three equations: stock growth, harvest function and profit function which is sometimes called the Schaefer-Gordon model[4] (Hartwick and Olewiler, 1986; Béné *et al.*, 2001; Knowler, 2002). A steady-state bio-economic equilibrium (where growth rate equals harvesting rate) is the overall objective for renewable resources, whereby a standing stock is maintained at an optimal level (Conrad and Clark, 1987). Practically however, fishermen continually harvest until there is no more profit, which implies that average revenue equals average cost of effort. This represents a common property or open access equilibrium, which is inefficient because marginal revenue is less than marginal cost (Conrad and Clark, 1987; Tietenberg and Lewis, 2009). When the marginal cost is equal to marginal revenue it is termed the private optimum and it means economic efficiency is achieved.

Studies in marine economics use these biological and economic concepts. For example, a bio-economic model was used to assess optimal size of marine reserves for a cod fishery (Sumaila, 1998). This research found that reserve size influences fish populations within protected areas and provides spillover effects to adjacent fisheries. Large sized reserves were found to lead to better productivity of fish stocks. Armstrong and Skonhoft (2006) also used a bio-economic model to

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4 Alternatively called Gordon’s model or Gordon-Schaefer or Schaefer-Gordon.

investigate the effects of marine reserves by assuming asymmetric density migration between inside and outside reserves. Their results revealed that dispersal between the fishing grounds and the protected areas influences the economic and ecological outcome. If policies incorrectly assume symmetric migration, then this can negatively impact long-term returns to resource use. Recently, simulations of fishery management have focused not only on harvesting equilibrium but also on ecological system properties and spatially specific analyses of fisheries. For instance, Lachica-Aliño *et al.* (2006) applied an ecosystem-based model which allows an investigation of the interaction and dynamics of multiple species and multiple gear in fisheries in Philippine. The models were derived from single species data such as yield per recruit and surplus production and integrated with an ecosystem-based approach. Pelletier and Mahévas (2005) used a spatially and seasonally explicit model to study the consequences of different policies on fishery dynamics such as gear restriction, marine protected areas and total allowable catch. Although the spatial and ecological models outlined above can include seasonal differences, none consider the heterogeneity of fishermen.

This research extends the bio-economic modelling literature by incorporating spatial analysis of fishery dynamics and heterogeneous characteristic of humans using a multi-agent simulation. Agent-based modelling (ABM) is considered an effective method, providing a novel understanding of scientific research enquiries, and can be used to explore the theoretical consequences of complex assumptions (Janssen and Ostrom, 2006). ABM goes beyond the models discussed above because it can deal with complex systems, and qualitative and quantitative inputs/assumptions. Multiple heterogeneous agents and different characteristics of environments can be included in ABM. Furthermore, spatio-temporal dynamics of fisheries and the individual level of agents can be studied. Although, cellular automata models can also address the research questions at the individual level, ABM is more appropriate to deal with a complex system like Tonle Sap because it enables the creation of various and heterogeneous characteristics of agents and landscapes. This goes beyond the study of a specific location and history which can be implemented within cellular automata (Janssen and Ostrom, 2006). There has been an increase in the number of papers combining ABM and other empirical methods such as laboratory experiments, case studies, role playing games (e.g., Adamatti *et al.*, 2005), and GIS (e.g., Robinson and Brown, 2009). ABM is one way of approaching the challenges in studying empirical social sciences which are complex and relate to contextual factors such as geography, culture, policy and economics. For environmental issues, ABM has been used to analyse land cover change (Evans and Kelley, 2004), ecosystem and catchment management (Becu *et al.*, 2003; Doran, 2006), wildlife ecology (McLane *et al.*, 2011) and cooperative behaviours (Touza *et al.*, 2012). It has also been used to analyse various interests in fisheries such as fleet response (Soulié and Thébaud, 2006), trading of multispecies fisheries quotas (e.g., ITQs) (Little *et al.*, 2009), and multiple use management of coastal marine resources (McDonald *et al.*, 2008). A more specific review of the ABM literature in accordance with the specific objectives is provided in Chapters 5, 6 and 7.

2.2 A CASE STUDY: TONLE SAP WETLANDS, CAMBODIA

2.2.1 An Overview of Cambodia

The Kingdom of Cambodia (Cambodia) is a part of the Mekong watershed or the Greater Mekong Sub Region (GMS[5]) in Southeast Asia (Figure 2-1). This country covers an area of around 181,035 square kilometres and has a tropical monsoon climate (Royal government of Cambodia, n.d). For administrative purposes, the country consists of 18 provinces and 2 municipalities. Importantly, 16 provinces mainly rely on fisheries for livelihoods and their economies.

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[5] The Greater Mekong Watershed or The Grater Mekong Sub Region covers areas of the Kingdoms of Cambodia, Thailand, Lao People's Democratic Republic, Myanmar (Burma), Vietnam, and Yunnan Province of the People's Republic of China. The Mekong river commission (MRC) was established in 1995 in order to make cooperation among those countries. The agreement of the regional cooperation program for the sustainable development of water and related resources in the Mekong basin was signed by the governments of Cambodia, Lao PDR, Thailand and Vietnam.

Figure 2-1. The first map (top image) shows the Greater Mekong Sub Region (GMS) which consists of six countries. The second map (bottom image) presents the Mekong watershed. The brown line depicts the boundaries of the watershed.

Source: www.psywarrior.com/CambodiaPsyop.html; google.com

Historically, Cambodia was prosperous and powerful under the Hindu state of Funan and the Kingdom of Angkor (or Cambodia) until the mid-nineteenth century (Bureau of East Asian and Pacific Affairs U.S. Department of State, 2008). However, the level of development of the country has lagged behind other Asian countries particularly up until 2004 (Swedish International Development Cooperation Agency; Bureau of East Asian and Pacific Affairs U.S. Department of State, 2008). Cambodia has been a colony and has also suffered from genocide during the Khmer Rouge period, when most educated people were killed (Swedish International Development Cooperation Agency). There were 14.31 million people in Cambodia in 2011, the majority of which (90%) are Khmer ethnic (Central Intelligence Agency, 2009; Royal government of Cambodia, n.d). In 2011 its GDP was 12.88 billion USD, while GDP per capita has increased from USD 632 in 2007 to USD 900 in 2011 (The World Bank, 2013). The Cambodian economy has been progressing rapidly from dependence on agricultural and service based sectors (The National Institute of Statistics, 2005) towards a growing industrial sector e.g., textile and cloth industries (Ballard, 2007; Brett, 2007). In addition, oil and natural gas deposits were discovered in 2004 (Chandler, 2008) which have been another boost to their economy. Although the economy has developed to a certain degree, an income gap (between the rich and the poor) still exists and the unequal distribution in natural resources is still a concern.

The abundance of natural resources and biodiversity has been used by Cambodia for development. Economic activities and household incomes mainly depend on natural resources. The main diet is rice and fish. Cambodian people annually consume (fresh and processed) 13-70 kilograms of fish per person (the average is 27-38 kilograms of fish per person). Rice is the main agricultural crop and is grown on most of the cultivated areas in the country. The rice fields constitute approximately 2.32 million ha from a total of 2.8 million ha of cultivated land, and around 0.6 million ha of cultivated lands are floodplain. From 2001 to 2002, the average farming household cultivated approximately 1.4 ha of rice and the average yield was around 2.1 tonnes/ha or around 2.4 tonnes/household (McKenney and Prom, 2002). Wet season rice is grown in every province but mostly in lowlands, whereas dry season rice is grown largely in the Mekong river floodplain which supplies water for the rice fields. Often households combine farming and fishing in their livelihood strategies. Most forests in Cambodia are non-commercial and highly degraded, such as the flooded forests which have mostly been cleared for agricultural purposes. The rate of deforestation has risen in the last decade due to illegal logging, corruption, ambiguous concession agreements and weak enforcement and management. The flooded forests decreased from over 1 million ha in 1973 to only 450,000 ha in 1997 (McKenney and Prom, 2002). This also impacts on fisheries as the flooded forests are the nursing grounds for fish.

Over the past decade, Cambodians have faced the increasing challenges of resource scarcity, competition and degradation due to an increase in population and weak implementation of policy and regulations. Tonle Sap wetlands are also faced with these problems.

2.2.2 Tonle Sap: biophysical environment, climate and livelihood

The Tonle Sap wetlands and Mekong river is the main hydrological system in Cambodia. It contributes to the water requirement of the country and supports the livelihoods of the majority of people in Cambodia. Indeed, over 90% of Cambodian livelihoods depend on this system as it contributes to the main economic activities, both agricultural and non-agricultural. Agriculturally, the main activities are inland farming and fisheries (International Centre for Environmental Management, 2003) including aquaculture[6]. For the non-agricultural sector, the main activities are forest product gathering, wildlife sanctuaries, and tourism (McKenney and Prom, 2002).

2.2.2.1 Physical geography of Tonle Sap

The Tonle Sap wetlands have a unique landscape and they are one of the most productive freshwater fisheries in the world and provide incredible advantages for Cambodia itself and other countries in Mekong watershed (International Centre for Environmental Management, 2003). A brief description of Tonle Sap is given in Table 2-1.

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[6] Aquaculture refers to fish-raising and other aquatic animals such as crocodiles, eels, frogs, and shrimp.

Table 2-1 Features of Tonle Sap

Feature	Wet season	Dry season
Length from northwest to southwest (up to)	250 km.	120-160 km
Width (up to)	100 km	35 km
Coverage	1,100,000-1,600,000 ha	250,000 -300,000 ha
Water flow	60,000 cubic metres per second	15,000 cubic metres per second
Water level increases by	15-18 metres	
Water temperature	28 - 29°C on the surface and 26-28°C at the depth	
pH	6.6 - 6.9	
Climate conditions - Monsoon - Average annual temperature	- Southwest monsoon in May - October - 26.7 °C (maximum at 40.3 °C and minimum at 9.5 °C)	

Source: modified from ASEAN regional centre for biodiversity conservation (2009), Bonheur and Lane (2002) and Hickling (1961).

Water in the Tonle Sap wetlands comes from the combination of melting snows in the Mekong headwaters (in Tibet), heavy monsoon rains in Cambodia and water flows from other countries in the upper catchment. These sources are able to raise the flow of water from 15,000 to 60,000 cubic metres per second in the rainy season (Hickling, 1961).The large volume of water cannot all be drained directly into the sea, so the level of water increases to the point where it flows over land on either side of the river. Forests surrounding the lake are flooded to a depth of many metres; sometimes water levels can rise 10 metres.

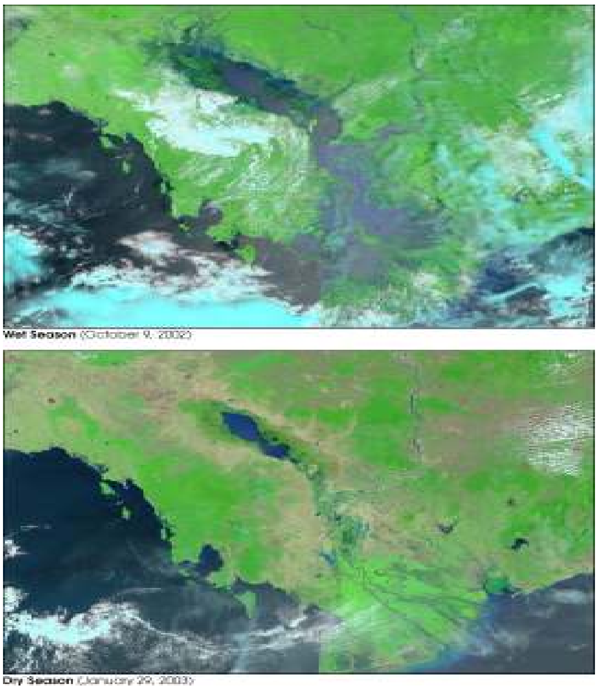

Figure 2-2 The Tonle Sap wetlands in wet (top image) and dry (bottom image) seasons

Source: http//earthobservatory.nasa.govIOTDview.phpid=3483

The various types of land and water resources, such as flooded forests, flooded grassland, seasonally flooded crop fields and swamp, support inland capture fisheries in these wetlands. The lake joins with the Mekong river system and 13 - 20% of the Mekong's flow enters Tonle Sap Lake in the rainy season making it five times its normal size (Sithirith and Grundy-warr, 2007) (Figure 2-2). In the dry season, when the water level of the Mekong river drops, the waters of Tonle Sap recede, replenishing this great river. These wetlands act as major nursing grounds for fish breeding before fish return to the Northern Mekong Basin, and the flooding also results in increased nutrient input into the ecosystem.

2.2.2.2 Variables that influence fish resources

The Tonel Sap wetlands are complex areas with high biodiversity and are a highly productive ecosystem. Variables that influence the availability of fish in Tonle Sap include river hydrology, floodplain quality, and fish migration.

Firstly, flooding is the main hydrological factor that influences the abundance of fish stocks. Floods establish the grounds for fish breeding and fish growth during the rainy season. The long duration of floods provides benefits for fish growth through increased nutrition. Not only does the longer flooding season provides a better environment for fish growth but also when the floods are early they influence sizes of fish stocks by providing good environmental conditions for larvae and juveniles (Kurien *et al.*, 2006). For example, low levels of water in 2003 resulted in an approximately 50% decrease in fish catch (Baran *et al.*, 2007b). Seasonal changes in water levels are called a “flood pulse”, which refers to the changes between high and low levels of a water cycle and explains the dynamic interactions between land and water which help to maintain diversity (Junk *et al.*, 1989). The flood pulse phenomenon is recognized as the most important factor in explaining the productivity of Tonle Sap wetlands. “If the Tonle Sap Great Lake is the heart of Cambodia, the annual “flood pulse” is what keeps it alive” (Baran *et al.*, 2007a, p.11). This concept was first used to describe the Amazonian floodplain. Ecological functions such as production, consumption and decomposition are driven by the flood pulse (Sparks *et al.*, 1990) and succession is driven by the tidal system (water fluctuations) (Middleton, 2002).

Secondly, the quality of the floodplain acts as an environmental variable driving fish biomass. Most of the primary organic matter that influences fish production is locally produced (Lamberts and Koponen, 2008). Higher diversity habitats such as flooded forests are considered the favourite habitat for fish. This corresponds with interviews (conducted for this research) with local fishermen that indicate how the most productive fishing grounds are near the shore, which are flooded forests, shrub and grassland. It is likely that important food for fish is derived from the land in flood dependent fisheries. With the rise in water level during floods, fish have access to wider and better food stores (Hickling, 1961) resulting in higher fish productivity even though less food is available from rivers. However, the amount of flooded forest has decreased year on year due to demands for land for rice fields (Kurien *et al.*, 2006) and for other infrastructure developments such as dams and irrigation systems. This infrastructure affects the wetlands' hydrology, fish habitats and routes for fish migration, factors that determine the productivity of Tonle Sap fisheries (Baran *et al.*, 2007a). Water flow and habitats are considered the main features driving ecosystem biodiversity (Hickey and Diaz, 1999).

Thirdly, fish migration is a crucial characteristic of Mekong fisheries. Fish move between feeding grounds, breeding grounds and sanctuary areas. Fish movement is a part of the biological cycle of fish after they have spawned in the floodplains or deeper riverine areas. The fish population is able to move out over the surrounding land into the larger habitat that is created by the floods. This enables fish populations to be much higher than if fish were restricted to river channels. The incredible productivity of the fisheries is driven by synchronisation between the annual floods and fish reproduction. Mekong fish species have evolved to be ready to spawn as soon as the floods start (Hickling, 1961). The floods not only provide an enormous living-space for fish but also abundance of food. In these conditions, mature fish are able to recover condition rapidly after spawning offspring are hatched where there is the maximum amount of food.

2.2.3 Livelihoods in Tonle Sap

Tonle Sap wetlands play an important role in Cambodian livelihoods, especially in rural areas where they are dependent on natural resources. There are many activities related to fisheries and livelihoods, such as fishing (including fishing in rice fields), fish aquaculture, fish trading, fish processing and fishing gear making. Households are also involved in farming, especially rice farming, livestock raising, fuel wood collection, small shop businesses, money lending and daily labour including boat driving. The Tonle Sap wetlands are essential for floating households (see a floating village in Figure 2-3) whose houses float on the Tonle Sap Lake. These households are extremely reliant on fishing and fishing-related activities. The floating villages in Tonle Sap Lake themselves are attractions for tourists, while land-based households have other sources of household income such as agriculture.

Figure 2-3 A floating village on Tonle Sap Lake

2.2.4 Cambodian fisheries

Fisheries are not only the main source of household income for poor people and help with their food security, they also support some wealthier households who are involved in fish trading businesses rather than fishing. Small-scale fisheries are the main type of fishery in Cambodia. The fisheries peak at the beginning of the dry season (November to February) when flood waters start to recede and fish stocks migrate from paddy fields and flooded forests into deep water. The fish catches at this time contribute highly to total global inland fishery capture. A property rights and conservation management system has been applied to fishery management in Tonle Sap in the form of fishing management zones consisting of private, common and conservation zones. Recently, the private zones have been (temporary) abolished in order to replenish fish stocks.

2.2.4.1 History of fisheries management

The formal management system in Cambodia can be traced back to the King Norodom era (1859-1897). Traders (or investors), particularly Chinese, bought fishing concessions from the King and sub-leased their rights multiple times (there could be eight stages of sub-leases between the state and actual exploiter (Hickling, 1961)). These concessionaires gained returns of around double the payments to the Royal Treasury (Degen and Nao, 2000; McKenney and Prom, 2002). The concession and sub-leasing system continued until the Democratic Kampuchea regime under Pol Pot emerged. After that, fishing activities were somewhat limited. Fishery resources were neglected in order to develop agriculture, which involved clearing flooded forests and wetlands. The fishing management system was changed again after the Democratic Kampuchea regime was overthrown in 1979. A fishery management system called collective fishing was undertaken through solidarity groups called Krom Samaki. During this era, access to fisheries was open to all. The concession system was brought back in the late 1980s and was reformed in 2000. The reforms involved a decrease in the fishing lot areas and establishment of community fisheries in order to deal with serious conflicts between fishing lot owners and local fishermen (McKenney and Prom, 2002). The fishing lots were designated plots for commercial fishing involving private concessionaires bidding for exclusive fishing licences. In late 2011/early 2012, the fishing lots were temporarily abolished in order to replenish fish stocks and to improve the livelihoods of small-scale fishermen (Royal Government of Cambodia, 2012).

2.2.4.2 Zonal designation and fishing lot system

Zonal designation has been applied to fishery management in Tonle Sap. The wetlands were previously divided into three different zones: 1) commercial zones or fishing lots, 2) conservation zones, and 3) communal or public fishing zones (Figure 2-4).

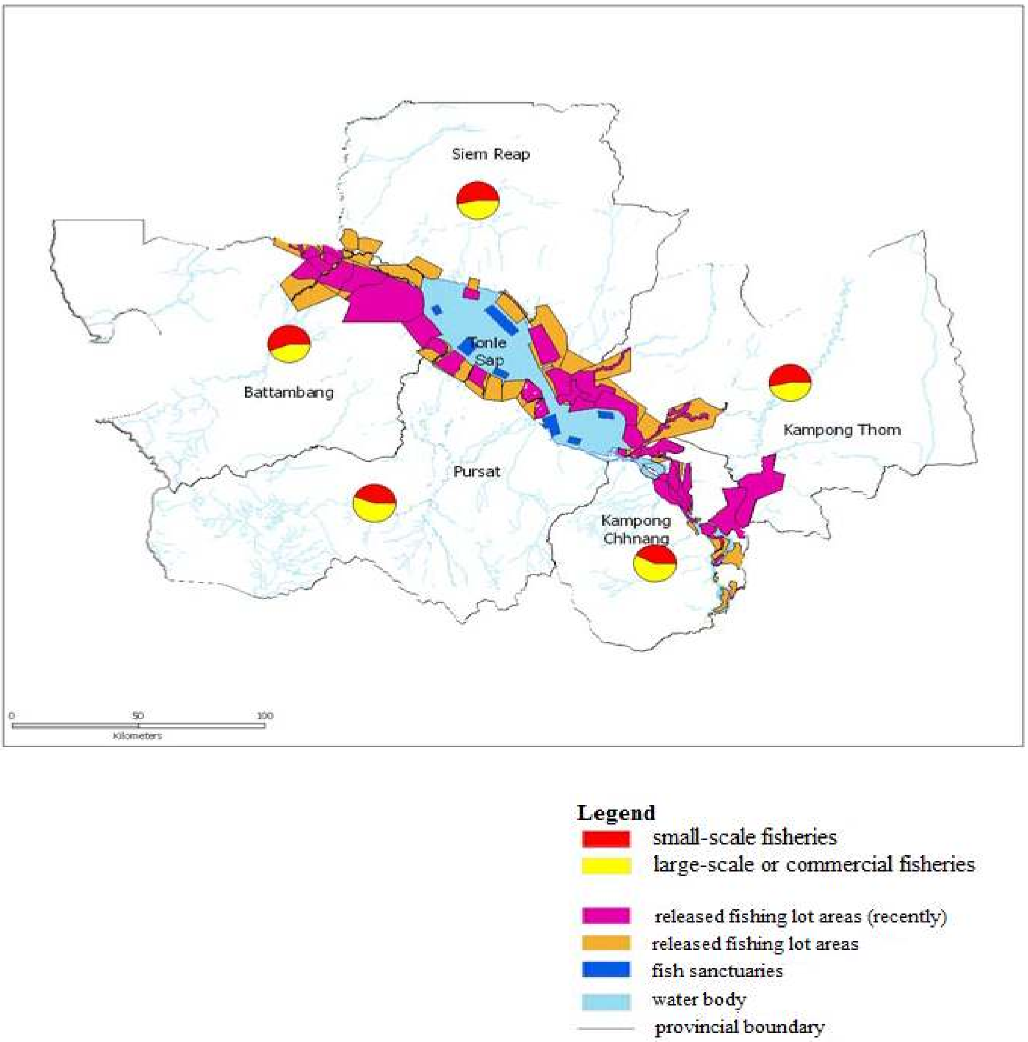

Figure 2-4 Zonal designation of Tonle Sap fisheries

Source: Tonle Sap biosphere reserve, 2009

Fishing lots (Figure 2-5), were designed plots for commercial fisheries involving private concessionaires bidding for exclusive fishing licences. The number of years that concessionaires had authority over the lots depended on the contract and type of fishing lot, and were generally two-year or ten-year contracts. The fishing lot areas existed and were allowed to operate in the open season only and they became public fishing zones in the closed season. The open season corresponded with the dry season which begins on the 1st of October and ends on the 31st of May north of Phnom Penh and starts on the 1st of November and ends on the 30th of June south of Phnom Penh. The closed season was the wet season. Fences constructed to be boundaries of fishing lots had to be removed when the closed season started.

Figure 2-5 An example of fishing lots

The fishing lots were leased by government through an auction. Announcements[7] for auctions would be issued a month in advance by the Department of Fisheries (DoF). Individuals who wanted to participate were required to submit their application[8] at least 10 days before the auction day. The auction was restricted to Cambodian citizens except government officers. Ad-hoc committees[9] would be set up to supervise the auction processes held in each province. However, attendees and retired fishing lot leasees complained about poor management including corruption (Tana and Todd, 2001). Lot owners were usually businessmen with power in terms of finance and/or networks with government.

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[7] Announcements consisted of date and venue for the auction day, the floor price for each fishing lot and specifications for fishing lots.

[8] The application had to include 1) personal biographical data 2) a declaration to comply with the regulations of the fishing lot 3) a deposit (one-third of the floor price as a cheque or cash) 4) a commitment form of payment. The first payment was two-fifths of the winning bid which had to be paid within 15 days of the auction day 5) a commitment form of payment for fine and service fees if the concessionaire failed to make the first payment within 15 days 6) a commitment form of payment if they wanted to abandon the fishing lot before the contract ended.

[9] Principally, the ad-hoc commission comprised of 1) Provincial governor or representative as chairperson 2) the vice chair as the director of the Department of Fisheries or representative 3) Head of the provincial planning department or a representative 4) Head of the provincial finance department 5) Head or a representative of the provincial agriculture department 6)Head or a representative of the provincial bank 7) Head or a representative of the provincial tax office 8) Head or a representative of the provincial fisheries department.

Once obtained, fishing licenses could not be legitimately transferred or sub-leased and lot owners were required to follow the fishing regulations set out in “the burden book”. This book specified the operating rules including the fishing allowance, payment regulations, fishing locations in the form of a map and GIS data (showing boundaries between the exclusive fishing area and public areas), and time periods for open and closed seasons (McKenney and Prom, 2002). Fences around the lots were constructed as a massive cage for fish at the beginning of the open season and were removed at the end of season. License holders usually employed guards to protect their lot boundaries. Interestingly, fishing lot owners might get a third party, called co-sharers or shareholders, to share responsibility, capital costs and benefits from the lots. Also, most of the lot owners illegally sub-leased some areas (usually after the first few harvests) to other fishermen by selling one-year sub-contracts and/or collecting a fee or sharing fish catches. In addition, the military might be offered some areas in return for boundary protection (Vuthy *et al.*, 2000). There were many barriers against small-scale fishermen accessing the fishing lot system. For example, sizes of fishing lots were often too large[10] and their floor prices were too high. Therefore, some small-scale fishermen could only be labourers in fishing lots in the fishing season.

The conservation zones were areas where fishing activities were principally not allowed at any time of the year. Areas outside the fishing lots and conservation zones were called public/common fishing zones, where anyone could fish all year around but were generally only used by small-scale fishermen. Fish production in these areas tended to be lower than in the fishing lot areas. Small-scale fishermen usually fished in the areas close to their homes for the whole year and used household or relative labour. Their harvests were and are mainly for household consumption and income.

There are a wide range of fishing methods used in Tonle Sap, from simple gear e.g., simple nets, lift-nets, hand-lines and traps, to more complicated gear e.g., barrages, which are made of split bamboo fencing rolls and are installed/attached with poles into the lake or river bed to confine the fish to a certain space or to lead them into various traps. The bigger the size of the enclosed area, the more works

[10] The previous lot number two in Battambang province covered an area of around 500 square kilometres (Allebone-webb and Clements, 2009)

and material needed including a large number of workers, high organisation, and long-established traditional skills (Hickling, 1961). For example, three large ships, five smaller boats for carrying bamboo fencing, ten sampans or dinghies, 40,000 stakes, 20,000 metres of split bamboo fencing, and 50 labourers (both fishermen and workers for cutting poles, repairing boats, making fences etc.) are required in order to work for a concessionaire operating a fishing lot around 20 kilometres in circumference. This contrasts with small-scale fisheries which require fewer labourers and simple gear.

Management systems have been the responsibility of the DoF under the Ministry of Agriculture, Forest and Fisheries (MAFF). This formal organization is responsible for developing and conserving fishery resources. The authority of DoF lies in enforcing regulations, issuing concessions, collecting fees as well as fines, and controlling fish processing and trade. Statistics from the Ministry of Economy and Finance in 2002 revealed that the official income of DoF was between 1-4 million USD per year, while local authorities earnings came from more informal revenue from fisheries (McKenney and Prom, 2002).

2.2.4.3 Fish catches and fish market values

The total harvest for inland fisheries in Cambodia varied between 290,000 and 430,000 tonnes/year between 1994 and 1997[11] and between 365,000 and 445,000 tonnes/year from 2006 to 2011 (Ministry of Agriculture Forestry and Fisheries, 2012). From the statistics on per capita inland capture fisheries, Cambodia is at the top of the list (McKenney and Prom, 2002; FAO, 2003b) and the majority of catches are from the Tonle Sap wetlands. Fish yields from Tonle Sap floodplain are estimated at between 139 and 230 kg/ha/year, which was higher than other countries in Mekong watershed (Baran *et al.*, 2007b). Rab *et al.* (2006) compared total fish catch in the open season in 2002 and the closed season in 2003 and

[11] These statistics are estimated based on a combination of survey research, such as socio-economic household surveys by Ahmed et.al (1998), rice field fisheries research by Gregory (1997), and combined data from studies of fish catch and consumption across different scales by Van Zalinge et al (2000). Department of Fisheries (DoF) provided significantly different fish yields at approximately 50,000-70,000 tonnes per year. Some papers such as (McKenney and Prom, 2002) claim that the statistics from DoF are problematic because the national statistics do not reflect the catch from small-scale fishermen and does not include fish production from 11 other provinces which were not licensed and leased by DoF (Ahmad *et al.*, 1998).

found that the harvests in the open season were around seven times more than the closed season. The price of fish depends on fish species and seasons. The lowest fish price starts when fishermen sell their harvests at the landing sites or to middlemen. The fish price for local consumers is 3 to 4 times higher than that paid to the fishermen (Baran *et al.*, 2007b). The highest price is paid for fish for the export market. The monetary values of fish caught is estimated to be 100-200 million USD at the landing site and market chains increase the value to 250-500 million USD (Van Zalinge *et al.*, 2000).

The products of freshwater fisheries are domestically consumed either as fresh or processed fish e.g., fermented fish, fish paste *(prahok),* fish sauce *(tuk trey)* and dried fish. The traditional ways that are used to preserve fish are sun-drying and smoking. Fishermen prefer to trade fish and processed products in local markets rather than export markets due to constraints such as government interventions, export licences, and official and unofficial taxes and fees (Ministry of Commerce, 2001). As a result, the export market has only a small share of fish products. Thailand is the biggest market for export followed by Vietnam, Hong Kong, Malaysia, Singapore, Europe and United States.

2.2.5 Main problems and conflicts related to fisheries

The main problems related to Tonle Sap fisheries are depletion of fishery resources and conflicts in fisheries derived from competition between land-uses. Degradation of fish stocks and fish habitats have been reported in several studies (McKenney and Prom, 2002; Song *et al.*, 2005; Sneddon, 2007; Nuorteva *et al.*, 2010). Clearing flooded forests and shrub vegetation for agriculture immediately destroys fish habitats and builds up sedimentation in the lake. However, high maize prices or an increase in demand for rice encourages farmers to clear flooded forest. The contaminated runoff water (pesticides and chemical fertilizers) also affects nearby fisheries and directly impacts on paddy field fish production (McKenney and Prom, 2002). The increase in sediment deposition reduces lake depth, especially in dry season, and amounts of dissolved oxygen. Other problems include overexploitation of fishery resources because of an increase in the number of fishermen, intensification of fishing techniques, widespread use of illegal fishing methods such as electro-fishing, use of poison and use of small mesh nets (McKenney and Prom, 2002), and destruction of fish habitat (Brett, 2007). Although, the catch per unit of effort and the value of the catch has declined, the overall tonnage of fish captured in Tonle Sap has increased, reflecting an increase in the fishing effort of fishermen and rapid improvements in fishing technology (International Centre for Environmental Management, 2003). However, a decline in some long-lived species, and a shift towards more short–lived species and smaller sizes of fish have been noticed (International Centre for Environmental Management, 2003).

Social conflicts over enforcement of boundaries between the different fishing zones and between different groups of users have also been reported (Bonheur and Lane, 2002; Keskinen *et al.*, 2007). Some of the fishing lots covered large areas of fishing grounds and overlapped with some transportation routes for inhabitants who lived in those areas. A long-term tension has been reported between lot owners and local fishermen due to inequitable access to productive fishing grounds (Keskinen *et al.*, 2007; Nuorteva *et al.*, 2010). Arguments over lot boundaries between local fishermen and lot owners are extremely common. Local fishermen claim that lot owners have tried to expand their boundaries illegally, while lot owners claim that local fishermen have tried to invade into their lots. There were also complaints about the auction system, such as lack of information about the auction and corruption. In addition, conflicts between fishermen and farmers are also problematic. Rice is the dominant crop in Cambodia and dry season crops are mainly grown on floodplain areas so as to be close to water and to make use of the nutrients deposited by the flood waters. As a result, harvests of dry season crops are higher than wet season crops. These temporary rice fields along the shore of the Tonle Sap Lake in the dry season lead to conflict among small-scale fishermen, fishing lot owners and farmers in terms of the impacts of intensive land use on the fishery.

To reduce the conflicts, fishing lots were reformed by decreasing the size and number of fishing lots in late 2000. Approximately 56% of fishing lot areas were decreased (surface areas of fishing lots were reduced from 954,000 ha to 417,000 ha and the number of fishing lots reduced from 135 to 82 in 2001) and the number of people associated with the fishing lots decreased from 756,000 to 148,000 (Degen *et al.*, 2002). Furthermore, all fishing lots were abolished in early 2012 (DAP-NEWS, 2011; Royal Government of Cambodia, 2012).

Difficulty in accessing the credit market is a problem for small-scale fishing households. From March to May (dry season), fish harvests for poor households do not meet their daily requirements because they do not have the modern fishing gear necessary for fishing in areas with very low levels of water. Loans from fish traders/ private lenders/ middlemen in form of money and fishing gear become important for them at this time. After harvesting, fish products are usually sold to creditors cheaply (lower price than the market) (Brett, 2007). However, there is no choice for poor households because they are not able to access credit elsewhere (Béné and Friend, 2011). Private loans are the only options that small-scale fishermen have to access credit (Turton, 2000; Kimkong, 2007). This problem may be a significant big barrier preventing small-scale fishermen in participating in the auction, leading to lack of access to productive fishing grounds in the open fishing season.

2.3 CONCLUSION

This chapter provides an overview of management issues of inland fisheries and a background of the case study: Tonle Sap fisheries. There are different management approaches that have been used for inland fisheries. The conventional approaches intend to regulate the type of fishing gear, amount of fish catches, and seasonal closure. The alternative approaches regulate in terms of, for example, ownership, conservation and co-management. Tonle Sap fisheries provide an interesting mixed-management approach combining property rights, market-based approach and conservation. However, degradation of fish resources and conflict between resource users are still obvious problems. Understanding attitudes and behaviour of fishermen and the spatial interactions between fishermen, management system and fishery resources are important to improve sustainability in fisheries. There is potential to use simplified simulation models of complex fishery systems to investigate the biological and socio-economic implication of choosing different management strategies.

Chapter 3

RESEARCH FRAMEWORK

This chapter describes the conceptual framework of the thesis. It provides an overall picture of the research and motivates the choice of methodological framework, while the research methods are presented in each of the empirical chapters. Two different approaches, choice experiments and agent-based simulation, are used in this thesis. The choice experiment approach is used to investigate the individual purchasing behaviours in the auction market for fishing lots. The agent-based simulation is used to analyse the complexity of fishery dynamics under different management. The combination of both approaches offers a framework for understanding the particular fishery system in Tonle Sap at both the micro and macro scales, and allows exploration of the spatio-temporal dynamics of the system.

The Tonle Sap fishery is an interesting case of mixed management in a complex fishery system involving multiple users. The concepts of property rights, conservation and market-based approaches are integrated in the Tonle Sap management system. The management aims to improve fishing efficiency, reduce fishing effort, encourage people to preserve fish stocks and their habitats, and also generate income for the nation. However, the results have never lived up to expectations. Small-scale fishermen are faced with limited access to the most productive fishing grounds during the fishing season because those areas are semi-privatised into (temporal) private fishing lots. An auction has been used to allocate exclusive fishing licences. It is likely that the auction itself and the design of fishing lot characteristics created barriers for small-scale fishermen, especially financially, because most of the previous fishing lots covered large areas and involved high investment, high bidding prices and many labourers. Furthermore, there is still continued degradation of fish stocks and habitats. In order to meet the fishery management goals (fishery biology, social justice, and economics), the following three main components of fisheries should be well understood: fishermen behaviour, dynamics of the fishery and the management system (regulatory system as well as institutional context).The framework used in this thesis is adapted from Ostrom (2009)'s framework for evaluating sustainability of socio-ecological systems. This framework demonstrates the associations of four core subsystems in social-ecological systems: resource systems, resource units, governance systems, and users.

Fishermen behaviour is one of the most important factors determining fishery sustainability. Hilborn (1985) claims, that most fishery management problems are caused by misunderstanding and mismanagement of fishermen more than limited information from fishery statistics. Fishermen have different preferences and dissimilar ways of thinking and conducting fishing activities. It is important to understand their behaviours because different behaviours result in different impacts on the ecosystem. It is also vital to understand their reasons, and thus processes of valuation as an underlying driver or motivation for their actions. Both fishermen decision and the management system are needed to be well understood because the management system partly controls fishermen incentives and spatial distribution of fish stocks and their reproduction. This thesis therefore focuses on the interactions among fishery regulations, heterogeneous fishermen and fish biology contexts under a sustainable management goal. In order to achieve fishery sustainability, there are different alternative policy decisions which can be evaluated using economic, social and ecological criteria (see Figure 3-1). This can help to inform decision makers and stakeholders.

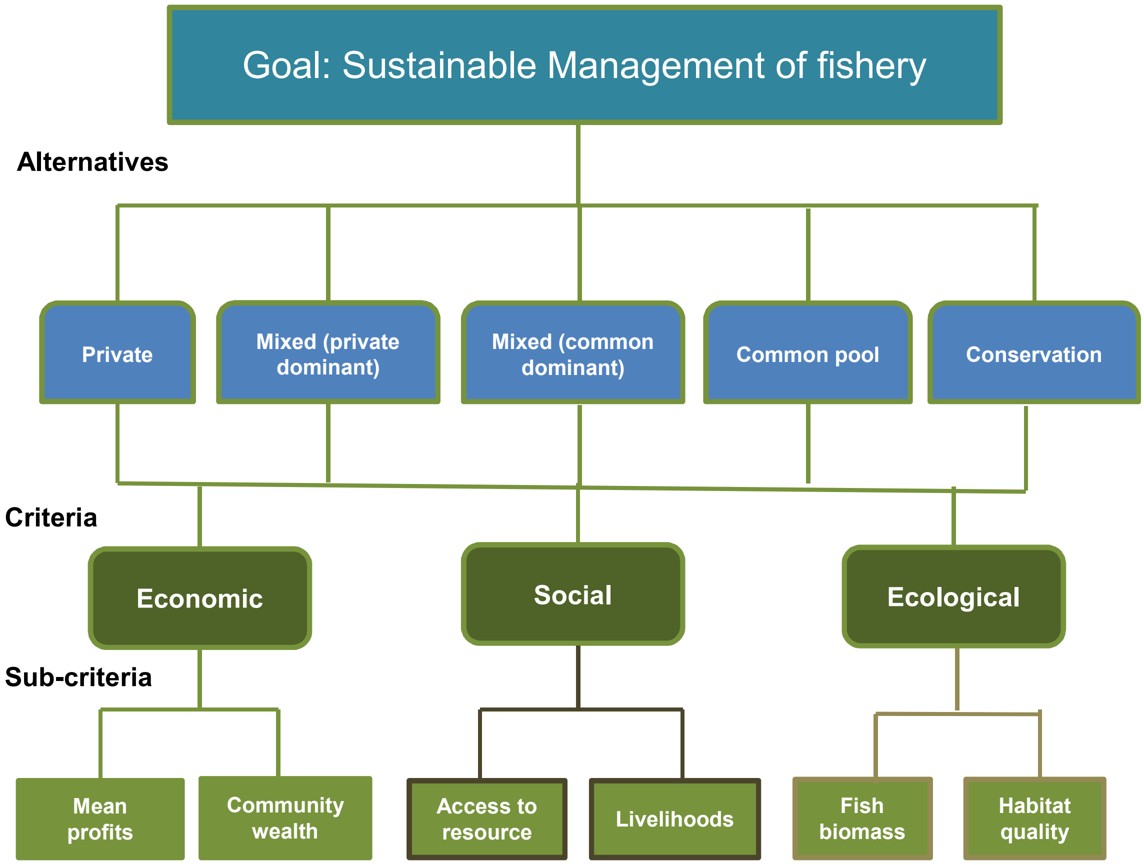


Figure 3-1 Framework for research problems

To understand the three important components, different methods are used at different stages (see Figure 3-2). The first part of thesis aims to understand the allocation of fishing rights and distribution of fishing licences through a market-based approach (an auction system), and to explore bidding behaviour of fishermen when they have to select between types of fishing grounds. Purchasing behaviours for private fishing licences involves multiple choices where fishermen need to assess different characteristics of each available fishing lot. A CE approach is applied to model fishermen behaviour in purchasing hypothetical fishing lots. The estimated choice model explains individuals' choice between buying potential fishing lots and the choice of only fishing in the public fishing grounds. The actual values of fishing licences are not the main finding of this thesis, but the valuation of different characteristics of fishing lots. This emphasis allows for an analysis of fishermen's heterogeneous preferences for attributes of the fishing lot system.

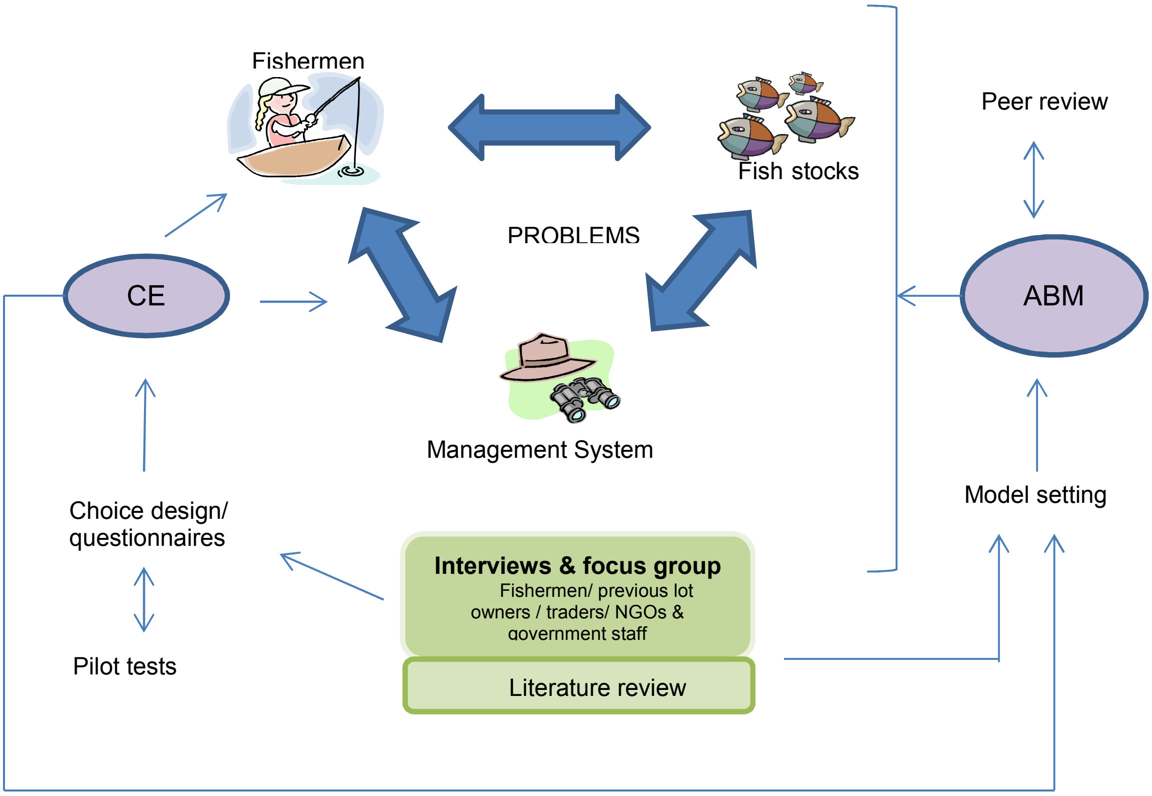


Figure 3-2 The framework of research methodology

Different techniques were used to collect data. Focus group and interviews were employed to collect data from fishermen, previous lot owners, government and NGOs staff in order to design questionnaires and choice sets including various characteristic of fishing lots. The questionnaires were piloted and improved to produce an appropriate questionnaire including choice options for small-scale fishermen. The survey was carefully conducted in different locations and covers different socio-demographic characteristics of fishermen. More information is included in Chapter 4. The analysis of the CE model seeks to identify different socio-demographic groups of fishermen according to their preferences. Furthermore, the analysis of preferences for different characteristics of fishing lots which allow an analysis of how fishermen trade-off different characteristics when considering alternative options.

The CE simulation does not cover analysis of spatio-temporal dynamics of fisheries, which is crucial for fishery management. The management of fishery resources is complex because it involves multiple users and the dynamics of fish and fishing fleets at different times and locations. A spatial model is developed to understand the interactions between fishermen, fish stocks and the management system under various and competing ways of management in order to improve the sustainability of the fishery. ABM was chosen as the most suitable model because of its ability to incorporate social, economic and biological aspects of the system into one model. In addition, complicated circumstances such as a mixed fishery management tools and a complex ecosystem can be examined at both individual and system level. The choice of ABM therefore allows a suitable tool for evaluation of the management system of the Tonle Sap fisheries. The model setting is based on the information from relevant fishery literature, questionnaires and the CE outcomes from the first part of the thesis.

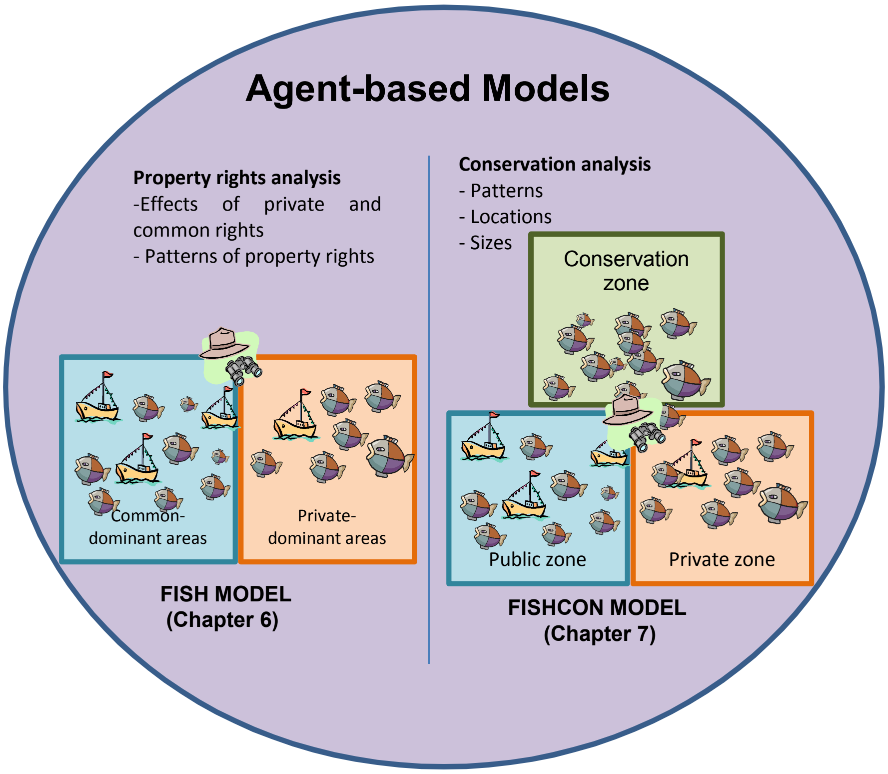


Figure 3-3 Two spatial models using an agent-based simulation.

The spatial analysis is divided into two sections (see Figure 3-3). The first simulation (FISH model) focuses on a dual property rights system with private and common areas. The first section investigates spatial effects of property rights through the interactions of fishermen behaviours, fish stocks and fishing regulations comparing between private and common property rights. These simulations use the same parameters and default values except different layouts of property rights assigning over fishing grounds. The results of private and common areas are compared in terms of fish stocks condition and fishing profits. Different combinations of private and common areas are also analysed including sensitivity analysis of model parameters. The second section develops a model including conservation areas into the FISH model. This model is termed the FISHCON model. The simulation evaluates a zonal (spatial) management system consisting of conservation, private and common areas. This model focuses on the effects of conservation, as the marine conservation literature (e.g., Russ and Alcala, 1996a; Wantiez *et al.*, 1997; Halpern, 2003) have suggested that the conservation areas benefit to fisheries due to spatial spill-overs. Different conservation sizes, patterns and locations are simulated. The simulations explore spatial dynamics of fisheries in three different zones: private, common, and conservation zones considering the socio-economic and biological effects of spillover from conversation areas. This spatial analysis help to fill a research gap as most literature does not explicitly include spatial interactions.

In summary, the combination of CE approach and ABM provides a better way of understanding the fishery dynamics and implications of the fishery management system because the overall outcome provides macro consequences derived from actions of and interactions between individuals. It is also important to understand the drivers of individual's decisions, actions, and interactions taking place at the local level. Only through understanding decision making is it possible to model the collective effects for the whole fishery and begin to understand the implications of alternative policy options.

Chapter 4
MODEL OF FISHERMEN'S BEHAVIOUR IN AN AUCTION MARKET

This chapter investigates how fishery management through an auction-based system affects different groups of small-scale fishermen using a choice experiment approach. The first section introduces to research interests, research questions, and the purpose of this chapter. The second section discusses the concept of property rights and its relevance to fishery management, outlining how the property rights influence overexploitation of fishery resources. This is followed by a description of Tonle Sap wetlands and a synopsis of the fishery management system to understand the context of the choice experiment. Then follows a section presenting the research methods and survey design, which is followed by results and discussions. The main findings show that small-scale fishermen are willing to bid for fishing licences; however an auction-based approach might not be an effective way to distribute the licences if a fair distribution is an important outcome.

4.1 INTRODUCTION

Regulation based on a mix of auctions and zonal designation has been used in Cambodian fisheries. The rationale behind using an auction system was that a market based approach generates resource rents to the government, and that by securing property rights to the resource, the system discourages overcapitalization (Mansfield, 2004; Acheson, 2006). The Tonle Sap wetland has been divided into a conservation zone, an open access fishing area and an area with individually auctioned fishing rights. The auction system has been in place since the late 1980s, involving private concessionaires bidding for exclusive temporary fishing licences for designated plots, called fishing lots. Statistics from the Ministry of Economy and Finance in 2002 revealed that the official income from the concession system was between 1-4 million USD per year, while local authorities might earn more from informal revenues (McKenney and Prom, 2002). The fisheries sector was reported to have increased revenues to government, contributing 3.2 – 7.4% of GDP in 1995, 11.7% in 2003 and 16% in 2004 (Baran *et al.*, 2007b) . However, the aim of the management system was also to achieve a more biologically sustainable fishery. Achieving this aim seems to have been less successful with reports of continuing degradation of fish stocks and fish habitats (McKenney and Prom, 2002; Song *et al.*, 2005; Sneddon, 2007; Nuorteva *et al.*, 2010).

The way in which the management system has been operating has also been questioned and social conflicts over enforcement of boundaries between the different fishing zones and between different groups of users have been reported (Bonheur and Lane, 2002; Keskinen *et al.*, 2007). Furthermore, local fishermen and auction participants have raised concerns about the unfair distribution of fishing licences. A lack of information about the bidding system has been cited as a particular problem. A long-term tension has been reported between more wealthy fishermen (fishing lot owners) and poorer users of the communal fishing grounds, due mostly to inequitable access to rich fishing grounds (Keskinen *et al.*, 2007; Nuorteva *et al.*, 2010). The imbalanced allocation of property rights to rich and poor (also called 'elite capture') is not exclusive to the Tonle Sap but has often been highlighted in different fisheries and other common pool resources vital to poor and vulnerable groups (Beck and Nesmith, 2001; Meinzen-Dick and Mwangi, 2008; Working Group on Property Rights, 2008). To counteract the developing conflicts in Tonle Sap, fishing licences were revoked in late 2011 and early 2012 to allow fish stocks to recover (DAP-NEWS, 2011; Royal Government of Cambodia, 2012). Access and use of renewable resources are key problems which research in the ecosystem management field attempts to solve (Bousquet and Le Page, 2004). With the possible future reintroduction of the auction-based system in Cambodia, it is important and timely to study the impacts of potential future licence based systems, to increase understanding of how alternative allocation systems might impact different groups of users of the resource.

This chapter investigates the scope for widening participation and the implications of implementing an auction system by focusing on small-scale fishermen who often have limited access under such a system. The attractiveness of alternative lot characteristics was measured through lot valuations using CE (Bennett and Adamowicz, 2001; Hanley *et al.*, 2001), where the lot characteristics define the attributes of a choice. The price of a fishing licence was represented by the floor price, which is the minimum bidding value in the auction. This floor price represents the monetary attribute in the CE design. This approach enables an assessment of the implications of using an auction-based system to allocate fishing rights and the conditions under which an auction-based system could help to improve access for smaller scale fishermen. Small-scale fishermen were targeted for study as they are in the majority in Cambodian fisheries but have limited access to the most productive fishing grounds. Initial investigations found that the majority of fishermen expressed an interest in the opportunities that a redesigned auction system might bring. However, this research expected to find variations in how individual fishermen assess the value of a fishing licence depending on size of the lot, location, productivity, management and financial restrictions as well as socio-demographic characteristics of the fishermen. This leads to the hypothesis that the characteristics of available fishing licences in the auction have significant implications for the extent to which the auction system creates access for a larger group of small-scale fishermen.

This research aims to understand how an allocation system impacts on the distribution of fishing rights and benefits in Tonle Sap. This research focuses on small-scale fishermen to explore the scope for widening participation as this group is in the majority in Cambodian fisheries but has had limited access to rich fishing grounds and has experienced barriers to participation in the auctions. In order to achieve this aim, the research investigates whether different groupings of fishermen can be identified in the study area, measured in terms of differences in their valuation of attributes of the fishing lots, and therefore their likely behaviour in an auction market. Furthermore, this research explores how the allocation system influences different groups of fishermen by asking how the designation of lots, i.e., their size, location, potential catch and fishery management restrictions, affects their attractiveness to different types of fishermen and whether they are likely to bid for the individual lots in an auction.

4.2 LITERATURE REVIEW: Property Right Regimes

The study of overexploitation of common pool resources such as fisheries has a long history (Gordon, 1954; Clark, 1973; Feeny *et al.*, 1990; Cunningham, 1994; Sinclair *et al.*, 2002; Hilborn *et al.*, 2003; Rosenberg, 2003; Pauly *et al.*, 2005; Ostrom, 2008), concluding that the open access nature of many fishing stocks leads to misallocation of fishing rights, which poses challenges for achieving economically efficient harvesting. The literature has suggested alternative ways to deal with overexploitation and improve efficiency and conservation of fish stocks such as individual transferable quotas (ITQs) (Morgan, 1995; Hannesson, 1996; Chu, 2009), seasonal closures (Watson *et al.*, 1993; Conrad, 1999; Hilborn *et al.*, 2004; Murawski *et al.*, 2005), and designation of protected areas (Carter, 2003; Marinesque *et al.*, 2012). Assigning property rights has been argued as a successful approach for decreasing fishing effort, generating resource rents and conserving fish stocks (Sinclair *et al.*, 2002; Sutinen and Soboil, 2003; Grafton *et al.*, 2006). For common-pool resources, property rights are defined through access and resource withdrawal rights but higher level property rights such as rights to manage, exclude and alienate are also important in fisheries management (Schlager and Ostrom, 1992). A property rights system which includes the right to alienation is often considered the most efficient as it can be defined as equivalent to private property (Ostrom, 2003). Lawrence (2000) points out that the necessary condition for a property rights system to lead to resource conservation is that ownership generates a tangible financial value from resource use over a long time period. Some empirical studies support this argument, e.g., studies of land based resources have shown that individual land ownership and more secure formal property rights to land have resulted in more investment in improved productivity of the land (Feder, 1987; Feder and Feeny, 1991). Furthermore, other studies show that fishermen who have clearly defined private rights are able to increase efficiency in the use of space and technology (Schlager, 1994) and generate a positive incentive for conservation (Bodal, 2003). For example, establishing access rights to members of an elite fishing caste in Padu, Estonia has been helpful in reducing the conflicts between fishermen and maintaining a sustainable marine fishery (Coulthard, 2011). However, it has also been argued that private property rights alone do not ensure resource conservation even when they are secure (Acheson, 2006). For example, property rights in marine fisheries in the form of ITQs have been reported to generate negative effects on sustainability due to high-grading, by-catch species dumping, and misreporting of fish catches as fishermen seek to maximize the value of their trip landing (Copes, 1986; Matthew A, 1997; Hilborn *et al.*, 2003; Grafton *et al.*, 2006; Sumaila, 2010).

4.3 BRIEF OVERVIEW OF FISHERY MANAGEMENT

This section provides a brief explanation of fishery management in order to understand choice simulations, the main attributes of the system have been introduced in Chapter 2. The number of years that fishing licence owners had authority over lots depended on the contract and type of fishing lot, and were generally either two-year or ten-year contracts. Fishing operations were divided into two different types classified by fishing gear and licences; small-scale subsistence fishing and large scale commercial fishing. Small-scale fishermen required no licence for fishing all year around in the public fishing areas, but were excluded from the fishing lots during the open fishing season. Large scale fishing operations were linked to fishing lots and dai lot fisheries[12]. The lots, which were normally located in the most productive fishing grounds, were allocated by the government. The concessionaires had authority to operate the lot for, normally, a two-year concession period. The lot owners were usually businessmen with power in terms of finance and/or connections with government. Fences around the lots were constructed as a massive cage for fish at the beginning of the open season and were removed at the end of the season. The licence holders usually employed guards to protect lot boundaries. The characteristics of the previous lots and administration of the auction system were both barriers to small-scale fishermen as the sizes of the lots were often too large[13] and their floor prices were too high. Therefore, a minority of actual fishermen were part of the fishing lot system, and if they were, it was mainly as seasonal labourers. Most small-scale fishermen only operated in the less productive communal fishing areas.

In early 2012, the fishing lots were totally abolished for at least three years with the purpose of fish stock replenishment and improvement in the livelihoods of small-scale fishermen (Royal Government of Cambodia, 2012). The management of the fishery is now being reconsidered in order to introduce more efficient and sustainable fishery regulations. It is therefore important to understand the previous

[12] Fishing lots were specific areas of land and water while dai lots were an anchoring position in a river for bagnet or stationary trawling, which were used for capturing fish during migration downstream.

[13] The previous lot number two in Battambang province covered an area of around 500 square kilometres (Allebone-webb and Clements, 2009).

system and potential changes that might be considered to address past failures. This study is designed to contribute to this by surveying the small-scale fishermen in the study area and assessing whether a redesigned auction system could address some of the conflicts observed under the previous system. In particular, this research focuses on the conflict related to the perceived unfair allocation of fishing rights to the productive fishing areas of Tonle Sap.

4.4 METHOD AND DATA ANALYSIS

The hypothesized management system is based on resource users choosing either to fish in the open access area or to purchase the exclusive right to fish in a fishing lot. This research therefore use a CE approach (Bennett and Adamowicz, 2001; Hanley *et al.*, 2001) to model fishermen's behaviour in a hypothetical auction market where the fishermen can choose to bid on different lots with given characteristics or choose not to bid (fish in the common areas). The combinations of characteristics for lots were designed for small-scale fisheries as previous market transactions only give information on the purchase of licences for larger commercial fishing grounds; hence the CE approach is used to explore behaviour in a hypothetical auction for lots that might appeal to small-scale fishermen.

The CE approach was developed from Lancaster's model of consumer choice (Lancaster, 1966) in which individual utility derives not directly from the goods themselves but from the characteristics of the goods (Birol and Cox, 2007). For a full explanation of the theory behind the CE approach to model choice behaviour please refer to Lancaster (1966), McFadden, (1974; 1984), Ben-Akiva and Lerman (1985), Heckman and Singer (1984), and Swait (1994).

4.4.1 Discrete choice models

There are several statistical model specifications available for estimating discrete choices among a set of exclusive options based on an assumption of utility maximization (Davies *et al.*, 2001; Train, 2009). The models are often referred to as Random Utility Models (RUM) (McFadden, 1974; 1980). Following this framework an individual n is faced with a choice among j alternative options. If U_{nj} represents the utility of option j to individual n, j will be selected only if $U_{nj} > U_{ni}$, $j \neq i$; where i is the other alternatives. For analytical tractability, U_{nj} is viewed as being divided into two components; an observable component or representative utility (V_{nj}) and an unobservable component (ε_{nj}): $U_{nj} = V_{nj} + \varepsilon_{nj}$ where $V_{nj} = f(X_{nj})$, and X_{nj} represents the characteristics of choice *j*, such as fish abundance and accessibility. The observable/deterministic component is analysable and based on the choice's attributes, while the unobservable random component is not (Bockstael and McConnell, 1983; Train, 2009). The probability of individual *n* choosing option *j* can be expressed as the probability that the utility from choosing option *j* is higher than the utility from any other option:

$$\begin{aligned} P_{nj} &= P\,(U_{nj} > U_{ni}\ \forall\, j \neq i) \\ &= P\,((V_{nj} + \varepsilon_{nj}) > (V_{ni} + \varepsilon_{ni})\ \forall\, j \neq i) \\ &= P\,((\varepsilon_{ni} - \varepsilon_{nj}) < (V_{nj} - V_{ni}))\ \forall\, j \neq i) \end{aligned} \qquad \text{(Equation 4-1)}$$

In this study, two different discrete choice models, the conditional Logit Model (CLM) and the Latent Class Model (LCM), are estimated using Nlogit 4.0 (Greene, 2007).

4.4.1.1 Conditional logit model

First, a conditional logit model is employed to estimate a simple choice model to address how the characteristics of a fishing lot affect the likelihood of purchase. All fishermen are assumed to hold the same preferences for the various lot attributes. The CLM specification assumes that the error term, ε_{nj} is distributed IID extreme value (Hensher *et al.*, 2005). The CLM assumes an independence of irrelevant alternatives (IIA) property (Hausman and McFadden, 1984; Hensher *et al.*, 2005; Train, 2009), which means that the relative probabilities of two alternatives being chosen are not affected by introducing or removing one of the other alternatives. Although CLM has some disadvantages (such as homogenous preferences and the IIA assumption), it provides an initial test of whether the different attributes are important determinants of choice.

In CLM, the probability of individual *n* choosing alternative *j* (P_{nj}) in preference to any other alternatives *i* is given as:

$$\mathbf{P}_{nj} = \frac{\exp(\beta_1 X_{1nj} + \beta_2 X_{2nj} + \cdots + \beta_k X_{knj})}{\sum_{i=1}^{I} \exp(\beta_1 X_{1ni} + \beta_2 X_{2ni} + \cdots + \beta_k X_{kni})} \quad \text{(Equation 4-1)}$$

Where β_k is the utility coefficient and X_{kni} is the level of attribute k for alternative *i* for fisherman *n*.

Although the basic CLM does not allow for any preference heterogeneity between groupings of fishermen, a CLM including socio-demographic interaction terms allows an examination of whether different fishermen displayed different preferences. This is carried out by testing interaction variables between socio-demographic characteristics and choice attributes.

4.4.1.2 Latent class model

LCM is used for the analysis of heterogeneity of preferences (Heckman and Singer, 1984; Boxall and Adamowicz, 2002; Greene and Hensher, 2003). A full discussion of the theory can be found in Heckman and Singer (1984). The basic CLM outlined above assumes homogenous preferences across respondents while preferences may in fact be heterogeneous, even within those socio-demographic distinctions which are observable to the analyst. LCM accommodates preference heterogeneity between latent segments of the fisherman population, while permitting for the number of segments to be decided endogenously by the data (Milon and Scrogin, 2006). This assumes that the fishermen in each segment are homogenous, while representing the whole sample heterogeneity by modelling several segments. The error terms are assumed to be distributed independently across segments and individuals (Swait, 1994). This means that each respondent has an estimated probability of belonging to a particular segment, each of which is characterized by segment specific utility parameters (Boxall and Adamowicz, 2002; Burton and Rigby, 2009).

In LCM, the probability that an individual *n* selects alternative *j* ($\mathrm{p'}_{nj}$) is characterized by:

$$\mathrm{p'}_{nj} = \sum_{s=1}^{S} \mathrm{P}_{njs}\, \mathrm{P}_{ns} \qquad \text{(Equation 4-3)}$$

Where *S* is the number of segments and P_{njs} represents the probability that individual *n* selects option *j* conditional on segment *S*. In LCM, the utility function (Equation 4-1) can be expressed as $U_{njS} = \beta_s X_{nj} + \varepsilon_{njs.}$ In this expression, the utility parameters are now segment specific and the choice probability becomes:

$$\mathbf{P}_{njs} = \frac{\exp(\mu_S \beta_S X_j)}{\sum_{i \epsilon k} \exp(\mu_S \beta_S X_i)} \qquad \text{(Equation 4-4)}$$

In this model individual *n* faces a choice of one option from a finite set and *k*, μ_S and β_S are the segment-specific, scale and utility parameters respectively. The error term is assumed to be distributed independently across segments and individuals with a type I extreme value distribution (e.g., Jacobsen *et al.*, 2012). By incorporating these assumptions, the probability of an individual's membership of segment *S* will take the form:

$$\mathrm{P}_{ns} = \frac{\exp(\alpha \lambda_S Z_n)}{\sum_{s=1}^{S} \exp(\alpha \lambda_S Z_n)} \qquad \text{(Equation 4-5)}$$

Where λ_S denotes a vector of the segment specific parameters and α is a scale factor that is assumed to be equal to one, each respondent therefore has a probability of belonging to a particular segment (Boxall and Adamowicz, 2002; Burton and Rigby, 2009). By substituting the choice Equation 4-4 and membership Equation 4-5, the probability in Equation 4-3 is expressed by:

$$\mathbf{P'}_{nj} = \sum_{s=1}^{S} \left[\frac{\exp(\mu_S \beta_S X_j)}{\sum_{i \epsilon k} \exp(\mu_S \beta_S X_i)}\right] \left[\frac{\exp(\alpha \lambda_S Z_n)}{\sum_{s=1}^{S} \exp(\alpha \lambda_S Z_n)}\right] \qquad \text{(Equation 4-1)}$$

The choices of each individual are therefore considered independently of other individual's choices, as there is no recognition of any learning from observing the bidding behaviour of other individuals or individual learning from repeating the choice experiment. The panel structure of the data set does however allow estimation of individual specific lot valuations (Greene, 2007). While it would be interesting to study bidding behaviour and estimate potential interaction between fishermen, this is not possible given independent data collection. Therefore, the small-scale fishermen are modelled as independent agents who consider their own fishing capability, their expectation about the return on investment, the need for labour and budget constraints.

Potential explanations for the observed heterogeneity are identified in a separate second stage analysis investigating the relationship between socio-demographic characteristics and membership probabilities using a binary model. This analysis establishes the evidence for any relationship between membership functions and socio-demographic characteristics.

4.4.2 Experimental design

Primary and secondary data from preliminary fieldwork and pilot tests were used to determine attributes and their levels for lot characteristics. It was very important to ensure that alternative attributes and their levels were meaningful to respondents. Several techniques were used to collect the information in order to generate a preliminary list of attributes such as literature reviews, focus groups, interviews and pilot tests. The various sources of secondary information on Cambodian fisheries and fishery management systems were reviewed before focus groups and interviews were conducted. Two focus groups and twelve face to face interviews were used to gather information from small-scale fishermen. Face to face interview is the main technique used to collect information from fishing lot owners (previous) and participants in the auction. The face to face interview provided in-depth information and clearer details on attribute selection. The focus groups allowed observation of the attitudes and views of fishermen on the fishery management system. Informal consultations have also been conducted with specialists and other researchers who have worked/ carried out research in Tonle Sap, such as staff from the Fishery Administration (FiA), an advisor to the Wildlife Conservation Society (WCS), an advisor to Conservation International, Cambodia

(CI), an exclusive director for the Fishery Action Coalition Team (FACT) and an advisor to FACT.

The attributes and their levels for the choice experiment represent different fishing lot characteristics; fish catch, floor price, leasing period, distance from home to the fishing lot and conservation management plans. These attributes and their levels were designed based on interviews and secondary sources. Two pilots were carried out to ensure that the questionnaires and choice experiment design were appropriate for small-scale fishermen. After the first pilot an additional characteristic of 'flexible finance schemes' was added to the list of attributes. So, there were six attributes all together used in the choice experiments design. This description was consistent with the information given for the options available in the real auctions, except flexible finance schemes, which have not been offered in the real auction. The attributes and their levels are especially designed for the targeted respondents. For instance, (after the first pilot) hypothetical fishing lots were resized to be smaller than the previous actual lot sizes which resulted in cheaper floor prices and less requirement for hiring labourers. Also, flexible finance schemes were included in order to evaluate the barriers created by a lack of capital access; as perfect credit markets rarely exist for small-scale fisheries (Béné and Friend, 2011). Private loans using middlemen, private lenders or relatives seem to be the only options fishermen have to access credit (Turton, 2000; Kimkong, 2007). In practise these options are usually very expensive and a flexible finance scheme might be attractive to poorer fishermen by postponing payment for the fishing licence until harvests have been sold, rather than requiring payment in advance on auction day.

4.4.2.1 Attributes

Six attributes were used to describe fishing lots: fish catch, floor price, flexible finance schemes, leasing period, and distance to fishing lot and conservation management plans. The explanations of each attribute are as follows;

(1) Annual fish catch

This attribute represents the 'official record' of average fish caught per year for the past years in the fishing lots.

(2) Floor price

This attribute is used to illustrate the minimum amount of money that concessioners have to pay annually to the Cambodian government in order to get exclusive fishing rights. The floor price in this research referred to the initial/starting price which was set for bidders in the auction. The floor prices of each lot varied depending on FiA calculation, which was based on a calculation of annual fish catches from individual lots and market prices. In the actual auctions participants are informed of the floor price and information about each fishing lot before the auction day.

(3) Flexible finance schemes

This attribute provides schemes to assist small-scale fishermen in overcoming budget constraints. The flexible finance scheme provides fishermen with access to a flexible payment system. The annual payment can be made at the end of the harvesting season every year instead of paying a large deposit on auction day and paying the balance before the fishing season started.

(4) Leasing period

This attribute is defined by the number of years that a concessionaire would have authority over a fishing lot. This permission is only active six months every year for two years or ten years. The length of the leasing period is indicated in a contract between a concessionaire and the government. There is no study exploring whether two-year or ten-year leasing periods helps with conservation in Cambodia. The hypothesis is that a longer leasing period helps to preserve fish habitats. The work of Yandle (2007) found considerable evidence that the longer a resource user's time horizon, the greater their incentive to manage sustainably because they are more confident of the long-term benefits. For example, lot owners may conserve flooded forests and avoid fishing gear that destroys their fishing grounds. Choice modelling will help establish whether the leasing period changes the attractiveness of the lot to fishermen.

(5) Distance

This attribute is used to describe the distance from a respondent's house to the fishing ground. A shorter distance leads to less expenditure (e.g., lower fuel costs). Also, it is assumed that fishermen have more fishing expertise in the areas surrounding their house. Local fishing knowledge, such as searching for productive fishing grounds, the direction of wind, the level of water and water flows are required in Tonle Sap fisheries.

(6) Conservation management plans

The attribute of conservation management plans explained restrictions on activities in fishing lots. This complied strictly with fishery law (Fisheries Administration, 2007). For instance, pumping water into small ponds and electro-fishing gear were prohibited. Also nets with mesh sizes bigger than four centimeters are not allowed. Including this attribute allowed an investigation as to whether a conservation incentive is valued by the right holder. Fishing lots has normally been located in the productive habitats and fish nursery grounds (near shore/flooded forests). Conservative behaviours of right holders are assumed to maintain/improve fish habitats and therefore encourage fish to return to the same habitat for breeding. This research applied this attribute to investigate how small-scale fishermen respond to conservation requirements.

4.4.2.2 Levels of attributes

The attribute levels were explained either qualitatively or quantitatively. Other research has shown that a large range of levels should be selected to get better parameter estimates and that it is statistically preferable (Hensher *et al.*, 2005; ChoiceMetrics, 2012). The more levels used in choice design, the higher number of choice situations will be generated, while also mixing the number of attribute levels for different attributes may yield even higher numbers of choice situations (ChoiceMetrics, 2012). Different value ranges were assigned to each attribute. The values of each level were revised to make them more appropriate for small-scale fishermen after the first pilot test. Table 4-1 shows the levels for each attribute. There were four quantitative levels for annual fish catch and floor price. Two different levels were assigned for leasing period, conservation plans and flexible finance schemes.

Table 4-1 Attributes and their levels for the experiment design

Attributes	Levels
1.Annual fish catch	5, 10, 20, 45 (Tonnes)
2.Floor price	400, 750, 1600, 3500 (USD)
3.Flexible finance schemes	with, without
4.Leasing period	2, 10 (years)
5.Distance	Less than or equal to 2, 10 (Km)
6.Conservation management plans	No restriction, with conservation

Remarks: 1 USD (US dollars) = 4,025 KHR (Cambodia Riels) (12 March 2011)

1 GBP (UK pounds) = 6,472.80 KHR (Cambodia Riels)

1 hectare = 0.01 square kilometer = 10,000 square meters

1 tonne = 1,000 kilograms

The levels were chosen to be realistic and represent the possible values of fishing lots. In addition, these levels were selected to parameterise the preference for each attribute so as to reflect the diverse quality and size of fishing grounds. For example, the floor price levels were adapted from past bidding prices in relation to fish catch statistics. This was done by reducing the size of commercial fishing lots to an affordable scale for small-scale fishermen.The fish catch was also reduced by the same ratio as the floor price.

4.4.2.3 Creating choice experiment

(1) Model specification

There are three unlabeled alternatives consisting of two resource used options (V_1 and V_2) and one status quo (V_3) as shown below:

V_1= U (lot A) = β_2*FISH_CATCH + β_3*FLOOR_PRICE + β_4* PAYMENT_SCHEME + β_5* DISTANCE + β_6* LEASING_PERIOD + β_7* CONSERVATION_PLAN

V_2= U (lot B) = β_2*FISH_CATCH + β_3*FLOOR_PRICE + β_4* PAYMENT_SCHEME + β_5* DISTANCE + β_6* LEASING_PERIOD + β_7* CONSERVATION_PLAN

V_3= U (no bid) = β_1

These options were used both to create a choice experiment with Ngene version 1.0.2 (ChoiceMetrics, 2012) and to estimate choice parameters with Nlogit version 4.0 (Greene, 2007).

(2) Generation of experimental design

The experimental design is generated for the specific utility model above using the simultaneous orthogonal factorial design to detect main effects. All possibilities of resource use options using full factorial design could not be applied in this case because the design would be too large and exceed the capacity of respondents (ChoiceMetrics, 2012). Therefore, “a fractional factorial design”, which is a subset of choice situations from the full factorial, is selected as a strategy to solve this problem. Orthogonal design is the most well-known type of a fractional factorial design but there are some limitations. As such there are choice situations in which a certain alternative is clearly more preferred over the others. The orthogonal design aims to minimize correlations between attribute levels (Hensher *et al.*, 2005). To summarise, the orthogonal fractional factorial designs (simultaneously orthogonal) generate a way that the attribute levels are orthogonal. It means this design provides no correlations between levels of attributes within alternatives and across alternatives. Using the orthogonal fractional factorial design, Ngene created 20 choice situations, which were still considered to be too many to present to a single respondent. “Blocking” was therefore used to split the choice situation into smaller design. 20 choice situations were blocked into two groups of ten choice sets per individual. An example of choice card is shown below (Figure 4-1) and the full sets of choice cards are provided in appendix A.

Q 2.3 Please choose <u>ONLY ONE OPTION</u> after considering the following three options.

Which option would you like to choose?

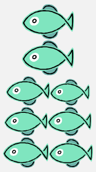
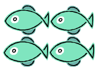
Attributes / Options	Annual fish catch (tonnes)	Floor prices (USD/ year)	A flexible payment scheme	Leasing periods (years)	Distance (kms)	A conservation management plan	My choice is (tick only ONE)
Option A			With a flexible payment scheme	2	10	No restrictions	
	Catch 45 tonnes of fish per year	The minimum additional annual Payment is 800 USD.	You have a flexible payment scheme	You have 2 years guarantee for exclusive fishing rights over the lot.	The fishing lot is located 10 km from your house.	There are no restrictions.	
Option B			With a flexible payment scheme	2	10	Include a CONSERVATION plan	
	Catch 20 tonnes of fish per year	The minimum additional annual Payment is 1,600 USD.	You have a flexible payment scheme	You have 2 years guarantee for exclusive fishing rights over the lot.	The fishing lot is located 10 km from your house.	A conservation management plan needs to be included in the lot operation.	
Option C	I do <u>NOT</u> want to bid or pay for any of these options.						

Figure 4-1 An example of a choice card

4.4.2.4 Sample size

The minimum sample depends on the statistical power needed for the model (Bennett and Adamowicz, 2001). Some guidelines suggest that the minimum sample size should be 50 (Hanley *et al.*, 2006; Barkmann *et al.*, 2007). Guidance on the appropriate sample size based on levels of attributes, number of alternatives per choice set and the number of choice questions per individual (Kanninen, 2007) is as follows:

$$\boldsymbol{N} \geq \frac{\boldsymbol{500C}}{\boldsymbol{TA}} \qquad \text{(Equation 4-7)}$$

where, "N" is a required sample size, "C" means levels on the biggest attribute, "T" denotes the total number of choice questions per individual, and "A" represents alternatives per card. This guideline was applied for this research and produced a minimum sample of 67 $((500*4)/(10*3))$ for each of the two block designs applied. The minimum sample of the survey therefore was 134 (67*2).

4.4.3 Questionnaire development and pilot tests

Questionnaires were carefully developed and pilot tests were conducted to deal with challenges of conducting a survey in a developing country.

4.4.3.1 Questionnaire development

Questionnaires (Appendix B) comprised of 4 sections: fishery background, choice card presentation, follow-up questions and socio-demographic information. Section one consists of questions about the fishery background of the respondent including fishing experience, the number of fish caught and the number of boats and labourers. The second section gives an explanation of the attributes followed by a "cheap talk" script, used to reduce positive hypothetical bias. This script reminded respondents about their budget constraints, which has been shown to reduce bias in contingent valuation and choice experiment surveys (Cummings and Taylor, 1999; Carlsson *et al.*, 2005; Aadland and Caplan, 2006; Hensher, 2010). Due to limited formal education, the short reminder version[14], which involved reading a script that clearly highlights hypothetical bias problems, was used instead of the long version. Afterwards three choice cards were presented and respondents were asked to select only one option in each choice set. The third section is a series of follow-up questions that not only helped understanding respondents' preferences but also assisted in checking for any problems with how respondents understood the questionnaire. This section included a question to investigate ignorance of attributes when an option from a choice card was selected, and questions on respondents' attitudes towards the allocation system. The last section contained questions on socio-demographic information and individual history of fishing in Tonle Sap wetlands such as age, education level and household income.

4.4.3.2 Pilot tests

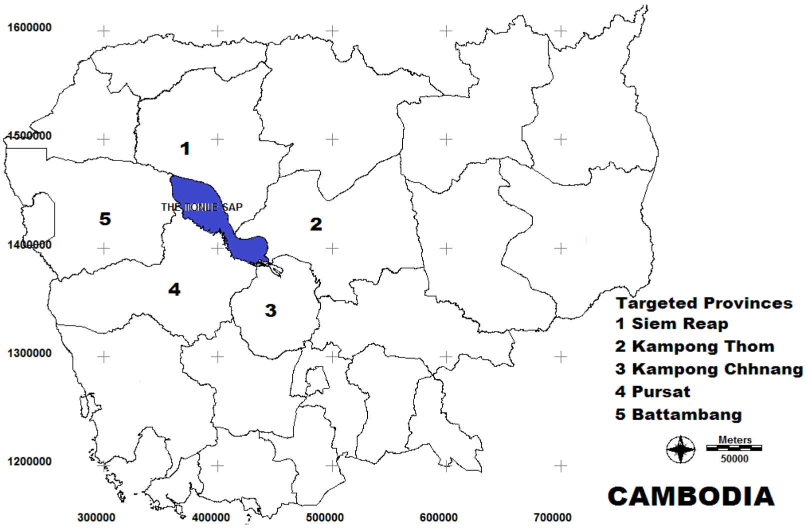
The questionnaires were piloted to test feasibility of the choice sets. Two pilot tests were carried out to ensure that the questionnaire was understandable and the attributes and their levels were meaningful to the target respondents. After the first pilot test, the presentation of the choice cards was improved by translating the choice sets to Khmer language with colour photographs. In addition, large coloured picture cards and less text on the choice sets were used to simplify choice situations for the respondents. Also, the levels of fish catches and floor prices were decreased and a new attribute called flexible finance schemes was added in order to provide more opportunity for small-scale fishermen to participate in the hypothetical auction.

[14] The cheap talk script is used in this study was as follows; **First**, I would like to remind you about your own household budget, at what price would your household be able to buy a fishing lot? The payment for a chosen lot option would be made annually and you also have other expenses. **Second,** keep in mind that there are alternative fishing grounds such as the public fishing areas. And **third**, please keep in mind that in the previous surveys we have found that people chose options that they actually would not be able or willing to purchase. For this reason, please imagine that your household is actually paying for the selected options.

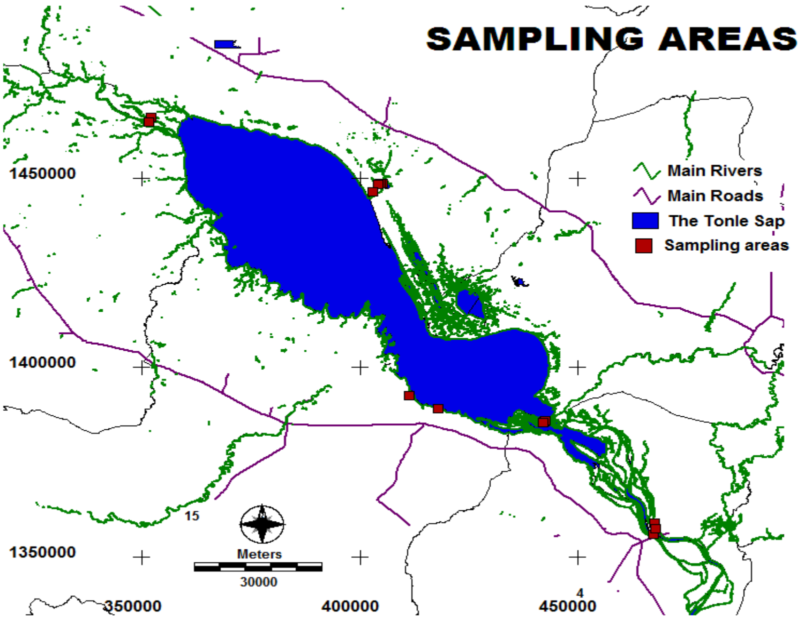
4.4.4 Survey implementation

The survey was performed in 2011 with small-scale fishing households in five provinces surrounding Tonle Sap Lake: Kampong Chhnang, Pursat, Kampong Thom, Battambang and Siem Reap. The targeted villages are shown in Figure 4-2. Small-scale fishermen has been targeted because this group is in the majority in Cambodian fisheries, but have had limited access to the most productive fishing grounds in the open season and have experienced barriers to their participation in the auction market.

Face to face interviews were considered the best means of data collection to avoid any misunderstanding of the questionnaire, as the respondents were expected to be unfamiliar with responding to questionnaires. Highly qualified enumerators with a high level of responsibility and experience in working with local people were recruited to carry out the survey. The enumerators had to complete a training process before starting. The villages were selected through consultation with local people and fishery organizations in each province in order to achieve a wide distribution of levels of income, location and socio-economic conditions. The sample covered households who lived in floating villages, land-based villages and half-year flooded villages (the villages are flooded for half a year every year). The poorest group seemed to live in the floating villages and the better off households were based on land. Arrangements were made with village chiefs to introduce enumerators and the purpose of the surveys. Systematic sampling was used and it was the priority to interview the head of each household. In each village, each k'th household was interviewed, where k is the number of households divided by the number of interviews needed. The number of interviews in each village was the total sample size divided by the number of targeted villages After that, enumerators used the survey instructions (Appendix C) to introduce themselves and to ask for consent from participants. Information on incomes and profits were carefully collected using techniques that assisted the respondents in recalling past financial information (e.g., Rozelle, 1991). This was done by requesting respondents to identify sources of household income (primary and secondary sources) and the amount of money from each source (per fishing trip/ per month/ per season) before summarizing total household income. Profit information was also collected by calculating profits from individual costs and revenues. The enumerators assisted them to calculate household incomes and profits.



(A) Targeted provinces



(B) Sampling Villages

Figure 4-2 Location of sampling areas

4.5 RESULTS

4.5.1 Respondents' socio-demographic characteristic

The data were analysed using responses from 272 households[15] operating small-scale fisheries in Kampong Chhnang, Pursat, Kampong Thom, Battambang and Siem Reap. Approximately 60% of the respondents were from floating villages and 40% were from land-based households. Demographic information about the respondents is shown in Table 4-2.

The target group has never participated in the actual auctions. Some of them had experience of illegal sub-leasing of fishing lots or being a labourer in a fishing lot. The average number of years of fishing experience in Tonle Sap was 23 years and the annual average fish catch was 2.1 tonnes. Approximately 34% of the households relied on fishing activities only, while the rest had other sources of income mainly from agriculture, especially aquaculture, rice and corn farming. Some were employed in fishing lots earning, on average, 5 USD a day[16].

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[15] There is no, to the authors knowledge, official information on the number of fishing households, however, the final census in 2008 showed that there are 13,395,682 people (10,781,655 in rural districts), and 2,841,897 households with an average household size of 5 people in Cambodia. The provinces that surround the lake have a population of nearly 3 million people (30% of the country population). Approximately 50 per cent of population have not completed primary school education and adult literacy in rural areas was 74%. (National Institute of Statistics, 2008). The number of households around Tonle Sap wetland was estimated at 219,621 households with a population of 1,186,192 people (Baran, 2005). The percentage of female-headed households in Cambodia was 29% in 2004 (Cambodia Inter-Censal Population Survey, 2004).

[16] There is no law setting a minimum wage in the fisheries sector. However, the regular minimum wage for factory workers is 55 USD/month (October 2010 - 2014). The average wages for manufacturing workers and construction workers are approximately 76 and 83 USD/ month respectively (Prake (2012).

Table 4-2 Socio-demographic information of the respondents

Variables	Mean	S.D.	Min	Max
Age (> 17 years)	41 years	10	18	65
Gender (% male)	68%			
Nationality (% Khmer)	91%			
Education				
- Illiterate	38.2%			
- Barely literate but never went to school	12%			
- Primary school	41.8%			
- Secondary school	7.6%			
- Diploma and above	0.4%			
Household members	6 people	2	2	13
Annual household income	USD1,776	1,416	275	10,300
Annual profits of current fishing activities	USD 679	578	45	3,750

4.5.2 Respondents' attitudes toward privatization and marketization of fishing licences

Respondents' attitudes towards the fishing lot system are shown in Table 4-3. The previous fishing lot system, relating to large commercial fisheries, was not supported by small-scale fishermen. They believed that the previous system did not lead to sustainable fisheries and the auction system was not the best way to allocate fishing licenses.

Table 4-3 Fishermen's attitudes towards the allocation system

Statements	Strongly agree	Agree	Disagree	Strongly disagree	Not sure
1. The fishing lot system depletes fish stocks	21.8	62.5	11.3	2.5	1.8
2. The fishing lot system is an unfair allocation system	23.6	67.3	5.1	0.4	3.6
3. Lot owners always have conflicts with the fishery community and I support the fishery community and I believe that all lots should be abolished	35.6	56.7	5.8	1.1	0.7
4. Lots' owners should be able to sub lease some areas	39.3	58.2	2.2	0.4	0
5. The fishing lot system is the best system because the fishery resources can be used in the best way	0.7	16	64.4	9.8	9.1
6. Fishing lot operation helps to protect bird species and flooded forests which are nursing grounds for fish	11.3	31.6	40.4	8.7	8.0
7. An auction system is the best way to allocate fishing rights	1.1	14.2	56.4	14.9	13.5
8. The auction system for allocating fishing lots in Cambodia should be improved	26.5	45.8	5.5	0	22.2

Unit: percentage of respondents

4.5.3 Estimates of discrete choice models

4.5.3.1 Date requirements

The primary data from the questionnaires needed to be prepared using appropriate codes for Nlogit analysis. Linear specification and dummy codes were applied to the attributes and socio-demographic variables for Nlogit version 4.0 (Greene, 2007) as shown in Table 4-4.

Table 4-4 Fishing lot attributes and their levels, socio-demographic variables, and model codes

Attributes/Variables	Definition	Levels	Coding
Attributes			
1.Annual fish catch	The average amount of fish caught per year from the fishing lot	5, 10, 20, 45 (tonnes)	Linear specification
2.Floor price	The minimum bidding price to secure exclusive fishing rights	400, 750, 1600, 3500 (USD)	Linear specification
3.Flexible finance schemes	The schemes provides fishermen access to a flexible payment system	with, without	Dummy: with =1, without =0
4.Leasing period	The time period of authority over the fishing lot	2, 10 (years)	Dummy: 2 years =0, 10 years =1
5.Distance	The distance from the lot owner's house to the fishing lot	Less than or equal to 2, 10 (km)	Dummy: Less than or equal to 2 km =1, 10 km = 0
6.Conservation management plans	Defines restrictions on activities in the fishing lots	No restriction, with conservation	Dummy: no restriction= 0, with conservation=1
Other variables			
7.Age (years)	Age of the respondent		Linear specification
8.Income (USD)	Household income per year		Linear specification
9. Education	Education level of the respondent		Dummy: illiterate and barely literate =1, otherwise =0
10.Fishing experiences (years)	The number of years the respondent has fished in the Tonle Sap wetlands		Linear specification

4.5.3.2 Results of conditional logit model

The results of the CLM estimations revealed the important factors in determining the value of a fishing licence, as shown in Table 4-5.

Table 4-5 Estimation results of discrete choice models: conditional logit and latent class models

Variables	Conditional Logit Model	Conditional Logit Model with interactions	Latent Class Model (2 segments)	
			Seg. 1	Seg. 2
	Coefficient	*Coefficient*	*Coefficient*	*Coefficient*
Fish catch	0.0531***	0.0544***	0.0731***	0.0673***
Floor price	-0.0014***	-0.0015***	-0.0049***	-0.0013***
Flexible finance schemes	0.6942***	0.7782***	1.1766***	0.9105***
Leasing period	0.0053	0.0669	0.3542**	0.3850***
Distance	0.3657***	0.4245***	1.0405***	0.4997***
Conservation management plans	0.0294	0.0299	-0.3160*	0.2797**
ASC (status quo)	1.133***	1.0937***	1.2428***	0.3814***
Floor price*age		-0.00001**		
Floor price*income		0.000001***		
Floor price*education		-0.0006***		
Floor price*fishing experience		0.00003**		
Flexible schemes*income		0.000001***		
Flexible schemes*fishing experience		-0.0173**		
Average probability of segment membership			0.59***	0.41***
Log likelihood	-1997.0	-1925.1	-1592.2	
Pseudo R-square	0.251	0.278	0.467	
Number of observations	2720	2720	2720	
Number of individuals	272	272	272	

*,**,*** indicate statistical significance at 5%, 1% and 0.1% respectively

The results of both the CLM and the CLM with interactions show that the signs of the estimates are in line with expectations for all models. For example, the results show a positive relationship between the value of the licence and the expected fish catch, presence of a flexible payment scheme, length of leasing period and distance to the fishing lot. This means that the respondents preferred lots that had a high rate of fish catch, where the fishing rights were secured for a longer period, provided them access to flexible payment schemes, and was close to their houses. Unsurprisingly, negative values are associated with the floor price attribute. The relatively high model fit indicators (pseudo-R^2) suggest that the variables might reasonably describe the choices made by fishermen in the Tonle Sap wetlands in an auction of this type.

For the model with interactions, richer fishermen were more willing to spend money on buying fishing lots than poorer fishermen, and older fishermen were less interested in investing in fishing lots. Illiterate fishermen were less likely to participate in an auction system than educated fishermen. However, fishermen who had more experience in the industry were more interested in participating in the auctions, possibly because they trusted that they were capable of making the investment pay. But the flexible payment schemes were not as attractive to them as they were to fishermen who had less experience. Surprisingly, the flexible finance schemes were not as attractive to poorer fishermen as to richer fishermen.

4.5.3.3 IIA test

The assumption of independence from IIA was tested (Hausman and McFadden, 1984). CLM may be biased if the IIA assumption is violated and in such cases a more advanced model is needed. For this specification test, first the model with all choices is estimated. Then, the model with a restricted set of alternatives and the same model specification is estimated (Greene, 2007). The results of the IIA test in Table 4-6 show that the basic CLM is inappropriate for analysis of the data because the IIA assumption is violated and a more advanced model is needed. Nevertheless, the conditional logit models (with/without interactions) offer a guideline in order to select an appropriate advanced model. The results of both models led to the choice of a latent class model for advanced analysis because it does not include the IIA property and it can represent proper heterogeneity of preferences.

Table 4-6 Test of independence of irrelevant alternatives

Alternative dropped	X^2	D.o.f	Probability
Lot A	38.89	6	0.000001
Lot B	26.76	6	0.000161
No bid	137.46	6	0.000000

D.o.f means degree of freedom and x^2 represents chi-square test

4.5.3.4 Latent class model

This model allows choice behaviour and segmentation of groups of fishermen to be described simultaneously. Choosing the number of segments is an iterative process that can be subjective, therefore latent segment models were estimated over 2, 3, 4, and 5 segments to select the most appropriate number of segments, using the minimum Akaike Information Criterion (AIC), the minimum Bayesian Information Criterion (BIC) (Swait, 1994) and McFadden's Pseudo R^2 statistics to guide the choice (Table 4-7). However, there is no fixed rule for determining the number of segments (Boxall and Adamowicz, 2002).

Table 4-7 Statistical model selection criteria for the latent class model

Discrete choice models	Log likelihood Function	Pseudo-R^2	AIC	BIC
Conditional Logit Model	-1997.03	0.251	1.47	1.48
Conditional Logit Model with interaction	-1925.14	0.278	1.42	1.45
Latent Class Model - 2 segments	-1592.23	0.467	1.18	1.21
Latent Class Model - 3 segments	-1385.08	0.536	1.04	1.09
Latent Class Model - 4 segments	-	-	-	-
Latent Class Model - 5 segments	-1339.31	0.552	1.01	1.10

All models based on sample size of 272 individuals, 4-segment latent class model failed to converge

LCMs showed better performance over the standard CLM with a higher level of predictive capability (Pseudo-R^2). The 2-segment LCM was chosen as the most appropriate model for further analysis. Statistically, the 5-segment LCM offered a better model than the 2-segment model in terms of the Pseudo R^2, AIC and BIC test statistics. However, it contained a segment with very few members (around two per cent). Considering the modest size of the data set, this segment was considered to represent too few respondents to justify selection of the model for further analysis. The 3-segment LCM did offer a statistically superior model specification to the CLM and the 2-segment model but had several statistically insignificant attributes and therefore limited interpretable explanation of segments.

It can also be concluded that the empirical data did not support a three segment specification. The results of the 2-segment LCM offered a significant improvement over the standard CLM model (with Pseudo-R^2 of 0.47) and all parameters were highly significant and their signs defined two distinct groups of fishermen (Table 4-5). This was further supported from kernel density estimation showing a bimodal distribution of valuations of the lot attributes (see Figure 4-4). Both the 2-segment model and the 3-segment model (see appendix D) showed a bimodal distribution of valuations. Therefore it was concluded that the 3-segment model did not provide much additional information about the likely bidding behaviour in the fishing community.

Segment one consisted of respondents who viewed the existence of a conservation management plan as a reduction in the value of a fishing lot, while respondents in the second segment regarded such lots as higher value, presumably believing them to be more productive in the long run. The coefficient of the attribute representing flexible finance schemes was highly significant for both segments, but highest values were revealed for segment two (Table 4-5). The majority of respondents were more likely to be in the first segment, with around two-fifths in the second segment.

4.5.4 Socio-demographics of segment membership

To understand the socio-demographic characteristics potentially underpinning bidding behaviour, the relationships between the probability of segment membership and all socio-demographic variables were estimated using a binary logistic model predicting segment membership of segment one. Income was the only socio-demographic variable which could be shown to distinguish fishermen between the two segments to some extent, as shown in Table 4-8.

Table 4-8 Socio-demographics of segment membership (predicting segment 1)

Variables	Coefficient	P-Value	Mean
Constant	0.30848	0.570	-
Age	0.01548	0.210	40.87
Education	0.30491	0.236	0.49
Income	-0.00036	0.038	1,757.87
Profit	-0.00030	0.453	669.12

Note: This calculation used segment two as the baseline for the prediction to socio-demographic of segments one (with codes 1 for segment one and code 0 for segment two)

This means that the odds of a fisherman being in segment one relative to segment two decreases 4% for an increase in income by 100 USD. The relationship is fairly weak, but does suggest that the fishermen who reported a higher income level were more likely to be members of segment two.

4.5.5 Estimation of willingness to pay

In discrete choice modelling, it is a common objective to measure the amount of money that individuals are willing to forfeit in order to gain some benefits. Willingness to pay (WTP) is measured as the ratio of two significant parameter estimates, holding all others constant (Hensher *et al.*, 2005). Estimation of WTP in US dollars was determined by calculating the marginal rate of substitution between the changes in the fishing lot attributes and the marginal utility of income which was represented by the parameter/coefficient of the floor price attribute multiplied by minus one (Birol and Cox, 2007).

$$\boldsymbol{WTP} = -\mathbf{1}\left(\frac{\beta_{attribute}}{\beta_{floor\ price}}\right) \qquad \text{(Equation 4-8)}$$

The WTP for each attribute is reported in Table 4-9 and kernel density estimates for empirical WTP are plotted in Figure 4-4 and Figure 4-5.

Table 4-9 Marginal Willingness to Pay for fishing lot attributes (USD)

Variables	CLMs	CLMs with interactions	LCMs (2 segments)	
			Segment 1	Segment2
Fish catch	38	36	15	52
Flexible finance schemes	496	519	240	700
Leasing period	-	-	72	296
Distance	261	283	212	384
Conservation management plans	-	-	-64	215
ASC	809	729	254	293

The respondents in segment two of the LCM had the highest marginal WTP overall and showed more interest in bidding for fishing lots. The marginal value of increasing fish catches was low compared to the market price of fish, which was variable depending on the fish species but in general was approximately one USD per kilogram. This may be expected as small-scale fishermen still have the option of fishing in the public fishing zone and fishing expenditures also need to be taken into account. In addition, the WTP might not correspond with the real market price in an auction because the floor price (which was used to calculate the WTP) represented the starting price in the auction (not the final price). Consequently, the calculated WTP in this study is expected to be lower than bidding values in the real market. However, the WTP can be used to provide information about which group of fishermen will bid in the auction and what characteristics of fishing lots they would prefer. The results indicate that the members of segment two would outbid members of segment one if an auction system was designed with the attributes tested in this research, independent of the combination of characteristics of the fishing lots. This corresponds with the kernel density estimates of individual WTP which separated two groups of respondents (Figure 4-4 and Figure 4-5). This result is illustrated for a specific fishing lot (Figure 4-3), but holds for the other possible lot specifications.

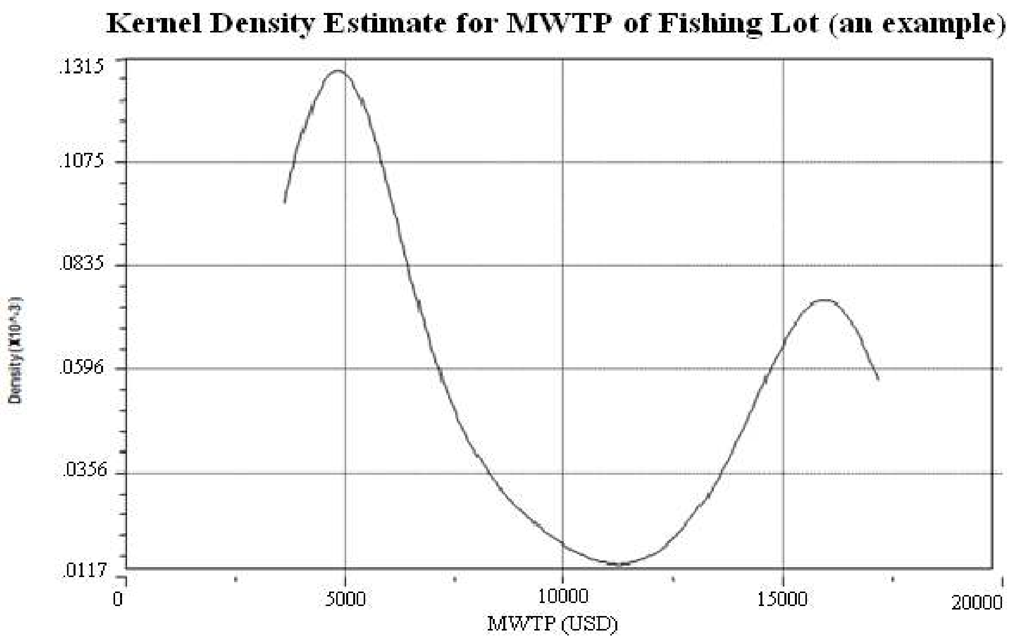
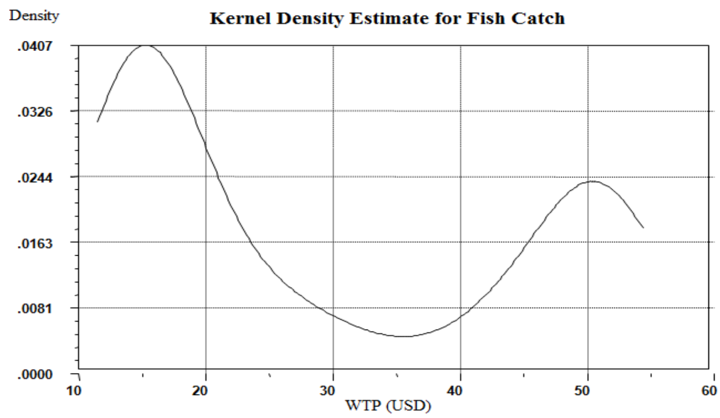
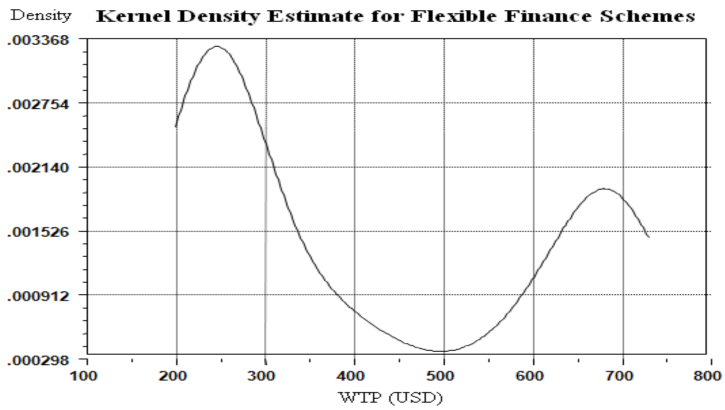


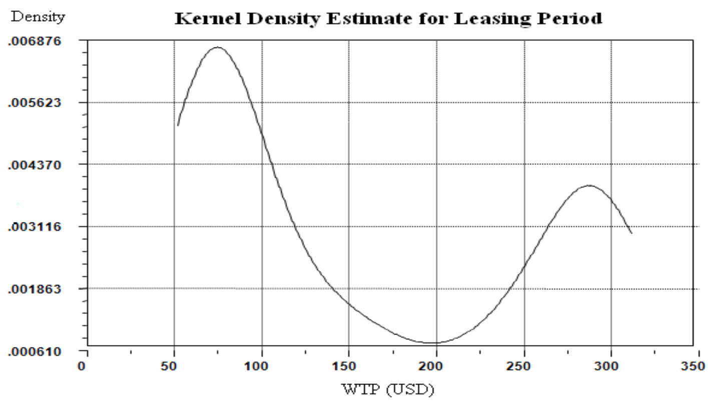
Figure 4-3 Value of fishing lot (300 tonnes of fish catch, no flexible finance scheme, 10-year leasing period, 2 km from home and with conservation plans)



(a) Value of Annual fish catch

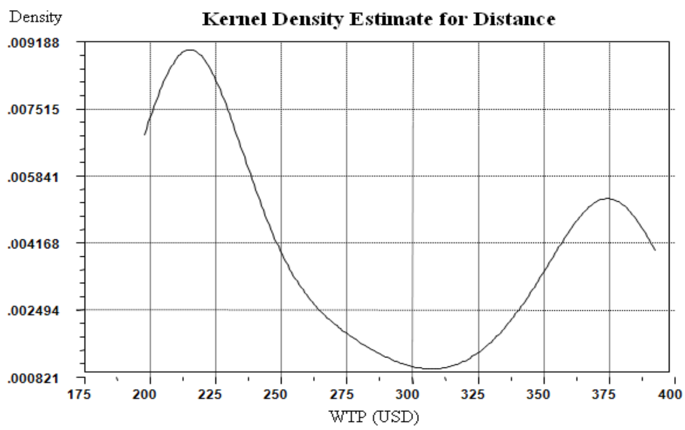


(b) Value of Flexible finance schemes

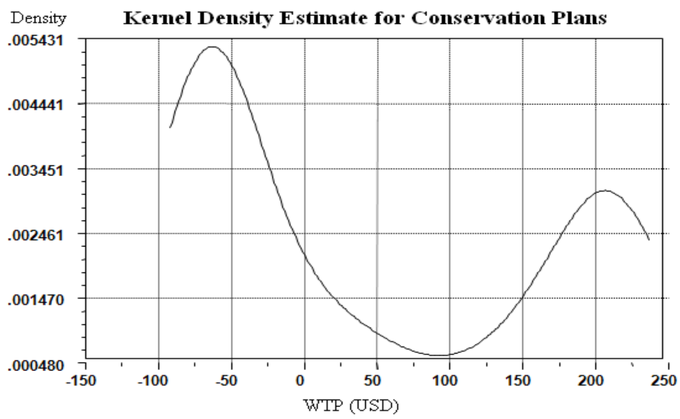


(c) Value of Leasing period

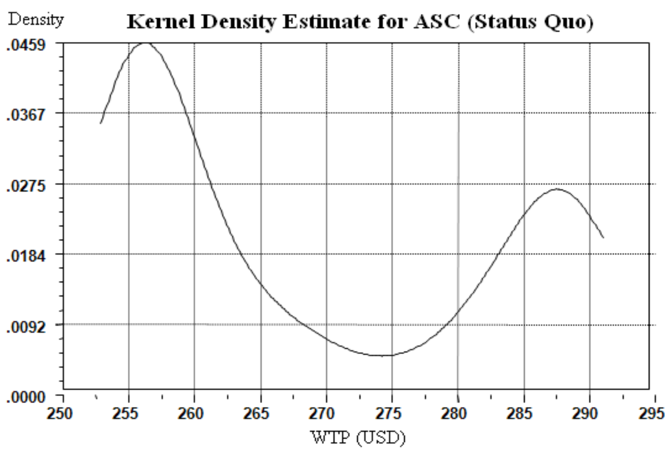
Figure 4-4 Kernel density estimates from the 2-segment Latent Class Model for fish catch, flexible finance schemes, and leasing period



(d) Value of Distance



(e) Value of Conservation management plans



(f) Value of Status Quo

Figure 4-5 Kernel density estimates from the 2-segment Latent Class Model for distance, conservation plans and status quo

4.6 DISCUSSION AND CONCLUSIONS

The CE approach was employed in this study in order to improve the understanding of fisherman behaviour in an auction. As suggested by the analysis, the CE design has captured key aspects of the factors determining interest and participation in an auction-based management system. The majority of respondents seemed to understand the questionnaire and had sufficient information about management context to make consistent choices in the experiment. The latent class model specification with two segments represented a good portrayal of the preferences in the study area and showed support for the existence of heterogeneous preferences. The model was preferred over the basic conditional logit model and the conditional logit model with interactions. Nevertheless, the conditional logit models (with/without interactions) provided useful information about key drivers of purchasing behavior in an auction market and the source of varying preferences across fishermen. This chapter has made the following contributions;

4.6.1 Policy implications

Acquiring a better understanding of the purchasing behaviours of small-scale fishermen in an auction market and sources of heterogeneity could help fishery managers to make adjustments to the fishery management system. For instance, they could offer different combinations of fishing lots' characteristics to different groups of small-scale fishing households. The latent class model revealed that all attributes significantly influence the utility of purchasing fishing lots. Depending on the combinations of characteristics and price of the lots, fishing lots are likely to be very attractive to small-scale fishermen. However, the analysis suggests that a number of small-scale fishermen will continue not to purchase access rights to fishing lots, irrespective of how fishing lots are designated. There is some evidence that the segment of the fishermen who will purchase access rights tends to be the richer segment although there is little difference between the socio-economic characteristics of the groups. Seemingly, therefore, an auction system is likely still to be criticised on equality terms because the poorest segment is still effectively excluded from the fishing lot system. However, the findings from this study can provide input to the evaluation of a redesign of the fishing lot system to benefit some small-scale fishermen. Restructuring the operation of the auction system in order to increase participation in the system is an option that policy makers should take into account. A further discussion on this point is provided below.

The model showed that the interest of fishermen to participate in auctions generally increased when they were provided with flexible finance. Indeed, the availability of such flexibility had a substantial influence on households' willingness to purchase fishing lots rather than choosing only to fish in the open access fishing grounds. Interestingly. However, it was the richer group that was most attracted by such flexible finance schemes. As a result, it is likely that financial schemes as they are designed in this survey will be beneficial mainly to those segments of the population who need such support the least. Both groups of fishermen value this attribute higher than other lot characteristics; however investment costs are still likely to act as a barrier for many individuals as the cost of a fishing lot is not the only expenditure. Other costs, which are not funded by the finance schemes, also need to be considered, such as fishing gear, fences, labourers and guards.

More support is needed to enable the poorest fishermen to engage with and access the auction system. Such support mechanisms could focus on assistance with the auction process, or support for the development of small-scale fishermen co-operatives that will enable them to increase their purchasing power. Alternatively, the problem of limited access to productive fishing grounds for small-scale fishermen could be solved if the fishing lots system is permanently abolished. However, this comes with the well-known risk of over exploitation of the stock (Gordon, 1954; 1996; Grafton *et al.*, 2000; Hilborn *et al.*, 2003; Ostrom, 2008). Consequently, there is a need to put in place other practical management strategies, such as fishing gear control. Finally, the auction method could be replaced by a system that distributes a quota of fishing lots to communities of small-scale fishermen on a rotational basis.

4.6.2 Evaluation of privatisation of property rights

As part of the Cambodian fisheries management system, fishing lots are forms of both privatization and marketization mechanisms for allocating exclusive fishing licences. Both mechanism are mean to generate incentives for conservation and to increase efficiency of resource exploitation (Mansfield, 2004). The system secures *de jure* rights to fish and licence holders have an incentive to choose the harvesting strategy which maximises income (Acheson, 1989) and ensures future benefits/income. However, in order to develop biologically and socially sustainable resource management it is essential to ensure security of *long term* property rights (Yandle, 2007). Yandle (2007) has shown that annual catch entitlements (ACE) create few incentives for management for long-term sustainability, as owners hold only access and withdrawal rights. Instead of long term and full owner rights to concessionaires, the Cambodian government only confers rights of access and withdrawal, as well as partial rights of management, exclusion and alienation. Such “incomplete property rights” are unlikely to promote conservation of fish stocks because they generate externalities such as fish habitat degradation (Schlager and Ostrom, 1992; Acheson, 2006; Yandle, 2007) by incentivising short term gains over long term sustainability. Interestingly, the findings from the latent class model showed preferences for longer leasing periods, as fishermen expressed a willingness to pay more annually for a longer leasing contract. It might have been expected that fishermen would value the fishing lots as a short term resource extraction opportunity; however the results suggest that fishermen also have longer term objectives. A possible explanation could be that fishermen have an interest in securing longer term fishing rights in order to avoid the uncertainty of future auction outcomes. This is an encouraging finding as it indicates that fishermen could possibly be encouraged fishermen to consider long-term profits as opposed to short-term resource exploitation. This could also lead to improvements in fish habitats as lot owners may be more willing to preserve habitats, therefore paving the way for fish to return to the lots in the future. Furthermore, this model illustrated that the segment consisting of slightly richer fishermen appeared to be more influenced by conservation objectives. There could therefore be a potential link between the characteristics of ‘private’ fishing lot owners and conservation behaviour which requires further empirical study. It has been argued that even private property rights holders will not be incentivized to reduce degradation if profits earned from investment are too low, when it takes too long to appreciate returns, or when economic pressure and uncertainty about the potential return or uncertainty about resource availability are high. (Lawrence, 2000; Acheson, 2006; Sandberg, 2007). Further research could provide evidence as to the relative influence of these factors in promoting potential conservation behaviour in a fishing system relying on private lot owners. Ultimately, to promote appropriate incentives for sustainable fishing practices, a combination of property rights along with price signals, harvesting responsibilities (under fisheries law), adequate monitoring and surveillance will all be needed in this context (Grafton *et al.*, 2006). Addressing the reported high levels of corruption is also a critical priority if the functioning of the monitoring system is to be improved in the short term.

4.6.3 Evaluation of marketizing fishing rights through an auction

In the two segment latent class model, the richer group of fishermen in segment two expressed a higher willingness to pay for fishing privileges and was more positive towards investment in fishing lots/participation in the auction than the fishermen in segment one. This is not surprising, as other studies have also pointed out that poorer groups in a community face more difficulties in accessing and exercising property rights (Beck and Nesmith, 2001; Meinzen-Dick and Mwangi, 2008; Working Group on Property Rights, 2008). This is related to their different budgets but also to levels of education, as wealthier fishermen are likely to be better educated and therefore more able to handle the formal documents that form part of the official auction system. As suggested by observation at a previous auction day in the region, this is indeed the case. The provision of flexible payment schemes may not improve the access of poor fishermen to fishing licences unless the auctions are designed in such a manner as to create more interest from this group. This might explain why the majority of respondents believe that sub-leasing fishing lots from lot owners is the way they can access the rich fishing grounds during the fishing season.

4.6.4 The challenges of using CE in the context of wetland fisheries in the developing world

This chapter contributes to the limited literature on the application of the CE approach in the context of wetlands and developing countries. There are challenges to using CE in the context of the developing world (recommendations for using CE in developing countries are given in Bennett and Birol (2010)). Generally, only a few studies have so far applied CE for wetlands valuation and management (Birol *et al.*, 2006; Milon and Scrogin, 2006; Birol and Cox, 2007), and even fewer in developing countries (Do and Bennett, 2009). In the mid-2000s, Wattage, Mardle and Pascoe (2005) applied CE to assess the importance of the United Kingdom fisheries management objectives. More recently, Agimass and Mekonnen (2011) used CE for valuation of fisheries and watersheds in the context of a developing country; Ethiopia. No published research has yet, to the authors' knowledge, employed CE for modelling fishermen's behaviour in auction markets. Further research could usefully expand the scope of the survey used here to include a wider range of socio-demographic characteristics, such as including groups of previous lot owners or businessmen, using different choice designs and questionnaires, and including larger samples in order to get better representation. Understanding the preference of 'private' fishing lot owners for conservation behaviour could also be enhance as a result of further empirical study. Comparing the behaviours of people who used to participate in auctions (previous lot owners) against people who have not participated in auctions before could indeed be an interesting undertaking. This could potentially reveal further segments of fishermen which would also need to be considered in the design of a future auction-based system. This research has highlighted the relevance of including small-scale fishermen in evaluations of future management plans.

Chapter 5

AGENT-BASED MODELLING FOR FISHERY RESOURCE MANAGEMENT

This chapter describes a social simulation approach called agent-based modelling (ABM). It introduces the literature behind ABM development and discusses how the simulation can be used in social sciences. Recently, ABM has become a popular research approach for understanding the complexity of resource systems under different scenarios (policies) (Railsback and Volker, 2012). This chapter formulates the framework for ABM to investigate how different scenarios (policies) might impact fishery resource systems and their utilization. The simulations of fisheries in a spatial context describe dynamic and complex interactions, i.e., the spatial distribution of fishing activity, fish reproduction and movement. This chapter also provides an overview of the model settings for the spatial analyses in Chapters 6 and 7. In addition, it outlines how fishermen and fishing grounds are specified in the models and identifies the parameters used to simulate the different scenarios analysed in subsequent chapters.

5.1 BACKGROUND

This study uses an ABM approach to investigate the spatial dynamics of fishery resources and fishermen behaviours. This bottom-up modelling approach enables analysis of the interdependence between fine scale processes and behaviours at local and larger scale patterns. It has been argued this approach allows the bridging of disciplines by combining similar issues that arise in two or more disciplines (Axelrod, 2006; Epstein, 2006a). In this context, the relevant disciplines are economics and biology. The focus is on understanding fishermen behaviour, the impact on fish stock and in turn, the fishermen's response.

An additional advantage to this approach is that it can be used to combine quantitative and qualitative methods by simulating hypothetical scenarios based on in-depth interviews and socio-demographic data (Nainggolan *et al.*, 2012). For example, quantitative (i.e., fish catchability and reproduction) and qualitative (i.e., fishermen's property rights) assumptions can be combined in the model implementation (Millischer and Gascuel, 2006). This can help fill the gap between theory and evidence from case studies by describing the emergence of macro-level effects or properties relying on micro-level interactions observed in case studies (Gilbert and Troitzsch, 2005). For example, the micro-level interaction between fishermen's fishing intensity results in macro-level effects on the fishing communities in terms of fish biomass conservation and socio-economic outcomes.

Recently, ABM is being used in environmental management (Monticino *et al.*, 2007; Little *et al.*, 2009; Worrapimphong *et al.*, 2010; McLane *et al.*, 2011). Bousquet and Le Page (2004) propose that agent-based models are useful tools to address the integration of social and spatial aspects, such as the complex dynamics of socio-ecological systems. (Touza *et al.*, 2012). In marine fishery management, an agent-based model has been applied to understand competition and cooperation in fisheries (BenDor *et al.*, 2009). Their research assesses the interactions between economic (i.e., fish harvests and economic returns) and ecological (i.e., multiple species interactions) systems. Furthermore, the seasonal and spatial pattern of fishing efforts in Danish fisheries has been modelled using an ABM approach (Bastardie *et al.*, 2010). Similar to this research, Little (2009) modelled the effect of an individually transferable quota system of multi-species fisheries in Queensland. Existing explorations of agent-based models in the context of fisheries, therefore, suggests that ABM can be a useful tool to analyse complexities in such systems.

5.2 AGENT-BASED MODELLING

This section provides a brief introduction to social simulation and ABM. A full description of ABM concepts can be found in Wooldridge (2009) and Paredes and Iglesias (2008).

5.2.1 Social simulation

Simulation is a particular type of modelling that has become a popular method in the social sciences for understanding the complexity of social systems. It is a simplified representation of a specific aspect of the system of interest. The model simplifies the complexities of the social phenomena (e.g., social dilemmas in relation to common pool resource utilisation) and complex dynamics of the environment (e.g., resource mobility and reproduction) by using a few sub-models and linking their behaviour in the model of the whole system. This approach makes it more understandable and transparent to users how the overall model outcome relates to individual sub-components and assumptions made about the behavior of the individuals (e.g., fishermen) and the dynamics of their environment (e.g., the biology of the resource).

Alternatively, statistical/mathematical models have been used in social science to gain insight into management of environmental problems. However, such models are often based on aggregate relationships between variables, ignoring individual heterogeneity of fishermen and the spatial heterogeneity of the environment. Therefore, mathematical models may be more appropriate for analysis of simple systems (Law and Kelton, 2000). Social phenomena often involve nonlinear processes that are difficult to predict using a single equation for the entire system.

It has been observed that the occurrences of complex behavior in real systems can be emulated by aggregation of comparatively simple actions (Simon, 1996). Therefore, simulation can be an effective technique to study nonlinear and complex behaviours by building the model from a set of simple relationships that generate complex behaviours when combined.

Rational choice theory has been the dominant paradigm for modelling social science processes (Axelrod, 2005). Human behaviour is complex, thus assumptions about rational behaviour are often imposed for modelling tractability. In reality humans make decisions using a variety of approaches and adaptive rather than fully optimal behaviour may be more realistic (Nielsen, 2012). Furthermore, humans often have a variety of objectives so two agents might both be “rational” yet behave in different ways. Simulations modelling a range of individuals might therefore be better suited to simulating real system dynamics. The adaptive behavior can be applied to multiple levels such as the individual level (through learning processes) or population level (through survival of different individuals) (Axelrod, 2005).

The use of computer simulation in social sciences began in the early 1960s; however, computer simulation started to be widely used for understanding social sciences in the 1990s (Gilbert and Troitzsch, 2005). During that time many computer simulation models were developed, such as spatial interaction modelling, microsimulation and cellular automata. Spatial interaction modelling is used for a flow analysis between various origins and destinations, i.e., the distance or time taken from the origin to the destination. The flows often represent migration, recreation or travel (Fotheringham and O'Kelly, 1989). Small-scale components, such as individual households, and heterogeneous behaviours of individuals are not incorporated in these applications. Microsimulation is based on large samples of populations of individual units (households, firms, individuals) by disaggregating data to the individual level (Gilbert and Troitzsch, 2005). This approach will not been used in this study as very limited data are available at both aggregate and individual level for the study site. Cellular automata is used to comprehend the properties of large aggregates of matter in mathematics, physics, chemistry and many other areas of science. Predicting global behaviours from local configurations can be explored in cellular automata; however, adding new interactions or features creates structural instability (Gilbert and Troitzsch, 2005). The lack of agents in this framework also makes it less useful to social science applications. Although there are many types of simulation, agent-based models are important in the social sciences. An agent-based model is a model based on individual agent behavior and interaction between agents. This means that agents are autonomous and not directed by higher level rules. The emergent properties are stable macro-level patterns arising from local interaction of agents (Axelrod, 1997; 2005). Agent-based models are therefore referred to as a bottom-up modelling approach as opposed to a top-down approach. Agent-based models will be discussed in more detail below (section 5.2.2).

Three specific features are important in any simulation (Axelrod, 2005). Firstly, the simulation programme should aim at internal validity, usability and extendibility. Internal validity means that the model itself is correctly implemented. The goal of usability and extendibility is to give other researchers and future users explanations and interpretations enabling them to adjust the model accordingly. Secondly, the ability to reconstruct results either by re-running models or generating more data for analysis is an important feature in social simulations. For example, if the data generated are insufficient, researchers can easily run the model again by increasing the number of runs or altering parameters to produce new scenarios. Finally, documenting model specifications is essential for advancing the work on social simulations. As outcomes are sensitive to model specifications, users would be unable to replicate the model without a fully detailed model description. Emphasis on common formats for documentation is therefore an important development in the field (Railsback and Volker, 2012).

5.2.2 Agent-based modelling

An agent-based model was first developed by Axelrod and Hamilton (1981). Initially, ABM was used to model animal behavior such as the behavior of bumble bees (Hogeweg and Hesper, 1983). In early social science applications, ABM was mainly used in economics and sociology. For example, Raberto *et al.* (2001) used ABM to simulate the dynamics of financial markets using basic trading rules. ABM also provides a unique approach to understanding social interaction by emphasizing the heterogeneity of individuals and describing how individuals interact as well as the consequences of such interactions (Epstein, 2006a).

ABM commences with assumptions of autonomous agents (i.e., decision makers) and their environment. The agents can be individuals or social groups such as households, agencies, communities or nations. The model can create agents with individual characteristics and investigate effects on group dynamics from individual behaviour.

It is relatively straightforward to capture social communications and complex physical environments using an agent-based model compared to using mathematical models (Axtell, 2000). At this point it is unmanageable to use pure mathematical methods to identify the dynamics of competitive interactions between multiple heterogeneous agents (Axelrod, 1997; Epstein, 2006b). Agent-based models can be flexible enough to capture dissimilar groups with the same model specifications (Brantingham and Brantingham, 2004). For example, two different groups of fishermen characterized by different economic characteristics can still be modelled using the same set of rules.

Despite the advantages mentioned earlier, there are some disadvantages to using ABM in the social sciences. For example, complex psychology and seemingly irrational behaviours can be difficult to capture in a model (Bonabeau, 2002). Furthermore, a small inaccuracy in one sub-component of the model can result in complex interactions in other sub-components. This can lead to exaggeration of the interpretation of the interdependencies in the systems.

While it has been noted that macro behaviours can emerge from micro actions, society (macro level) and individuals (micro level) effect each other in both directions, not predominantly from micro to macro (O'Sullivan and Haklay, 2000). This aspect is not sufficiently captured in most ABM applications. Furthermore, while it is argued that ABM can offer an improvement to modelling human behavior, the extent a model can characterise an agent with bounded information and bounded computing capacity is limited (Axelrod, 2005; Epstein, 2006a). Grüne-Yanoff (2009) claims that agent-based models can only partially explain a social phenomenon, and will never be able to provide causality or a complete explanation. Grüne-Yanoff (2011) argues that decision makers may not fully appreciate the uncertainty related to model assumptions when the agent-based model is developed from a small number of cases. However, this problem is not specific to ABM applications. In decision-making processes, information from a variety of sources and different approaches should be considered. While O'Sullivan and Haklay (2000) raise the issue of the individualist bias in agent-based models, the same paper also suggests solutions for constructing an agent-based model in order to deal with this specific issue.

Researchers have developed a classification of agent attributes or characteristics that can be used to specify agents in particular model developments (O'Sullivan and Haklay, 2000; Epstein, 2006a). The following agent characteristics have been used:

Autonomy and self-direction: Agents are independent in their own environment i.e., not under direct control by a top-down or central controller. This characteristic is appropriate when modelling human society. An individual agent can interact with others and its environment with the ability to understand its circumstances (Macal and North, 2010). An agent responds by using probabilistic rules to determine its behavior in the next time step, based on its own characteristics, other agents and its environment.

Heterogeneity: Either agent populations are heterogeneous or they can be aggregated into a few homogeneous groups. Individuals can be different genetically, culturally and socially. The agent’s preferences can be adapted and changed over time. For example, fishermen in this thesis have different wealth and fishing capacities.

Reactivity and proactivity: Agents engage in goal-directed behavior. Also, agents can perceive and respond to changes in their environment. The responses can be proactive and indicate the direction of their goal-orientated behavior (Wooldridge and Jennings, 1995). In this thesis, the goal of fishermen's behavior is profits. Fishermen recognize qualities of fishing grounds and can observe the extent to which other fishermen are successful.

Explicit space and local interaction: In this thesis, the explicit space is fishing grounds. The interactions of an agent and its neighbours are controlled by their location.

Bounded rationality: Agent actions are performed with limited perception (bounded rationality) of their environments and other agents. Thus, the agents interact locally because they use simple rules based on local information (Epstein, 2006a). Their choices are therefore not perfectly optimal (Castle and Crooks, 2006).

For the model design, some agent attributes are important to consider. In computational processes, human intelligence is never included in the model (Gilbert and Troitzsch, 2005), rather the agents are specified in a simplified manner by the analyst according to the research requirements. The agent's action is based on their knowledge and belief. If they have incorrect information, they will have incomplete knowledge.

ABM has the potential to be a powerful scientific tool to represent spatial distributions of heterogeneous autonomous agents with bounded information and capacity to interact locally (Epstein, 2006a). Although fishermen cannot be perfectly modelled as humans, the agent-based model has the capacity to simulate fishermen with differing perspectives of fishing opportunities and heterogeneous fishing capacities. Furthermore, ABM is suitable for modelling complex system dynamics which is relatively difficult to capture using traditional mathematical modelling.

5.2.3 NetLogo Modelling Language

There are many ABM platforms such as Cormas (CIRAD, 2012), RePast (Argonne National Laboratory, 2013), DIMA (Guessoum, 2000) and NetLogo (Wilensky, 1999). NetLogo was selected for this research because it is appropriate for complex and dynamic system analysis. It is widely used (Wilensky, 1999) because it is free, user-friendly and advanced enough for many research fields (Papert, 1980; Wilensky and Novak, 2010). It is a good medium to use when building multi-agent models that are simple to specify and fast to simulate (Gilbert and Troitzsch, 2005). In addition, NetLogo includes a graphical user interface (GUI) that allows the researcher to monitor agents and create graphic illustrations of the results. The model code is integrated with a software tool called *BehaviorSpace*, enabling researchers to run the model under different parameter settings. This tool also records the results of each performance of the model (Wilensky, 1999). Due to the above-mentioned qualities, NetLogo facilitates sharing between model developers and users thus encouraging the development of models for specific policy advice.

NetLogo can be used to analyse the dynamics of complex fisheries that include many interacting components. The programme outcomes present changes in the states of the fishery system over time through a discrete sequence of clock ticks. The same set of rules can be applied to execute all agents (called “turtles” in NetLogo) at each time interval (called “clock tick”) while collective behaviours will not be repetitive because the turtles have different internal properties (i.e., catchability coefficient and wealth) and are positioned in different environments (i.e., locations in the wetlands defined by habitat properties and fishing regulations).

5.3 THE RATIONALE FOR DEVELOPING A SPATIAL ANALYSIS

Spatial analyses are required to develop the spatial model framework used in the previous chapter. According to the literature reviewed above, an ABM framework is considered a suitable approach to understand the complexity of fishery management, including property rights regimes.

The ABM approach is well suited to capture the nature of fisheries involving heterogeneous autonomous fishermen, different fishing regulations, such as various fishing zones and seasonal or area closures, and various types of fish habitats and fishing grounds. Given the above classifications, the agents (fishermen) in the agent-based model are heterogeneous and autonomous because they can autonomously react to different fishing grounds and can exchange information with other agents. The artificial fishermen in the model capture important aspects of real world fishermen. As shown in the previous chapter real world fishermen can have heterogeneous preferences and will not have uniform decision making regarding the selection of fishing grounds, fishing gear and effort. In addition, they can communicate with each other to improve their fishing ability. The goal of fishermen's behaviour can be set in the agent-based model. Although the agents may execute the same set of rules, the individual behaviours will not be identical and repetitive as each agent may have different internal properties, may be located in different environments and may communicate with and learn from different fishermen. Furthermore, ABM is particularly suited for dealing with varying spatial contexts (environments) such as zonal designation of fishery management regulations including private fishing lots, common fishing areas and conservation areas. All of these properties can be captured using an agent-based model approach. Using a simplified mathematical model would force the researcher to exclude most aspects considered important for the issues addressed in this thesis. ABM provides not only a bottom-up evaluation of spatio-temporally defined fishery management but it also gives flexibility to easily add, adjust or change agents and rules in the model. Thus, the macrostructure of fishery dynamics can be generated from the specified micro-level dynamics in the ABM.

NetLogo is chosen as a platform for ABM because it is a user-friendly software with sufficient flexibility to address the research questions in this thesis. This means that the benefit of NetLogo is not only for the modeller but also for other researchers and stakeholders (e.g. policy makers) to discuss the scenarios or to suggest further extensions of the model.

5.4 MODEL PROTOCOL

This study uses NetLogo version 5.0.4 (Wilensky, 1999) to simulate fishing activities involved with different fishing zones and exclusive licenses. The principle of the model, Overview, Design Concepts and Details (ODD) of Gilbert and Troitzsch (2005) is used as an outline for the model design and documentation. A common model setting for ABM in this chapter is also used for Chapters 6 and 7. The simulation in Chapter 7 is a modified version of the model used in Chapter 6. The overall primary modifications are fishing fees and zonal systems. The details of the additional and modified settings are described in Chapter 7.

5.4.1 Fishery simulation

A key challenge for modelling fishery resource management lies in the integration of insight into micro-level activities with evidence of cumulative macro phenomena emerging from those micro processes. In other words, fishermen make decisions or exchange information on fishing activities at the individual scale such as selecting fishing grounds and fishing effort. The consequences of these micro-level activities affect both micro-level aspects, such as the individual fisherman and local fish stocks, and macro-level aspects, such as other fishermen and fish stock distributions. The effects can accumulate and influence the whole ecosystem.

In this research, the spatial simulations allow us to investigate whether assigning property rights to fishery resources generates pro-environmental behaviours of small-scale fishermen. The simulations are used to analyse the effects of different fishery policy scenarios. The ABM applications are divided into two chapters, Chapters 6 and 7. Chapter 6 presents an analysis of the consequences of a property rights system for fishing behaviours and sustainability of fish stocks. The analysis includes the spatial analysis of two different fishing areas, common and private. The model in Chapter 7 is further developed from Chapter 6 by including conservation areas. The fishermen's behaviours in all fishing grounds are observed and analysed in terms of economic and biological sustainability. Various policy scenarios are developed and simulated. The results of these analyses can be used to offer alternative suggestions for fishery policy makers. Better understanding of the interaction and dynamics of the socio-ecological system with respect to natural and socio-economic sustainability is needed in order to improve fishery sustainability.

5.4.2 Overview of the simulation

This model captures actions and interactions of the agents (i.e., fishermen) and is designed to investigate how local (micro) level actions affect the overall (macro) system. It incorporates mobile agents who reside both initially and through time at different places in the spatial landscape (fishing grounds). Fishermen can choose the best location available in the fishing grounds from their perspective. The locations/patches represent geographically located fishing grounds containing various levels of fish biomass and different qualities of habitats. They are characterised by particular property rights rules (private and common). Private property patches tend to be located in good habitats. The attributes of fishermen comprise different wealth and fishing abilities. One time step (or one tick) of the model represents one year's activities and includes different activities as shown in Figure 5-1.

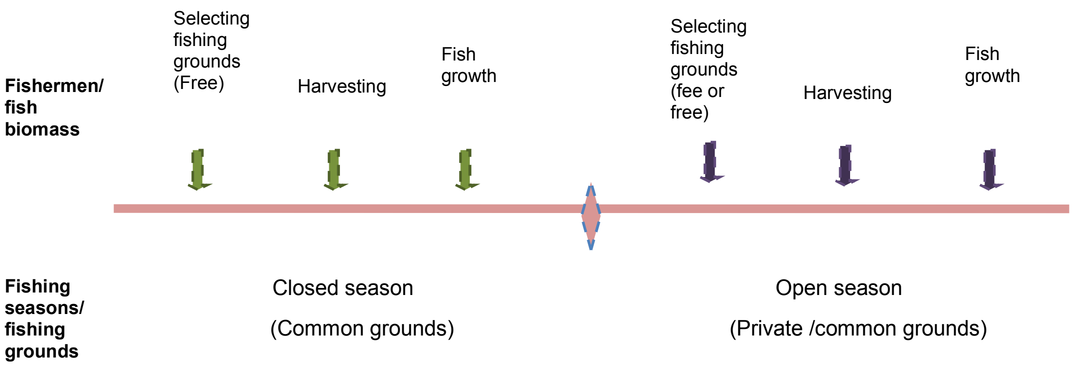


Figure 5-1 Timeline of fishermen activities in one-year time period

A one-year period consists of two fishing seasons, closed and open, with six months in each season. The first six months are a closed season. Fishermen select the location for fishing and communicate with other fishermen in order to adopt fishing strategies from the most profitable neighbour. After fish are harvested and sold, fish stocks reproduce. The last six months of the year is the open season, where fishermen must decide whether to purchase an exclusive fishing licence or to fish in common fishing grounds. A fisherman who buys a private fishing license becomes a "private" fisherman, and in the same way a fisherman who occupies a common fishing ground is a "common" fisherman. Boundaries of private patches are designed to be closed. This means that fish cannot migrate and other fishermen are excluded from entering the area. The simulation is run without incorporating demographic growth of the fishermen population.

5.4.3 Design concept

The basic principle of this model is that competition among fishermen for limited renewable fishery resources may lead to overexploitation without fishery regulation. The emergent phenomenon (overexploitation) results from relations between fishermen and between fishermen and fish stocks; however, management can regulate this relationship. In order to survive in the fishing business, the fishermen's goal is to make a profit. They adapt their fishing efforts by observing and learning from the fishermen around them. They attempt to imitate their most successful neighbour. This feedback mechanism can be observed through fish stock density, harvesting intensity and numbers of fishermen in private or common areas. This model is a simplified representation of the real situation with standard assumptions made for growth, harvesting and profit functions (Conrad and Clark, 1987). This simple model could be further adapted to represent specific management contexts but an empirical parameterisation is beyond the scope of this research.

5.4.4 Habitats

Fisheries vary in quality of habitat. The most productive fishing grounds are usually close to mangrove or flooded forests. The simulations in this model include four different hypothetical habitat qualities that influence the rate of fish growth where better habitats have higher rates of fish reproduction. In the model the habitat quality is modelled as a variation in growth rate. The layout of habitats is shown in Figure 5-2. The lighter colour represents the better habitat in the simulations.

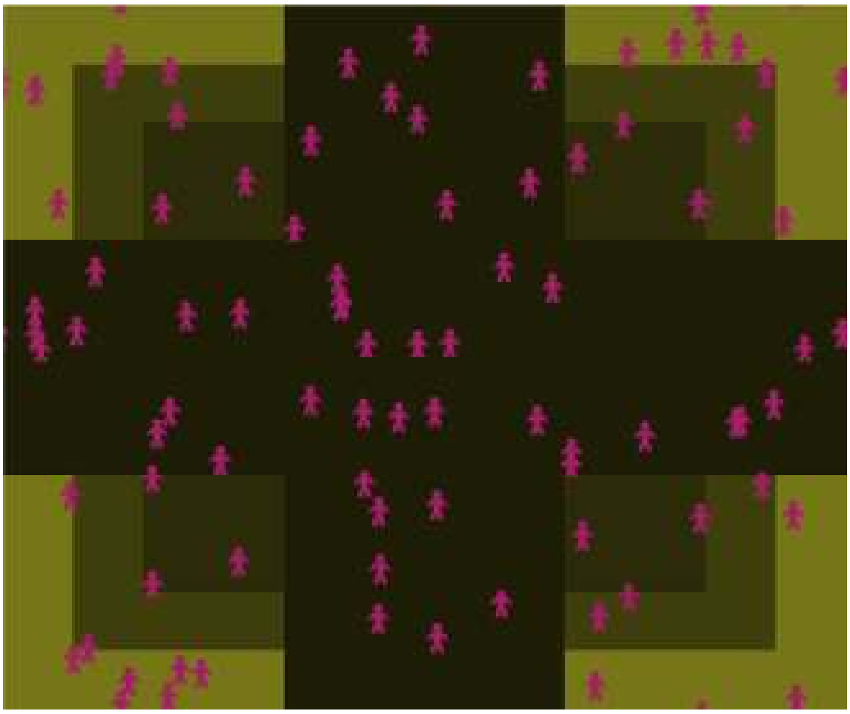


Figure 5-2 Layout of different habitat qualities; the lighter colour represents better habitats

5.4.5 Property rights

The two types of property rights are specified as patch attributes in the model in order to analyse the effects of property rights regimes. All fishing grounds are common property with free access in the first half of the year. After that, private or common property rights are assigned to each patch. Fishermen need an exclusive fishing license in order to access private patches.

5.4.6 Dynamics of fish stocks

The mathematical equations specifying fish stock dynamics are adapted from standard equations widely used in resource economics of fisheries. Further details can be found in Conrad and Clark (1987),Clark (1990) and Conrad (1999).

5.4.6.1 Fish stocks

Fish stocks are mobile and renewable. Stock size or stock density is influenced by migration, harvesting and reproduction. In this study, fish biomass grows twice a year and the fish stock is scaled according to standard formulation used in bio-economic models such as Touza *et al.* (2012). There are different levels of fish biomass in private and common patches due to spatial movement, harvesting and fish growth. $X_{i,t}$ is the amount of fish biomass in grid *i* at season *t*. The amount of fish biomass harvested in grid *i* at year *t* ($I_{i,t}$) is determined by harvesting rate ($H_{i,t}$) and size of fish biomass in the grid ($X_{i,t}$). The harvesting rate is between zero and one. In this study, *r* is the growth rate which is determined by the habitat quality (*r* = 0.05, 0.08, 0.12, 0.24). A constant proportion (*m* = 0.2) of fish biomass is assumed to migrate from each cell. There is no data available on migration of fish in Cambodia, however McClanahan and Mangi (2000) assumed an emigration rate from marine reserves to fishing grounds of approximately 0.5. Fish can also immigrate from neighbouring grids *(L(i))*. The number of neighbourhoods (N) surrounding cell i can be set as four or eight cells.

For a common patch, the natural growth, spatial movement and harvesting activities are the main parameters to determine the dynamics of fish biomass in a focal common fishing patch as show in (Equation 5-1)

$$\boldsymbol{X_{i,t+1} - X_{i,t} = rX_{i,t}\left(1 - X_{i,t}\right) - I_{i,t}\left(X_{i,t}, H_{i,t}\right) - mX_{i,t} + \frac{m}{N}\sum_{l\in L(i)} X_{l,t}} \qquad \text{(Equation 5-1)}$$

For the focal private fishing patch, the changes in fish biomass from season *t* to season *t+1* is determined only by fish growth and harvesting activities. There is no spatial movement between the focal private patch and others because the boundaries are closed (Equation 5-2)

$$\boldsymbol{X_{i,t+1} - X_{i,t} = rX_{i,t}\left(1 - X_{i,t}\right) - K_{i,t}\left(X_{i,t}, H_{i,t}\right)} \qquad \text{(Equation 5-2)}$$

5.4.6.2 Harvesting

The harvesting equation (h) is called the Schaefer harvest function (Schaefer, 1957). The production function is known as catch per unit effort function (CPUE) or discrete time analogue of catch function. This should be proportional to the fishable stock (qX_t). Harvest (H) is denoted as the output whereas fishing effort (E) and fish stock (X) are the inputs ($H = f(X_t, E_t)$) (Conrad, 1999);

$$H_{k,t} = qE_{i,t}^{\alpha}X_{i,t}^{\beta} \quad \text{(Equation 5-3)}$$

CPUE is relative to the stock density. The catchability coefficient or the efficiency of the fishing fleet, represented by (q), is a constant number greater than zero. The parameter α is the congestion effect which affects fishing efficiency when more fishermen are fishing in the same location, while β accounts for the fishing gear saturation coefficient (e.g., limitations of the capacity of boats or fishing gear). The functional form of the harvesting function is therefore general, but for simplicity it is assumed that α and β are equal to one in the simulations. Fishing effort is an important variable in this model. It is formulated based on adaptive behaviour which is a learned process based on accumulated experiences from interactions with other agents and the environment.

5.4.7 Adaptive behaviour

Adaptive behaviour represents behaviour that aims to achieve goals, but the agents are unable to derive the behaviour that is in their best interest due to the complexity of the management situation. Agents therefore learn from observation of the results when trying out different behaviours as well as the results that other agents achieve from their behaviour. In the fisheries, fishermen communicate and learn from their neighbours' fishing strategies. By comparing their profits and their neighbours' profits, fishermen try to apply the best strategy from the most profitable neighbour who is in a similar situation. In the model developed in this thesis a similar situation is that the fishermen have the same catchability coefficient (i.e., fishing gear). Fishermen can learn from what other fishermen are doing by adopting fishing effort (i.e., fishing hours, location) from their most successful neighbour. The decision to purchase a licence is not modelled explicitly. Chapter 4 modelled the decision to purchase a fishing licence. In this chapter and the following modelling chapters, the focus is on modelling fishing location and effort. In Chapter 4 data derived from choice experiments with individual fishermen was used and this chapter was therefore unable to derive interdependence in fishermen purchasing behaviour. No data exists on individual fishing effort and location, and the models cannot be empirically parameterised. Therefore, the model is developed using adaptive behaviour, a standard assumption about agent behaviour in ABMs. It is reasonable to assume that fishermen rely on observation of other fishermen both when purchasing licences and developing fishing strategies. In this work it has only been possible to include interaction between fishermen in the ABM formulation.

In this model, fishing ability is determined by the catchability coefficient. The catchability coefficient is assigned initially to each fisherman randomly, varies between 0.02 and 0.05, and represents the different skills or different fishing gear of the individual fisherman. There is only a little variation in the catchability coefficient. This is supported by the questionnaires conducted for this thesis, where the variability between individual fishermen was quite low. The initial fishing effort is assumed to vary in the range from 0.4 to 0.8 but is altered during the simulations as fishermen adopt fishing effort from the most profitable neighbour to optimise their business. So, in this study this process captures direct social interaction (communicating and learning). Fishermen also indirectly impact each other through their influences on fish stocks and available fishing grounds.

5.4.8 Profits

The payoff function is specified as fishing revenue minus fishing cost. The equation is shown as π = ($H_{i,t}$*1000) – (catchability coefficient* fishing effort *500). The fishing activity brings costs that are derived from fishing intensity which assumes the cost of fishing is 500 USD per unit of fishing intensity (catchability coefficient* fishing effort). The harvest revenue is driven by the marginal revenue (R), assumed to be a constant of one USD per one tonne of fish. So, income is 1,000 USD per tonne of fish. The average selling price of fish per kilogram in Tonle Sap is around 1 USD (from the interviews).

5.4.9 Summary of model protocol

The model includes fish biomass dynamics and fishermen activities. Fishermen are goal oriented to survive and accumulate wealth. Table 5-1 summarizes the dynamics of the model procedures in a one-year time period.

Table 5-1 Summary of equations and logic behind fishermen's decisions

	Activities/Timeline	**Common patches**	**Private patches**
Closed season	Search for fishing ground	Max (fish stock), fishermen vision and closest to themselves	
	Profit (Income – fishing cost)	π = ($H_{i,t}$*1000) – (catchability coefficient* fishing effort *500)	
	Select fishing effort	Max (profit) of neighbours or their own fishing effort	
	Harvesting	$H_{i,t} = qE_{i,t}^{\alpha}X_{i,t}^{\beta}$	
	Fish growth	$GX_{i,t} = rX_{i,t}\left(1 - X_{i,t}\right)$	
	Update fish stock (from growth, harvests, migration)	$X_{i,t+1} - X_{i,t} = rX_{i,t}\left(1 - X_{i,t}\right) - I_{i,t}\left(X_{i,t}, H_{i,t}\right) - mX_{i,t} + \frac{m}{N}\sum_{l \in L(i)} X_{l,t}$	
	Update wealth	Wealth = wealth + π	
Open season	Fee of private property	0	Fee = habitat values * 500
	Decision of selecting fishing grounds	Max (fish stock)	Max (habitat) and fee ≤ ¾ of wealth
	Profit	π = ($H_{i,t}$*1000) – (catchability coefficient* fishing effort *500)	π = ($H_{i,t}$*1000) – (catchability coefficient* fishing effort *500)
	Update fish stocks	$X_{i,t+1} - X_{i,t} = rX_{i,t}\left(1 - X_{i,t}\right) - I_{i,t}\left(X_{i,t}, H_{i,t}\right) - mX_{i,t} + \frac{m}{N}\sum_{l \in L(i)} X_{l,t}$	$X_{i,t+1} - X_{i,t} = rX_{i,t}\left(1 - X_{i,t}\right) - I_{i,t}\left(X_{i,t}, H_{i,t}\right)$
	Update wealth	Wealth = wealth + π	Wealth = wealth + π

5.5 MODEL VERIFICATIONS

There are several model verification methods when using NetLogo as a simulation platform. Although NetLogo is a user-friendly programme, software mistakes such as run-time, syntax and formulation errors are common. Simulations were tested several times using different techniques for debugging and verifying the NetLogo programme.

5.5.1 Syntax checking

The syntax checker, which is a part of NetLogo, helped detect and interpret error statements resulting from unclear code. The syntax check was frequently used each time a few programme lines were written.

5.5.2 Visual and spot testing

Visual tests were done by observing unexpected behaviours through NetLogo's interface. The world display can be used to spot test both the overall programme and individual agents. The programme display used a simplified design such as different color settings to show important data and graphs. For spot test calculations and observations, the monitor displayed variable values for each individual (patch and turtle).

5.5.3 Print statement

NetLogo input and output primitives, such as export-output, print, show and write, are written to a file or display that are useful in understanding programme steps. Print statements are used to detect where programme errors occurred. The export-output was consistently used during development of the models.

5.5.4 Stress tests

Input data and parameters outside the normal range of value are run for stress or extremes tests, which are helpful in finding hidden errors under normal conditions. For example, fish biomass should decrease rapidly with intensive fishing activities but if fish biomass remains stable, this could indicate errors in the model specification.

5.5.5 Code reviews

Peer review is a very good technique to inspect a programme. It is important that peers compare code to model formulation and search for logic or typographical errors. This can be very valuable because fresh eyes are more likely to find errors the developer may not notice or identify. Also, peers can provide feedback to ensure codes are well organised and understandable. A few peers helped check the pilot models. In addition, discussions with peers were helpful in improving the model's settings.

5.6 CONCLUSION

This chapter presents the arguments for the use of a social simulation approach, in particular ABM. It argues that ABM is appropriate in this research context. Specifically, ABM's flexibility allows the simulations of dynamic and complex systems capable of including different characteristics of agents and wetland fishery. Furthermore, the chapter provides information on how agents and their environments are specified and the rationales behind agent behaviour. The model setting explains fish habitats, property rights, and the dynamics of fish in model landscapes. It also describes adaptive behaviour and economic returns from fishing activities. Each fisherman is randomly assigned wealth, a fishing-coefficient, and initial fishing effort. The strategy for choosing fishing effort is adaptable and dependent on the learning process. Fishermen adopt the fishing effort from the most profitable neighbour. This model description and justification helps other users or readers understand the model and interpret the model outputs.

Chapter 6

THE SPATIAL ANALYSIS OF PROPERTY RIGHTS REGIMES IN FISHERIES

This chapter uses an agent-based modelling approach to understand the spatial dynamics of a freshwater wetland fishery. The aim of the chapter is to develop a tool that can be used to assess various and competing ways to improve management of the fishery. The interactions between fishermen, fish stock dynamics, and fishing regulations are particularly important components of the model. The first section outlines the aim of the chapter and the rationale for the analyses. The second section provides a literature review focusing on property rights debates using simulation techniques. The third section provides a conceptual framework of FISH model and a summary of model procedures. The fourth section specifies how the wetland biology and regulation is modelled and outlines the policy scenarios. The penultimate section presents the results of an evaluation of the effects of different spatial distributions of property rights. Furthermore, a sensitivity analysis of critical model parameters is presented. This is followed by a discussion and conclusion of the main findings. The result of the analysis shows that the indicators for fish biomass and profits are higher when private property rights are allocated to fishery resources. For systems combining private and common property rights, the main finding is that designs of fishing grounds with the majority of the area allocated as common property outperform other designs. This is mainly because a large area under common property benefits the largest proportion of fishermen.

6.1 INTRODUCTION

The management of Tonle Sap wetlands that is described in Chapter 2, section 2.2.4 includes the allocation of property rights on fishable areas. For fisheries management, the wetlands are divided into three different zones under different regulations based on the spatial distribution of property rights. One zone is for fishery conservation; the other two zones are allocated for fishing purposes. This chapter focuses on the fishable zones where private and common property rights are implemented. Findings from the choice experiments (Chapter 4) suggest a potential connection between conservation behaviours of fishermen and property rights. This has also been supported by other research (e.g., Mansfield, 2004; Yandle, 2007) indicating that the allocation of property rights could create incentives for conservation and increase efficiency of resource use. Following on from this work, this chapter investigates whether a private property rights approach can encourage sustainable fishing in the context of small-scale fisheries.

Fishery systems are socially and ecologically complex. They involve multiple subsystems (such as multiple users, several regulations and the resource system) at different levels (e.g., individuals, groups and whole communities), and spatially heterogeneous fishery resources. It is therefore important to take spatial structures and dynamics of complex fisheries into account when assessing the implications of alternative spatially explicit management policies.

A simulation approach is used to analyse the effects of the interactions between fishermen in the spatio-temporal dynamics of fisheries with a mix of private and common property fishing areas. Agent-based modelling (ABM) has been selected as an appropriate tool for examining the complexity of fishery dynamics. The rationale for selecting ABM is described in Chapter 5. Previous studies have simulated the effects of allocating property rights to fishermen in the form of harvesting quotas or individual transferable quotas (ITQs) which allocate a share of a total allowable catch. This approach is used to encourage fishermen to minimise fishing effort and maximise profits (by catching when fish prices are high) (Grafton *et al.*, 2006). For example, Guyader and Thébaud (2001) modelled ITQs and evaluated the parameters that relate to distributional issues in the operation of ITQs. However, they used a static model although the analysis of fishery practices must consider fishery dynamics. The dynamic approach taken here builds on the work of Little *et al.* (2009) who used a spatially explicit and dynamic model to study the effect of ITQs for multiple species fisheries. However, all these papers provide a different perspective on property rights in fishery management to that of this thesis. For ITQs, property rights are assigned to a quantity of fish (harvesting quotas), while in this thesis ownership is allocated to a fishing area with closed boundaries.

The aim of this chapter is to explore how different spatial patterns of resource extraction rights influence the sustainability of inland fisheries. Particularly, fishery sustainability is evaluated according to two indicators: biology and socio-economics. The biological indicator is measured through the level of fish biomass and the socio-economic indicator is measured by fishing profits and the wealth of the fishing society. To address this aim, the relationship between fishing intensity of heterogeneous fishermen and fish biomass is simulated under fishing grounds characterized by different habitat qualities and differential zoning of extraction rights. In order to reveal the effects of the allocation of property rights on the sustainability of the fishery, the results are compared between private and common property rights patches and among different policy scenarios.

6.2 LITERATURE REVIEW

Several researchers are using simulation techniques to address the issues of resource degradation and pollution. Their results have indicated that property rights are important for resource management. For instance, Angelsen (1999) explores the expansion of agriculture and deforestation using different modelling approaches to investigate the implications of assumptions relating to the allocation of property rights, labour markets and household objectives. The result shows that an increase in deforestation may be caused by land titling and intensification programmes in the agricultural sector because clearing forest land gives farmers property rights over the land. However, one model found that changing from private ownership to open access did not increase levels of deforestation; this may be partly because the benefits from private ownership (i.e., forest products) are not included in the private property simulations. This means that maintaining private property rights might still be important. This is supported by the work of Webster and Wu (1999) who show how important private property rights are for the reduction of urban pollution. They use a cellular automata modelling approach together with GIS to study the implications of alternative property rights systems on the regulation of urban pollution. Their simulation develops two scenarios: with and without community property rights for land use. The preliminary results of both scenarios reveal that industrial land without property rights for land use may create a socially inefficient city. This is because the intensity of development ignores external costs and increases to a point where the marginal costs exceed marginal social benefits. Cellular automata models enable a large number of agents to be included; however, their ability to accommodate complicated designs of agents is low (Gilbert and Troitzsch, 2005).

Other types of simulations have also been used to study common-pool resources and property rights such as a system dynamics and bio-economic modelling. For instance, Castillo and Saysel (2005) model individual decision rules of resource users and their incentives for cooperation using a system dynamics approach. The target participants (agents) were people who relied on common-pool resources and encountered cooperation dilemmas. This model can be used to define relevant factors in decision-making for resource management. A combination of laboratory experiments and simulation modelling has also been illustrated as a promising approach to examining social dilemmas related to common-pool resources. Nevertheless, system dynamics models cannot include more than one level of analysis so they are not suitable for investigating phenomena such as the effects of property rights on two or more variables (e.g., individual and societal). An agent-based model can overcome some of the disadvantages of system dynamics models as it can model highly complex agents and allow for communication between them. ABM is appropriate for analysing property rights issues since these issues generally involve not only different types of property rights but also agents with sophisticated characteristics.

ABM has been used to address property rights issues in different contexts such as simulating the effects of intellectual property rights (Boisot *et al.*, 2007). Their models are developed to understand the creation of new knowledge and the social costs relating to new knowledge in economic systems. For natural resources, Bowles and Choi (2002) use ABM to investigate how the collectivist attitudes of hunter-gatherers could persist over long time periods and how individual property rights change this social order. They suggest that the long-lasting social order of hunter-gatherers can be attributed to the presence of inter-group conflicts and to people who followed the traditions and second-order social punishments (in order to avoid violations of the norms). The model results reveal that emergence of agriculture and an increase in possession can lead to the introduction of individual property rights. The study concludes that although past society consists of socialists, reduction in this typical attitude and introduction of property rights provide a better system of coordination among members of groups. This system is only possible after the insecurity of land tenure is reduced and crops and livestock are domesticated.

Most of the papers investigating the effects of property rights systems or comparing different types of property rights show positive effects from the enforcement of formal ownership. However, in this paper the focus is on the consequences of different combinations of two types of property rights (private and communal) on small-scale fisheries. This emphasis is new to the literature, especially the simulation to investigate the spatial distribution of dynamic resource availability and fisherman behaviour. The analysis provides information on behavioural adaptation in terms of the evolution of fishing effort as a response to the allocation of fishing rights. This is very important in order to identify effective management solutions taking into account potential changes in fishery pressure as a result of alternative patterns of fishing rights (Hilborn, 1985; Millischer and Gascuel, 2006; Bastardie *et al.*, 2010). If fishery managers understand the spatial pattern of harvesting pressure, they can implement specially designed management to better account for spatial variability in the productivity of the stock, the spatial variability in pressure and the mobility of the resource.

6.3 THE “FISH” MODEL STRUCTURE

Overall, the FISH model simulates a small-scale fisheries world. The model is specified to represent the small-scale fisheries in Tonle Sap wetland (described in Chapter 2). The model simulates interactions of fisherman behaviour in terms of purchasing exclusive fishing licences and harvesting in different property rights zones. The conceptual framework of the model is shown in Figure 6-1. Four different policy scenarios are simulated to analyse the effects of property rights in terms of the proportion of the area allocated to different property rights zones and their spatial patterns. The results of those scenarios are compared in terms of fish biomass and profit per fisherman.

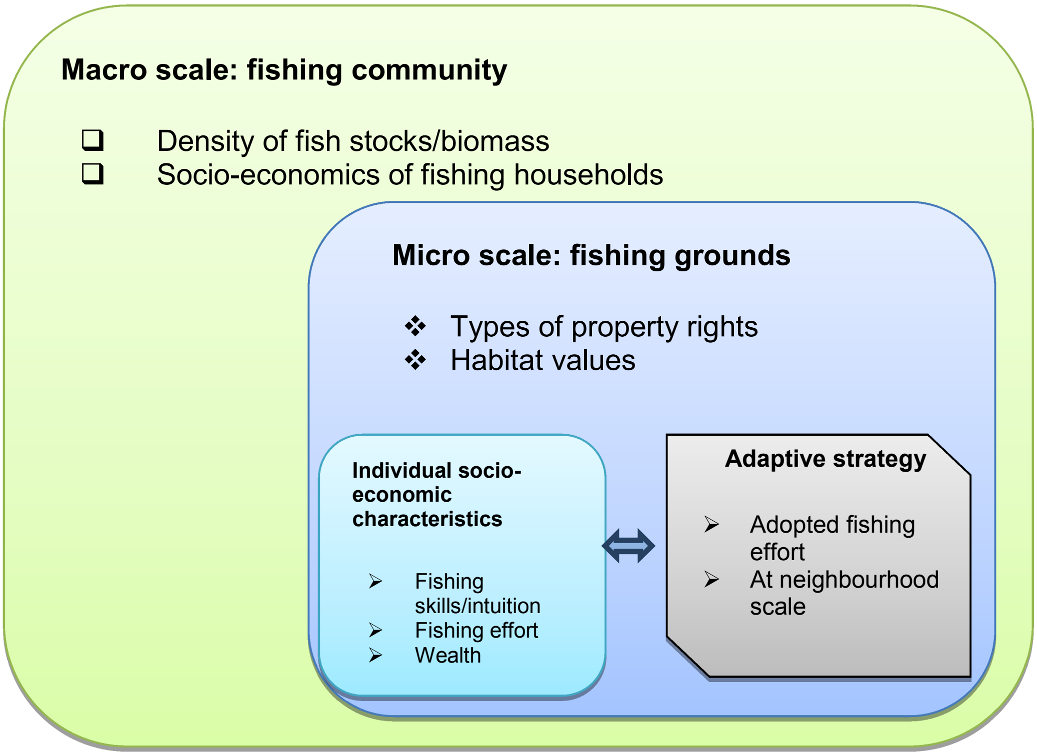


Figure 6-1 Conceptual framework of FISH model

In terms of property rights two types of fishing grounds are defined: private and common (or public). Each time period in the simulation equals one year, which comprises two seasons of fishing: closed season and open season. All fishing grounds are open access for all fishermen in the closed season (i.e., all are common fishing grounds). Some of the common fishing grounds in the closed season are converted to private fishing grounds in the open season. The private fishing grounds are usually located in better-quality habitat. The fishermen decide on their fishing location, either in the private or common fishing grounds, based on the best available fishing ground in the best habitat within a neighborhood. The agents are autonomous and self-directed and have the ability to learn from each other. The fish stock in each cell reproduces and the reproduction dynamics depend on harvesting rate, habitat quality and fish migration. The model is written in NetLogo (Wilensky, 1999) and the user interface is shown in Figure 6-2. The figure demonstrates an example of FISH model run over a period of 1,000 years. The interface consists of controllers of model variables, plots of economic and biological variables and the view of the fisheries world.

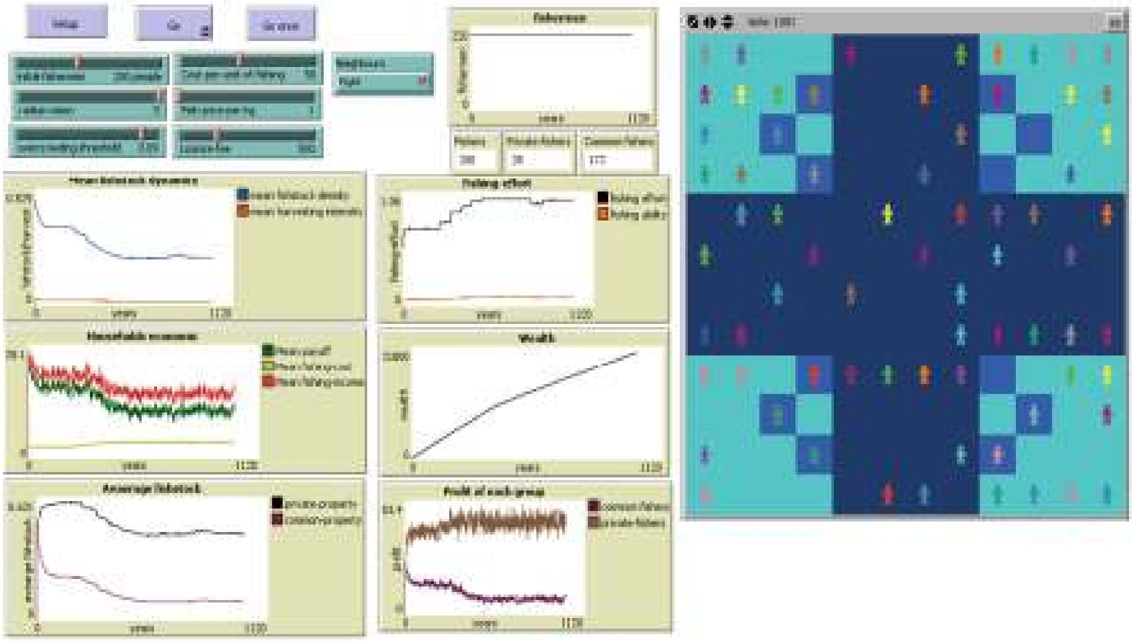


Figure 6-2 The user model interface showing the changeable parameters, output plots, and the emergence of the fishery at 1,000 years. Dark blue shows common fishing grounds; light blue represents the common fishing grounds in good habitats; and cyan (greenish-blue) shows the private fishing grounds.

The fisheries world consists of a fishing ground of 12 x 12 cells of *HABITAT* that have *FISHSTOCK* in them as it allows the representation of the pattern of property rights and habitat qualities in Tonle Sap in a symmetric pattern. The relatively small number of plots ensures that the model simulations can run quickly which is essential during model development. This provides 144 cells of fishing grounds which can be rearranged to represent alternative property rights characteristics and variability in the habitat properties. Initially, the density of fish stock is randomly distributed. The two main characteristics of the fishing grounds are habitat quality and property rights. Four different values of habitat qualities and two types of property rights can be assigned to each cell. Fishermen initially have different *WEALTH, CATCHABILITY COEFFICIENTs* (e.g., fishing gear) and *FISHING EFFORT* (e.g., number of boats and fishing hours). Initially, each fisherman is randomly located but they can later search and move to better habitat in neighborhood depending on their *RADIUS OF VISION* (the distance they can see). Within each radius of vision, fishermen can select less overcrowded locations where the total catchability coefficient is less than an *OVERCROWDING THRESHOLD*. The model begins with a closed season when all fishing grounds are open for everyone to harvest. The *HARVESTING* is controlled by the *CATCHABILITY COEFFICIENT* multiplied by *FISHING EFFORT*. Fish biomass in each cell is updated after the *HARVESTING, GROWTH, EMIGRATION* and *IMMIGRATION* processes. The quality of fish habitat and the availability of fish stock influence fish growth in the future. In particular, the *GROWTH* rate varies depending on *HABITAT* types, while the migration rate relies on *NEIGHBOURS*' fish biomass (four or eight neighbouring cells). After harvesting in the closed season, fishermen can adjust their fishing strategy by learning and adopting the fishing effort of the most profitable fisherman from within their *RADIUS OF VISION*, and this fishing strategy is used in the next fishing season. For the open season, some fishing grounds are converted into private fishing areas. Fishermen have to decide between purchasing a fishing licence for an exclusive fishing area, or fishing in the common fishing grounds for free. The licence fees for private fishing grounds reflect the quality of fish habitat (the better the habitat, the higher the price). When the open season begins, fishermen search for the best habitat within their neighbourhood *RADIUS OF VISION* and check whether that cell is *PRIVATE PROPERTY* or *COMMON PROPERTY*. For a private fishing ground, if it is still available to purchase, fishermen need to have *WEALTH* greater or equal than 1.5 times the licence fee to be able to purchase exclusive access. The other procedures in the open season are the same as the closed season, apart from the migration procedure. Fish in private areas cannot migrate because all boundaries are closed.

6.4 POLICY SCENARIOS

This chapter does not analyse purely common or private rights scenarios but focuses on the combination of both types. The policy scenarios are created from the combination of two main patterns of property rights allocation and two sizes of private fishing grounds. There are four scenarios (Figure 6-3) incorporating combinations of spatial pattern and share of private fishing ground. Policy scenario cross private dominant represents the cross pattern of a combination of 92 cells of private fishing grounds and 52 cells of common areas. The policy scenario scatter private dominant represents a scatter pattern created from a combination of 92 cells of private fishing grounds and 52 cells of common areas. Policy scenario cross common dominant represents a cross pattern of a combination of 52 cells of private fishing grounds and 92 cells of common areas. Policy scenario scatter common dominant is a scatter pattern created from a combination of 52 cells of private fishing grounds and 92 cells of common areas. All patterns are hypothetical designs. The cross pattern is adapted from the layout of fishing lots in Tonle Sap fisheries, while the scatter pattern is designed to analyse the impact of distributing private property rights over the entire wetland area.

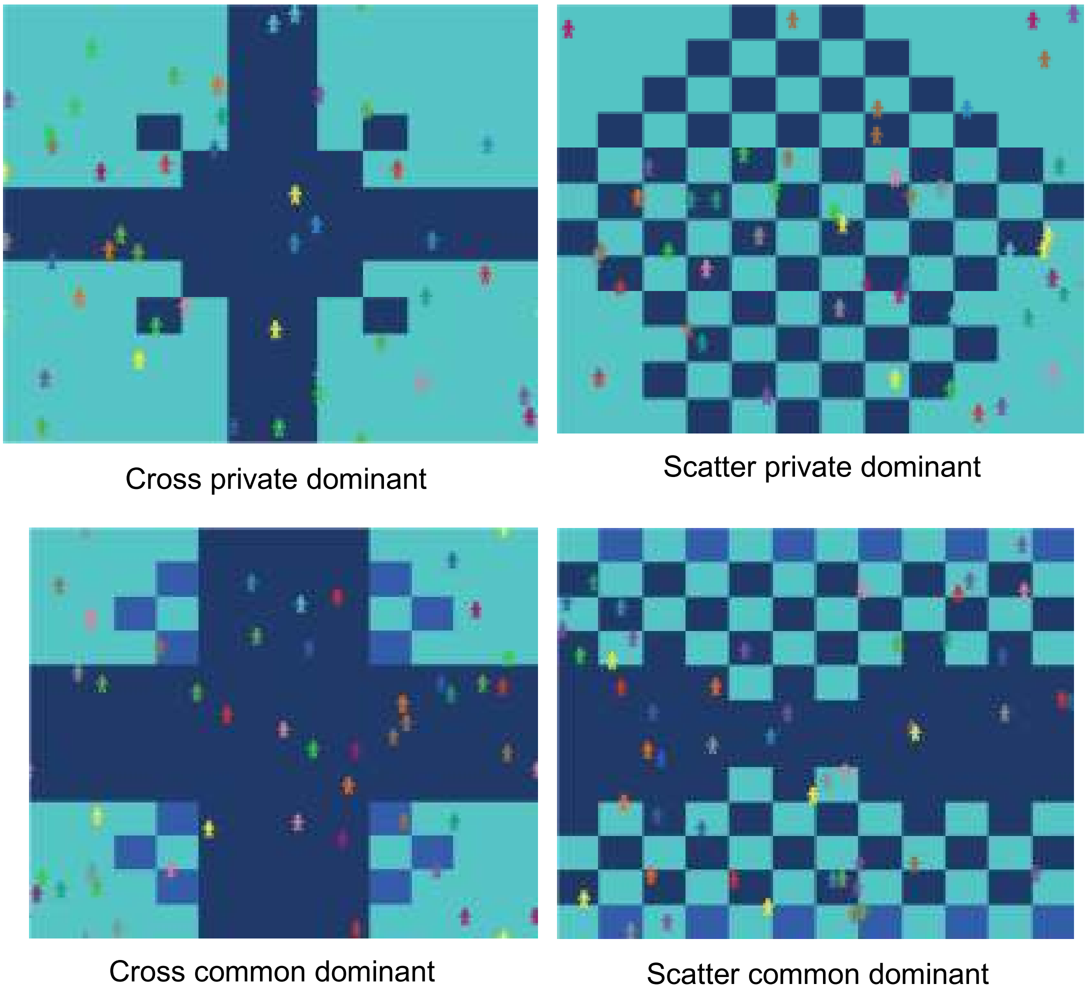


Figure 6-3 The different patterns of fishing grounds for four policy scenarios (dark blue shows common fishing grounds; light blue represents common fishing grounds in good habitats; and cyan (greenish-blue) shows private fishing grounds)

All policy scenarios are simulated using the same default values for each run (Table 6-1). One hundred repetitions of each scenario are run and an average of the hundred simulations is used as the final result (as there was very little variation between runs).

Table 6-1 The default values of the FISH model parameters

Parameters	Default values
Catchability coefficient	Random between 0.02 and 0.05
Fishing effort	Random between 0.4 and 0.8
Fisherman population	200
Radius of vision	3
Licence fee	25, 40, 60, and 120 USD

6.5 RESULTS

The models demonstrate how regulation of local interactions between fishermen and fish biomass lead to different outcomes at a macro level. The state of the fishery that emerged as a result of the interactions is presented in the following three sections. Section 6.5.1 compares the simulation outputs of private and common property rights. Section 6.5.2 demonstrates the effects of different combinations of property rights in terms of patterns and sizes of fishing grounds. Section 6.5.3 presents the results of the sensitivity analyses of selected parameters of interest. The sensitivity analysis illustrated in the chapter relates to the number of fishermen and their radii of vision.

6.5.1 Effects of property rights

This section evaluates the effects of private and common property rights using fish biomass and fishing profits as indicators. It compares the profits between private and common property fishermen and the quantity of fish biomass in private and common fishing grounds. For all scenarios, private property rights seem to offer benefits to licence holders and provide more fish in the future. The results show that fishermen who bought exclusive fishing licences always make higher profits irrespective of the policy scenarios (policy scenario cross common dominant is shown in Figure 6-4). In the long term, the profit trend for common property fishermen declines slightly, whereas the profit trend for private fishermen slightly increases before stabilising. At year 1,000, the profit of private fishermen is almost double that of fishermen using the common fishing grounds. Fish biomass in private fishing grounds is also constantly higher than fish biomass in common property areas for all scenarios. Figure 6-5 (policy scenario cross common dominant) shows that fish biomass in both types of fishing grounds decreases in the first 500 years before stabilising.

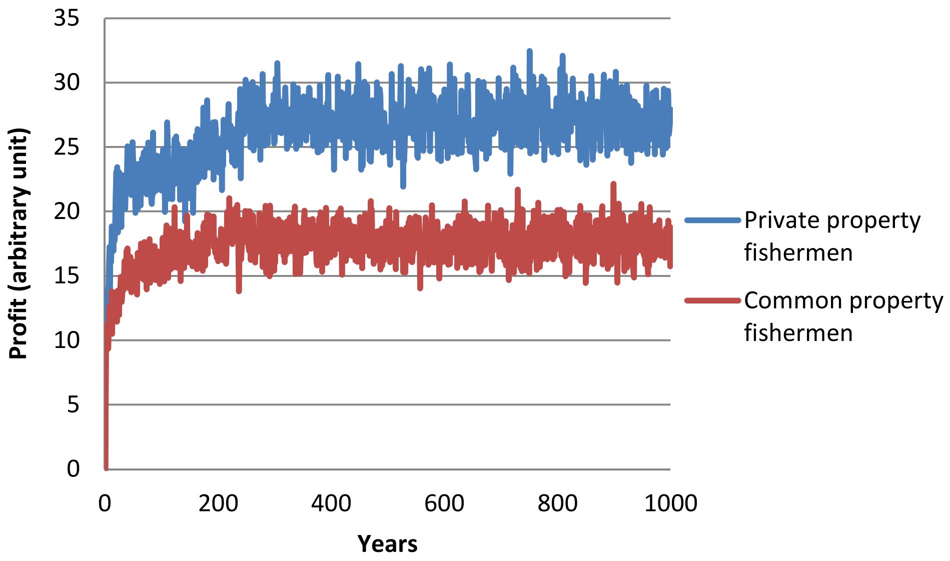


Figure 6-4 The dynamics of the profits of private and common property fishermen over the thousand years of the model run (policy scenario Cross common dominant)

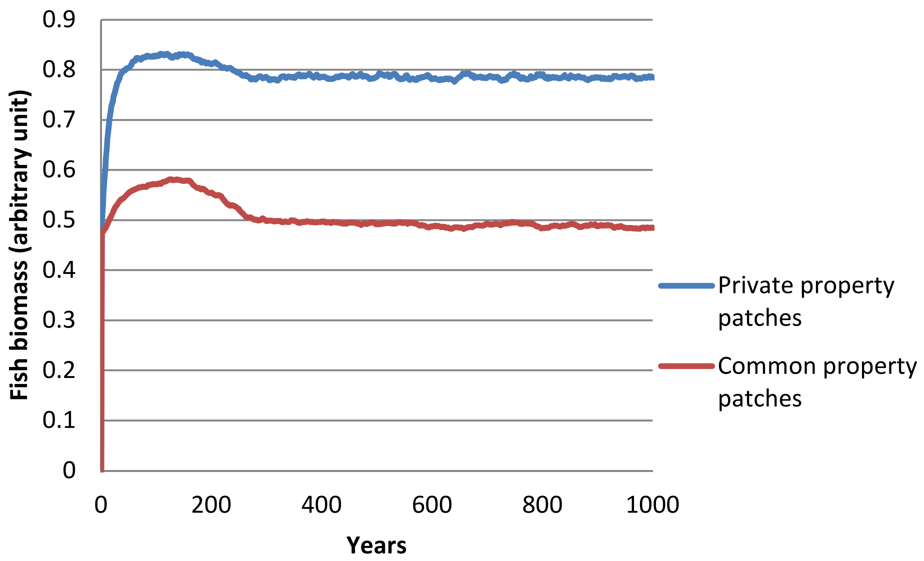


Figure 6-5 The dynamics of fish biomass in private and common property fishing grounds over the thousand years of the model run (policy scenario Cross common dominant)

6.5.2 Policy scenarios analysis

This section analyses the consequences of the combination of private and common property rights through the four different policy scenarios. The results are presented in two parts. The first considers the effects of the socio-economics of fishermen, analysing the relationship between wealth and fishing intensity. The second part considers the relationship between fish biomass and intensity of fishing activity. The results show that the scenarios that are dominated by common areas are preferred in terms of socio-economic and biological outcomes. This results seem to contradict the results reported in section 6.5.1 (property rights effects) showing the superiority of private property rights on fish biomass. However, section 6.5.1 evaluated private and common property rights in each year on their own, while this section analyses the different combinations of both types of property rights. In the mixed property rights systems those that have larger areas of common property rights produce better outcomes for both profit and fish biomass. This chapter shows that the evaluation of different scenarios needs to consider other key parameters together with the model outcomes, such as the number of fishermen and their radii of vision. The details are explained in section 6.5.3.

6.5.2.1 Socio-economic sustainability

Scenarios where private property rights dominate contribute more to the overall economy of the community when the resource rents (licence fees) directly benefit the local economy. This is illustrated by the model results when the licence fees collected are included in the community economy. However, the FISH model scenarios reported below assume that licence fees do not directly contribute to the local community. The revenues from selling licences are assumed to go to the government. Hence, the following model results present community economies including only the direct income from fishing. The trends in collective wealth resulting from all policy scenarios significantly increase over time (Figure 6-6). This implies that when private property rights are dominant, it may not always provide the best aggregate outcome for the community even though the outcomes are superior for the licence holders (Figure 6-4). The scenarios in which common property rights dominate are a better option in terms of social and economic sustainability for the fishing community as a whole. To understand this, some of common fishing grounds in the policy scenarios that are dominated by common property rights (cross common dominant and scatter common dominant) are located in good habitats and are adjacent to private fishing grounds that have a lower harvesting intensity. So the common property fishermen, who comprise the majority of the fishing community, directly benefit from effects of good habitat and spillover effects from private areas. Moreover, the common property fishermen have more area per person when there are more common property areas, which lead to less intensive fishing, i.e., reducing overfishing.

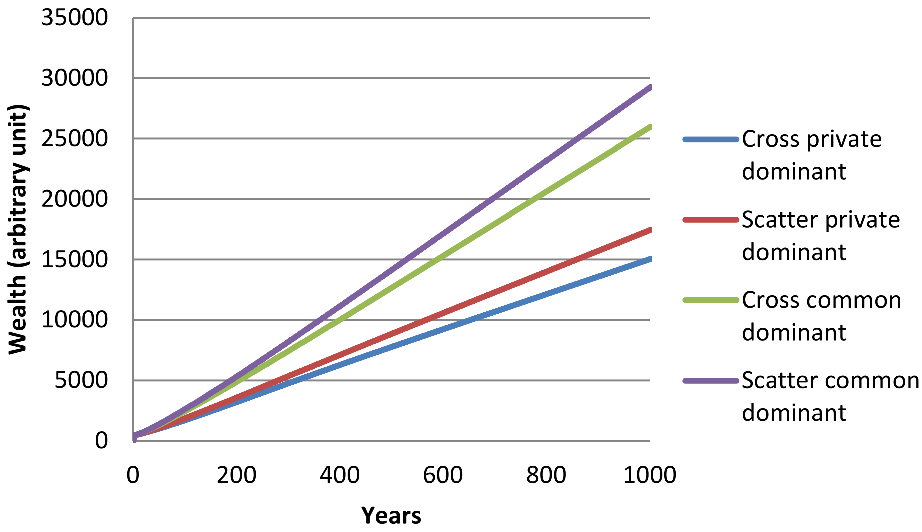


Figure 6-6 The dynamics of the collective wealth over the thousand years of the model run for policy scenarios Cross private dominant, Scatter private dominant, Cross common dominant, and Scatter common dominant

Figure 6-7 shows higher profits from areas that are dominated by common property rights compared to areas that are predominantly private. The dynamics of profits are strongly linked to the quantity of fish harvested (Figure 6-8). This also explains why the overall accumulated wealth of the scenarios that are predominantly common property is higher than scenarios dominated by private areas.

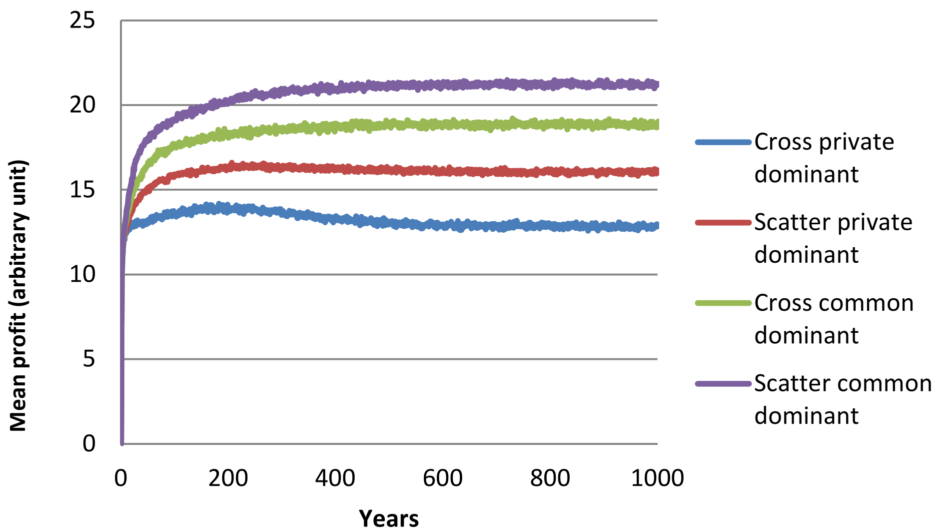


Figure 6-7 The dynamics of profit for a thousand-year model run under each of the policy scenarios Cross private dominant, Scatter private dominant, Cross common dominant, and Scatter common dominant

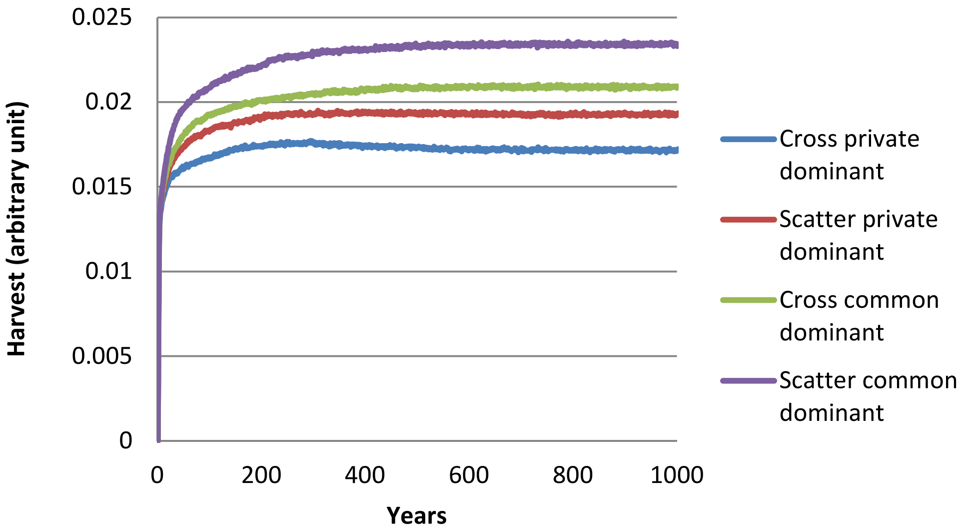


Figure 6-8 The dynamics of fishing intensity for a thousand-year model run under each of the policy scenarios Cross private dominant, Scatter private dominant, Cross common dominant, and Scatter common dominant

The simulations of all scenarios show that the number of common property fishermen is always more than four times higher than the number of private fishermen in each year. Scenario cross private dominant and scatter private dominant (dominated by private property rights) can provide 92 exclusive fishing licences, which means a maximum of 46% of fishermen can benefit from private property rights. Whereas there are only 52 exclusive fishing licences allowed in scenarios Cross common dominant and scatter common dominant (dominated by common property rights). In these scenarios only 26% of fishermen can become licence holders. The model results in Figure 6-9 reveal that licence holders comprise approximately 20% and 12–15% of the total fishermen in scenarios dominated by private property rights and common property rights, respectively. In particular, there are approximately 3 fishermen per common property patch for policy scenarios cross private dominant and scatter private dominant, while there are around 1.8–1.9 fishermen per common property patch for scenarios Cross common dominant and scatter common dominant. The number of fishermen who buy fishing licences fluctuates in the first few years before becoming stable. This may be because of the random initial location assignment of each fisherman. Later, fishermen learn whether or not purchasing a fishing license is profitable and the number of licenses stabilise. The percentage of fishermen who purchase exclusive fishing licences is lower than the maximum possible for all scenarios. The reason for this is fishermen have either not had sufficient wealth to purchase fishing licences, or private fishing grounds are further than the *RADIUS OF VISION* of those fishermen, i.e., the locations of those fishermen are not close to private fishing grounds. As the community is dominated by fishermen with common property rights fishing in communal areas, the overall outcome for the community is mainly a result of the outcomes for these fishermen.

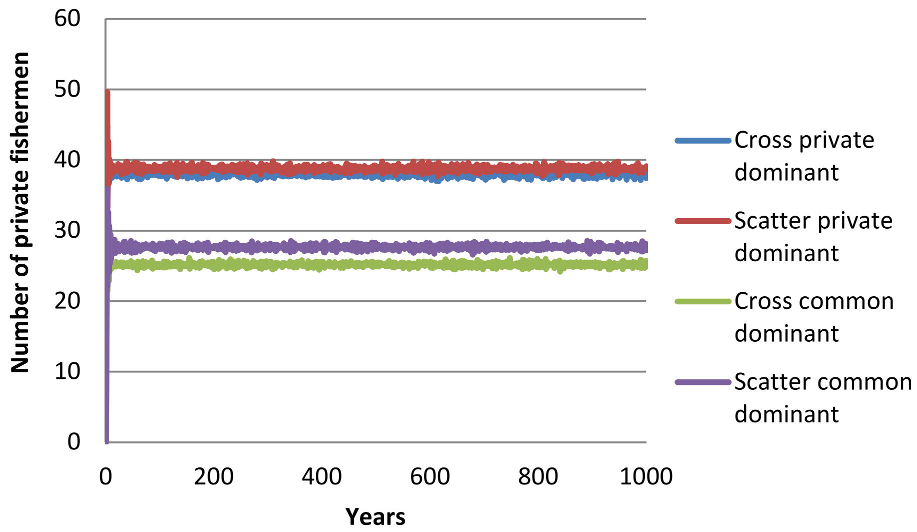


Figure 6-9 The number of fishermen who purchase exclusive fishing licences under each of the four different policy scenarios (policy scenarios Cross private dominant, Scatter private dominant, Cross common dominant, and Scatter common dominant), n = 200

6.5.2.2 Biological and ecological sustainability

Fish biomass and fishing intensity develop over time. Figure 6-10 shows that the trend of fish biomass for all scenarios increases before gradually declining and becoming stable. Scenario scatter common dominant provides the greatest fish biomass. Improving the amount of fish biomass in the system leads to higher harvests (Figure 6-8), profits and collective wealth. In particular, when there are higher levels of fish biomass, the number of fish caught per unit of effort will be also higher. Figure 6-11 shows almost identical upward trends for fishing effort regardless of policy scenario but that harvesting levels show considerable differences between scenarios.

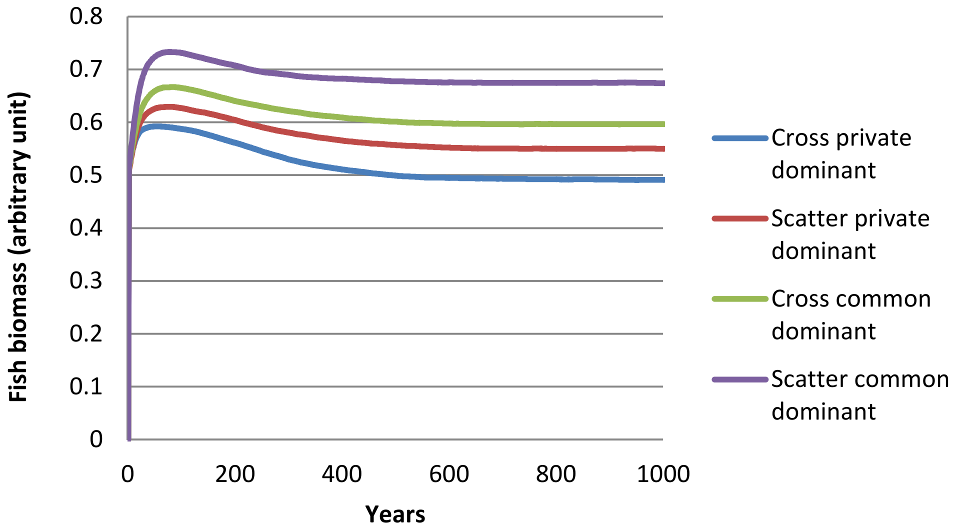


Figure 6-10 The dynamics of fish biomass for a thousand-year model run under each of the policy scenarios Cross private dominant, Scatter private dominant, Cross common dominant, and Scatter common dominant

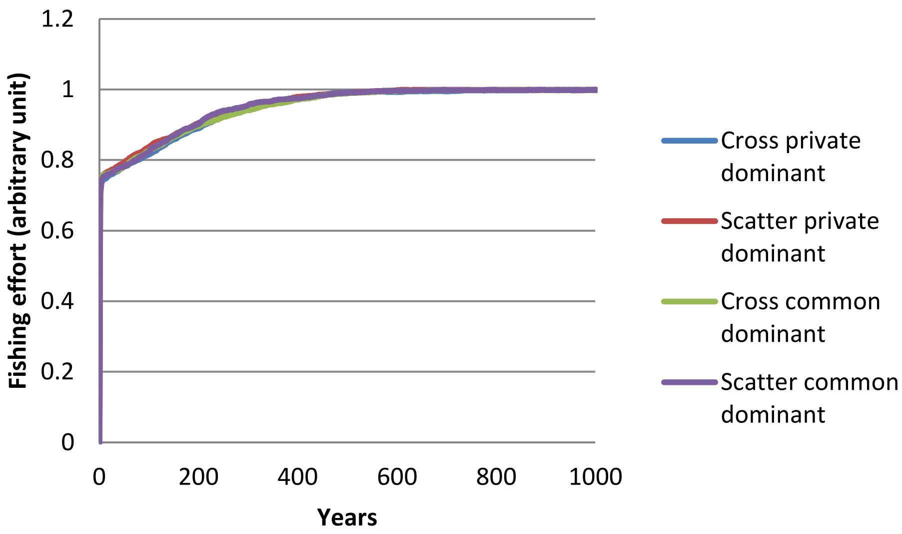


Figure 6-11 The dynamics of fishing efforts for a thousand-year model run under each of the policy scenarios Cross private dominant, Scatter private dominant, Cross common dominant, and Scatter common dominant

6.5.3 Sensitivity analysis of the model parameters

This section analyses the relationships between the dynamics of fishery sustainability and input variables such as number of fishermen. In modelling this, the values of the variable of interest are changed while other variables are fixed at their default values (Table 6-2). Five repetitions were simulated for each combination of parameters to ensure that repetitive runs reveal consistent results. The model outputs show which variables influence fish biomass and the wealth of the society, and how.

Table 6-2 The model range and default values of baseline parameters

Parameters	**Model range**	**Default values**	
		Private property–dominated scenario	**Common property–dominated scenario**
Fisherman characteristics			
Fishing effort	0.4–0.8	Random 0.4-0.8	Random 0.4–0.8
Catchability coefficient	0.02–0.05	Random 0.02–0.05	Random 0.02–0.05
Wealth	300–600	Random 300–600	Random 300–600
Radius of vision	1–4	3	3
Fisherman population	1–400	200	200
Fishing grounds			
Neighbours	4 or 8	8	8
Habitat quality	0.05, 0.08, 0.12 or 0.24	0.05, 0.08, 0.12 or 0.24	0.05, 0.08, 0.12 or 0.24
Percentage of private fishing grounds	36 or 64	64	36

Sensitivity analysis of the model parameters identified two that significantly influence the model results: the vision of the fishermen and the number of fishermen.

6.5.3.1 Radius of vision

When fishermen have wider vision (i.e., larger radii of vision) to select fishing grounds, the collective wealth of the fishing community is lower (Figure 6-12). This can be explained as the consequence of the distribution of fishing effort. Fishermen use the radius of vision to search for better-quality fishing grounds. If all fishermen have equivalent wider vision, they all have almost similar information on fishing ground qualities. So, the wider vision results in higher numbers of fishermen competing for the same fishing grounds (i.e., the productive fishing grounds). This situation can reduce fish catch per unit effort, which then negatively impacts on the overall wealth of the community. However, when fishermen have narrow vision, they can only select fishing grounds close to their current location. This means that fishing effort is spread out over the whole area. This result is independent of the initial spatial allocation of fishermen. If fishermen are clumped together initially, they will still be dispersed after a few years even with narrow radii of vision. Fishermen are then able to catch more fish, even when fishing grounds are not the most productive, because they do not have to compete with other fishermen.

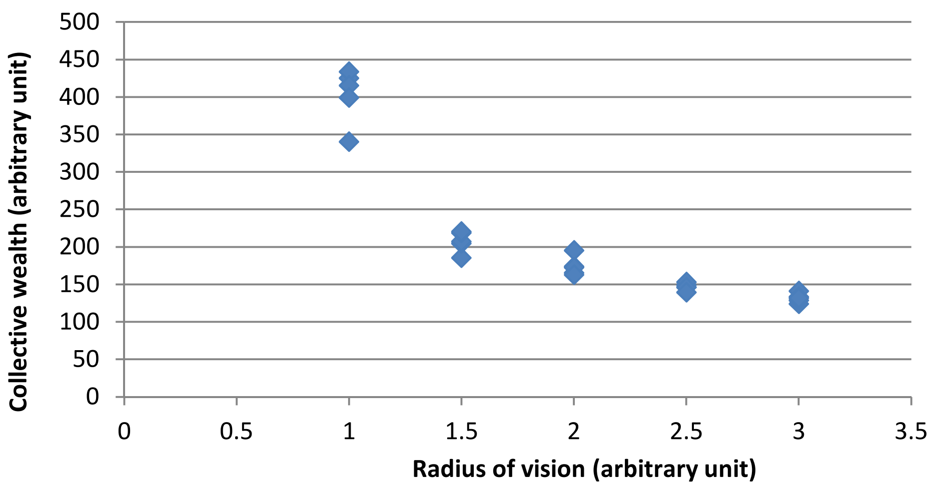


Figure 6-12 Wealth of fishing community as a function of fishermen's radii of vision

6.5.3.2 Fisherman population

The results show that the size of the fisherman population influences the collective wealth of the fishing community. A larger population leads to higher overall collective wealth (Figure 6-13) until a certain number fishermen (500), where collective wealth becomes stable. When the number of fishermen increases, more wealth is contributed to society even when profits per fisherman decrease because of the higher population. Figure 6-14 illustrates how overall profit reduces with an increase in fishermen because the amount of resource shared among them remains the same. In particular, when there is a smaller group of fishermen on private property, fishermen with common property rights are competing more over the common property areas. However, an increase in the number of fishermen does not significantly affect fish biomass (Figure 6-15). Although a smaller population of fishermen results in somewhat higher fish biomass, the bigger population of fishermen does not degrade fish biomass significantly.

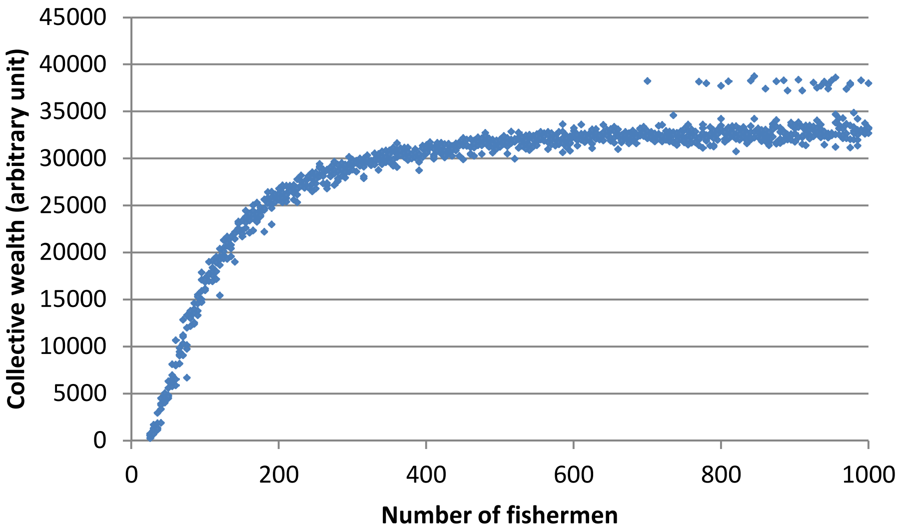


Figure 6-13 Collective wealth at year 1,000 as a function of number of fishermen

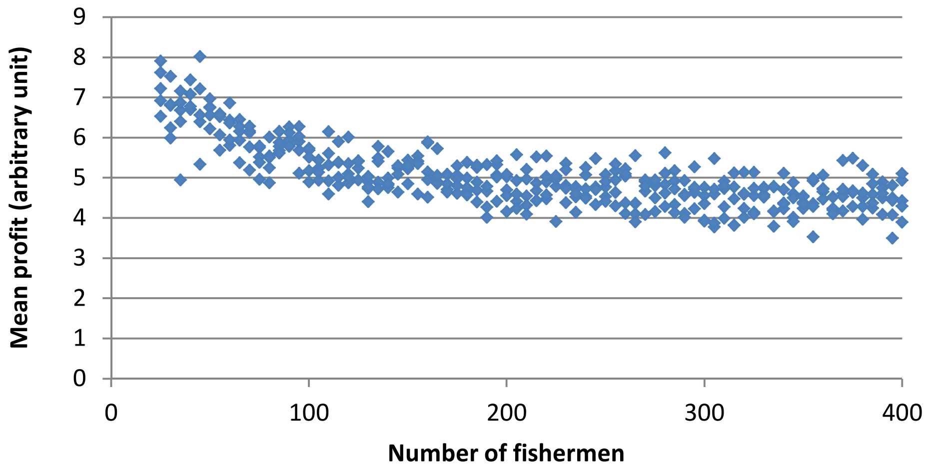


Figure 6-14 Mean fishing profits per fisherman at year 1,000 as a function of number of fishermen

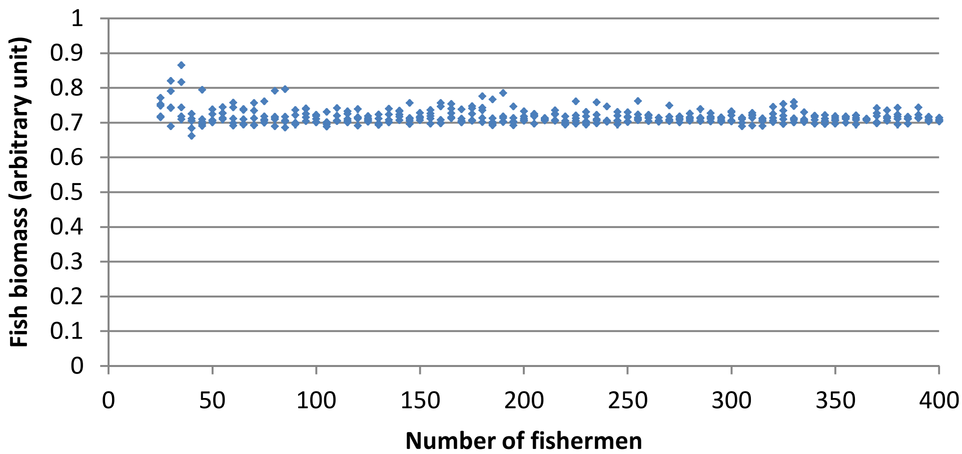


Figure 6-15 Fish biomass at year 1,000 as a function of number of fishermen

6.6 DISCUSSION AND CONCLUSIONS

This chapter aims to analyse the effect of different distributions of property rights on fisheries using an agent-based model. The model investigates the emergence of fishery dynamics from interactions between fishermen and fish stocks in private and common property fishing grounds. The FISH model gives reasonable projections of fishery dynamics. The simulations suggest that private property rights provide more security for society overall in terms of both the socio-economics of the fishermen and the availability of fishery resources in the future. Even though private property rights provide the best return to fishermen, the reality is that it is not possible to offer all fishermen private rights. When a system that combines both private and common property rights over fishing grounds is examined, the results show that the overall benefits are higher when common property fishing grounds dominate. The appropriate combination of private and common property areas becomes important when the availability of private fishing grounds is limited and when not all fishermen have the money to invest in fishing licences. The results from the analysis of a variety of policy scenarios show that scenarios where common property fishing grounds dominate are the best for the production of fish biomass and overall community wealth.

6.6.1 Spatial effects of property rights

Private property rights are expected to create incentives for fish conservation and to improve efficiency of resource exploitation (Mansfield, 2004). This is supported by the findings of this research where fish biomass in private and common property areas in the model is compared. In each year, the areas under private ownership are more economically productive than areas under common ownership. The fishermen in privately licensed areas are able to adjust their harvesting strategy to maximise their income. The model results support the arguments of Sinclair *et al.* (2002) and Grafton *et al.* (2006) who assert that allocation of property rights will create resource rents and preserve fish biomass. The results reveal that without regulating fishing effort or fishing technology (modelled through the catchability coefficient), fish biomass might collapse in some areas. This is consistent with Grafton *et al.* (2006) who identify that, in addition to property rights, other management tools, such as price signals, harvesting responsibilities (e.g., following fishery regulations) and adequate monitoring and surveillance may be needed to create sustainable fishing practices.

The short period of private access rights (six months in each year) in the model is adapted from a past actuality where some small-scale fishermen in Tonle Sap illegaly sub-let a small area from lot owners (commercial fisheries) for a few months every year. Although this chapter is not focusing on investigating the consequences of long or short periods of private property rights, the model outcomes show a positive effect on fish biomass even when private rights are assigned for a short time (Figure 6-4). This result contrasts with Yandle (2007) who argues that security of long-term property rights is important for developing biologically and socially sustainable resource management. However, the key to improving fishery sustainability might not be the length of ownership period, but instead the distribution of fishing efforts. If some areas are intensively harvested, the sustainability of the whole fishery system might be affected too. For example, when only areas outside the private areas are fished intensively, the whole fishery system is impacted (by, for example, affecting fish reproduction and the quantity of fish biomass) because fish are a mobile resource. The short length of the ownership period in this model not only gives more opportunity for all fishermen to rotate rights over private fishing grounds in each year, it might also improve access to the productive fishing grounds among small-scale fishermen. Fishermen with common property rights are the first group of fishermen to lose profits if fisheries are overexploited and fish biomass is in decline.

This chapter also shows that the different spatial patterns of joint private and common property fishing grounds results in different levels of fish biomass and wealth. Private areas are usually located in better-quality habitats than common property areas. However, the entire community benefits more when private fishing grounds are alternated with common fishing grounds (the scatter pattern). In the model simulations, the patterns are shown to be important for fish migration (from private areas to common property areas) but also for the ability of fishermen to access different fishing grounds. This might be due to underlying patterns of fish dispersal and quality of habitat. In particular, when private and common fishing grounds are alternated, common fishing grounds benefit from fish dispersal from private fishing grounds faster than for the other patterns because there are more neighbouring private fishing areas.

6.6.2 Policy implications

The FISH model has been used to determine the relevant factors in decision-making for fishery resources. Understanding spatial dynamics of fisheries and household economics may help to improve management of small-scale fisheries.

Adjusting the property rights system could be a management tool used to improve the livelihoods of small-scale fishermen. However, the model outcomes also suggest that fishery regulations such as gear restrictions (i.e., controlling the catchability coefficient) are needed along with adjustments to the ownership system, as suggested by Grafton *et al.* (2006).

The number of private fishing grounds should take the population of fishermen into account in its design. As the model outputs indicate, the scenarios that are dominated by common property rights result in higher fish biomass This is particularly the case when fishermen population is high, even though some of them move to private fishing grounds. However, there are still a lot of fishermen competing in the common fishing grounds because of the limited availability of fishing licences. However, when the number of fishermen is reduced (i.e., below the number of private fishing grounds available), the scenarios dominated by private property rights provide slightly higher amounts of fish biomass. This implies that if there is a smaller group of fishermen, the privately dominated scenarios contribute more to the sustainability of the fishery in terms of fish reproduction. However, if private fishing grounds dominate and the fishermen population is high, then high levels of competition exist in the common areas resulting in lower fish biomass. This means the population density of common fishermen on the common property fishing grounds considerably influences the overall dynamics of fish biology and the socio-economics of the community. Although, individual private licence holders can contribute to a higher level of wealth-creation in the community, the majority of community members are common property fishermen. So, when policy makers decide on the size of private areas or the number of private fishing grounds, they should also consider the size of the fisherman population since this will affect the overall benefits of fishing. For example, if the fisherman population is high, larger common property fishing areas should be designed.

The price for licence fees should be considered carefully, particularly for small-scale fisheries. The results show that licence fees influence the allocation of fishing effort. A price increased does not generate greater wealth for the wider community and does not necessarily result in a more sustainable fishery. If the price is high, some common property areas are intensively harvested because more fishermen are excluded from buying fishing licences and so fish in the common fishing grounds instead. This means harvesting pressures are moved into the common fishing grounds reducing fish biomass for the fishery as a whole.

6.6.3 Applications of agent-based modelling in fisheries

This chapter contributes to the literature dealing with applications of ABM as it is the first agent-based model to simulate the interactions of small-scale fishermen under different property rights over fishery resources. Other researchers have applied simulation approaches to property rights in marine fisheries (Guyader and Thébaud, 2001; Guyader, 2002; Little *et al.*, 2009). However, these papers explore the effects of ITQs for commercial marine fisheries. The resource extraction rights are assigned to the resource itself (i.e., fish) rather than over areas for fishing as in this thesis. Studies of property rights issues in the context of fisheries also usually use qualitative methods. For example, Ahmed *et al.* (2008) used Schlager and Ostrom (1992) concept of Property-Rights Regimes and Natural Resources to study wetland ownership in Bangladesh by surveying the villagers who live around the Hakaluki Haor wetlands. Their main findings indicated that villagers who have management rights are likely to participate in conservation activities. The Seri, a self-governed community of small-scale fishermen in Mexico, have ownership over fishing grounds and have succeeded in continuing to manage their fisheries in a sustainable way. They not only manage fishery resources for their members but also regulate rules for outsiders who want to access their fishing grounds. In addition, Toufique (1997) used a case study of an inland fishery in Bangladesh to analyse how and why a property rights regime failed to be established. However, it is difficult to deal with spatial and temporal research questions using qualitative methods such as surveys, in-depth research or case study analysis. This chapter provides a different perspective to the analysis of property rights issues by using a spatio-temporal model in the context of small-scale fisheries. This approach overcomes the disadvantages of non-spatial models, such as bio-economic models, by providing spatially dynamic outcomes. These can be useful in predicting spatially dynamic consequences for different policy scenarios before implementation. For fisheries management, it is also necessary to understand spatial interactions between fishermen and the dynamics of the resource. ABM can handle spatio-temporal analysis of fishery resources and take into account fish biomass as a mobile resource. The model in this thesis has the ability to include heterogeneity of fishermen and fishing grounds to reflect the real world of fisheries. Last but not least, the combination of the flexibility of ABM and the user-friendly interface of NetLogo software means that policy makers and other researchers can use these models to test other scenarios for fisheries management and the model code can be developed for different purposes in the future.

Chapter 7
RESERVE CREATION: EFFECTIVENESS OF ZONAL MANAGEMENT

This chapter further investigates conservation management in Tonle Sap explored in the choice experiment analysis in Chapter 4. The small-scale fishermen from Tonle Sap revealed a preference for fishing grounds where conservation restrictions were imposed; however, improved conservation is also sought through zonal management. Therefore, the aim of this chapter is to explore the fishery dynamics of the wetland when conservation zones are included in the spatial agent-based model developed in Chapter 6. The first section of this chapter therefore introduces the rationale and aim of the chapter. The second section provides an overview of the literature on impacts of reserve creation on fishery productivity. The debate is both about whether such benefits exist and about the influence of various reserve designs on fishery sustainability. The third section presents the methods used in this chapter by outlining the model structure and scenarios analysed. This is followed by a results section, which shows that the most favourable reserve creation, in terms of economic returns to the community, is achieved when a fairly large area is conserved in locations where the habitat is sub-optimal in terms of fish productivity. Furthermore, the results show that a single-block reserve is superior to a fragmented reserve in terms of conservation of fish stocks and community economic returns. Moreover, solely in terms of the economic returns to the community, the results show that a fragmented reserve is also favourable. The last section presents the discussion and conclusions.

7.1 INTRODUTION

Reserve creation has been commonly used as a fisheries management tool in both freshwater and marine fisheries but especially for the latter. Reserves include marine protected areas (MPAs) and no-take zones (NTZs). The establishment of MPAs does not necessarily imply a complete ban of all fishing and other economic activities in the area but it does mean that all activities need to be under specific management schemes (Hilborn *et al.*, 2004). In this thesis, however, the conservation zones are defined as areas in which all types of fishing activities are excluded as this reflects how conservation areas are managed in Tonle Sap. The conservation measures aim to help maintain and enhance fish biomass and fish biodiversity because they eliminate fishing mortality from fishing activities inside the protected areas. This in turn has impacts on non-protected areas due to spillover of fish stocks (Ward *et al.*, 2001). Successful conservation should lead to more egg production and more dispersal of fish to the fishing grounds (Roberts, 1995). The value of the spillover effect from the reserve is not only the increase in fish biomass but also the increase in fish size (Russ and Alcala, 1996a; Wantiez *et al.*, 1997). However, fish biomass will still be significantly greater inside than outside protected areas (Halpern, 2003). Fully protected marine reserves clearly confer benefits inside the reserves (Roberts, 2000) and may also help to increase harvesting levels outside the reserves in the long run. Marine biologists have argued that fully protected no-take reserves achieve more for sustainability than reserves that allow limited harvests (Roberts, 2000) (even if those limited-take reserves are well enforced). In particular, fish densities in the Philippines increased by over 800% in 11 years in the no-take Apo Island Reserve (Russ and Alcala, 1996b), and on the Southern Cape coast in South Africa fish abundance is thirteen times higher within a reserve than outside (Buxton and Smale, 1989). Conservation areas also provide a buffer against an increase in fishing effort (Botsford *et al.*, 2003) and habitat degradation. However, others argue that the creation of a reserve may cause degradation of fish habitats outside conservation areas due to increased exploitation in the non-reserve areas (Armstrong and Skonhoft, 2006).

Conservation areas are also expected to reverse the decline in habitat quality from fishing activities inside the reserves (Ward *et al.*, 2001). The effect on fish stocks of designating conservation areas may be similar to the effect of reducing fishing effort (Botsford *et al.*, 2003); however, the opposite has also been argued: that a reduction in fishing effort will not improve fish habitats to the same extent as a conservation areas do because of, for example, the effects of habitat destruction from fishing gear (Roberts, 2000).

However, conservation might not succeed without the support of other management tools such as limitation of fishing effort and capacity (Hannesson, 1998) along with careful planning and assessment (Hilborn *et al.*, 2004). Without a reduction in fishing effort outside reserves, fish stocks can still be overexploited (Roberts *et al.*, 2005). Despite the promising results from implementation of MPAs, they are still only used to a limited extent. Less than 10% of MPAs achieve their conservation aims, and their spatial extent only covers 5.2% of the marine area worldwide (Wood *et al.*, 2008).

Several pertinent questions relate to fisheries conservation: whether conservation is needed (e.g., Hilborn *et al.*, 2004), where reserves should be located (e.g. Roberts, 2000; Roberts *et al.*, 2003), how size impacts the effects of reserves (e.g. Roberts *et al.*, 1997; Murawski *et al.;* Gell and Roberts, 2003; Russ *et al.*, 2003) and the effects of habitat characteristics on conservation outcomes (Hawkins *et al.*, 2006). Several methods have been used in studies of fisheries to assess the effectiveness of MPAs. These include direct observation (e.g. Roberts, 1995), statistical analysis (e.g. Hawkins *et al.*, 2006) dynamic modelling (e.g. Pelletier *et al.*, 2008) and static bio-economic modelling (e.g. Armstrong and Skonhoft, 2006). This chapter addresses questions focusing on reserve sizes, location and habitat types because they are important for designing conservation strategies. However, this thesis uses a different type of modelling framework and is set in a different context to the existing literature. No previous research, to the best of the author's knowledge, has studied the spatial and dynamic effects of conservation combining different property rights and conservation zones. The spatial model in this thesis analyses the interactions between harvesting, mobility of fish stocks and the fishing regulations operating on both the spatial and temporal dynamics of the fishery.

In Tonle Sap, the zonal management system consists of three different zones: private, common property and conservation. The private and common property zones are fishable areas that are clearly divided by boundaries. In conservation zones all fishing activities are prohibited. However, based on the evidence of fishery and habitat degradation, previous attempts to designate conservation zones in the Tonle Sap wetlands do not seem to have been successful (Sneddon, 2007; Nuorteva *et al.*, 2010). Although licences for private fishing areas have been (temporarily) revoked since 2012 (Royal Government of Cambodia, 2012) (to allow fish replenishment by reducing fishing effort from commercial fisheries), redesigning and enforcing conservation areas might be a management alternative for improving fisheries conservation in the future, not only in Tonle Sap but elsewhere. It is therefore important to understand the consequences of different conservation designs on fishery dynamics in general in order to maximise the benefits from conservation.

The spatial patterns investigated in this chapter are adapted from the single-large-or-several-small-reserves debate, i.e., whether reserves comprise *large single* or *small fragmented* blocks. The management choices of reserve location also involve choosing the quality of habitat in which reserves are located, i.e., ranging from most productive to least.

The impacts of the design of conservation management involve multiply agents in space and time. Any management of fisheries will reallocate that fishery's resources among different users. ABM is a useful tool for analysing the effects of conservation in fisheries as it can deal with their multiple heterogeneous agents and spatial dynamics. In this chapter, the results of model simulations in terms of fish stocks and the livelihoods of fishermen are analysed and compared between reserve designs for fisheries.

7.2 LITERATURE: AGENT-BASED MODELLING

Wetland conservation is often argued to be an effective management tool to improve degraded fisheries. Although conservation research in fisheries covers a range of contexts and methodologies, most focus on marine fisheries. For example, Batista *et al.* (2011) aimed to develop a methodology for evaluating the effectiveness of MPAs as a management tool for small-scale marine fisheries. The approach is based on scoring a set of indicators, which are grouped into ecological, economic, governance, social and management indicators, before and after the establishment of an MPA. The main finding from the case study suggests an improvement in the trend of the scores for ecological, management and governance indicators but a decrease in the scores of the social and some of the economic indicators.

One of the popular debates during the 1970s and 1980s was about whether a single large or several small reserves are preferred in terms of biodiversity conservation (McNeill and Fairweather, 1993; Stockhausen and Lipcius, 2001; Tjørve, 2010). According to the theory of island biogeography (MacArthur and Wilson (1967), the single block is favourable in terms of species richness. However, Daniel Simberloff argued against this theory and presented the idea of nested species composition. This concludes that if small reserves have no shared species, they can possibly have more species than a single large reserve (Simberloff and Abele, 1976; Simberloff and Abele, 1982; 1984). In natural seagrass beds, a large proportion of species do not overlap among beds; therefore a single large bed has comparatively fewer species than several small beds (McNeill and Fairweather, 1993).

To optimise conservation and economic benefits it is important to identify the reserve size needed to distribute benefits to fishing grounds. Research by, amongst others, Le Quesne and Codling (2009) and Hannesson (1998) supports the establishment of larger reserve areas while others (Ballantine, 1995; Roberts, 1995) highlight the achievement of even small reserve areas. Hannesson (1998) used deterministic (bio-economic) equilibrium models (a continuous-time model and a discrete-time model) to study the effects of a marine reserve under three different scenarios: 1) entirely open access, 2) open access to the areas outside a marine reserve, and 3) optimal fishing. One of the key results was that conservation only generates small benefits if the reserve is established without constraining fishing capacities and efforts. Le Quesne and Codling (2009) applied population dynamic models to identify the optimal conservation area in terms of fishery benefits. They found that conservation areas need to comprise around 70% to 80% of the whole fishing area to be effective. The paper suggests that the yield from fishing in an open-access regime can be increased by introducing an optimally sized protected area ranging from 5% to 97% (depending on parameter values and time horizon). However, in empirical research there are cases showing an achievement of smaller reserve sizes. For example, at Sumilon, in the Philippines, a reserve of around 0.4 km^2 has proved effective (Russ and Alcala, 2003) and at Saba, in the Caribbean, a reserve of around 0.9 km^2 has been shown to have significant effects (Roberts, 1995). Ballantine (1995) suggested, from a case study in New Zealand, that the size of no-take reserves should be 10% of total areas. These studies imply that reserve size is not the only factor to affect fish replenishment but others, such as habitat quality and restrictions on fishing efforts, also have an impact.

Better habitat quality within a reserve may significantly influence the conservation effect (Hawkins *et al.*, 2006) since habitat characteristics significantly shape the degree of biomass production. The relationship between habitat quality and fisheries is particularly strong for shoreline habitats such as mangroves and flooded forests. For example, Nagelkerken *et al.* (2002) proposed that (mangrove and seagrass) habitat degradation has a negative impact on Caribbean fish stocks (especially coral-reef fish species) because these habitats function as nursery sites for several reef-species juveniles. Similarly, with freshwater fisheries a positive relationship between fish productivity and the quality of habitat in riparian zones (the ecosystems between terrestrial and aquatic systems) is found. Riparian zones are important for aquatic ecosystems (Welcomme, 1979; Naiman and Décamps, 1997) because they (and floodplains) supply the essential energy to the food chain (Junk *et al.*, 1989) and also transfer material and nutrients to the ecosystems (Pusey and Arthington, 2003 for details).

In more recent studies, economic impacts have also been addressed (Hannesson, 1998; Sanchirico and Wilen, 2001; Smith and Wilen, 2003; Armstrong and Skonhoft, 2006). For example, Armstrong and Skonhoft (2006) introduced asymmetrical density-dependent migration between fishery reserves and adjacent areas into their bio-economic model. The model examined how four different scenarios (maximum harvest, maximum current profit, open access and maximum sustainable yield) were affected by the conservation management tool. Differences in ecological conditions inside and outside the reserves were expected due to habitat exploitation and consequent degradation. The authors suggested that the characteristics of the dispersal of the fish would impact the results. They compared the simulations under symmetrical and asymmetrical dispersal and concluded that under symmetrical dispersal the effect of conservation interventions is jeopardised and thus conservation creates negative profits and lower fish stocks.

Location of marine reserves depends more on opportunities and social criteria than on scientific research (Roberts, 2000). Roberts *et al.* (2003) argued that, ideally, the biological criteria should be a priority when selecting a reserve location. However, past examples show that socio-economic criteria have often been given a greater weight: a likely effect of political intervention. Although the socio-economic context should be included in the design and implementation of the reserves (to facilitate support and compliance with regulations (FAO, 2007)), the reserve may not have the desired effect if its biological value is low (Roberts *et al.*, 2003).

Several studies have investigated different fishery reserve sizes, patterns and habitat qualities, as mentioned above. However, few studies have focused on both the biological and socio-economic aspects of conservation design using a modelling approach. In addition, there are no published papers investigating the effects of designating fishery conservation areas under combinations of private and common property rights zones, as is practised in Tonle Sap.

7.3 THE “FISHCON” MODEL STRUCTURE

The FISHCON model is developed to investigate the spatial effects of the creation of conservation areas for fisheries. This model is developed from the FISH model by including conservation areas, with no harvesting pressure, into the model. The model shows the consequences of interactions between fishermen and fish biomass in private, common-property and conservation areas. The fish biomass varies with harvesting, fish growth and migration. The whole area (fishable and non-fishable grounds) in this model is characterized by two main attributes: quality of fish habitat and type of fishery management zone.

The detailed specification of the model structure can be found in Chapter 5, section 5.4 and Chapter 6, section 6.3. To summarise, the fishermen fish in different fishing grounds divided into 12 x 12 plots. One run of the model comprises one year split into a closed and an open season. The closed season is for the first six months when fish freely migrate everywhere and fishermen have free access to all fishing grounds except for the conservation zones (i.e., only conservation zones areas and common property fishing grounds exist in the closed season). The private fishing grounds are added when the open season begins (for the last six months of the year). The private fishermen have exclusive fishing rights in fenced-off areas. Apart from the harvesting process, which is excluded in the reserve area, most of the processes in the FISHCON model are almost identical to the FISH model. The FISHCON model also uses NetLogo (Wilensky, 1999), and the user interface is shown in Figure 7-1. The same methods of validating the FISH model described in the Chapter 6 were used for FISHCON model.

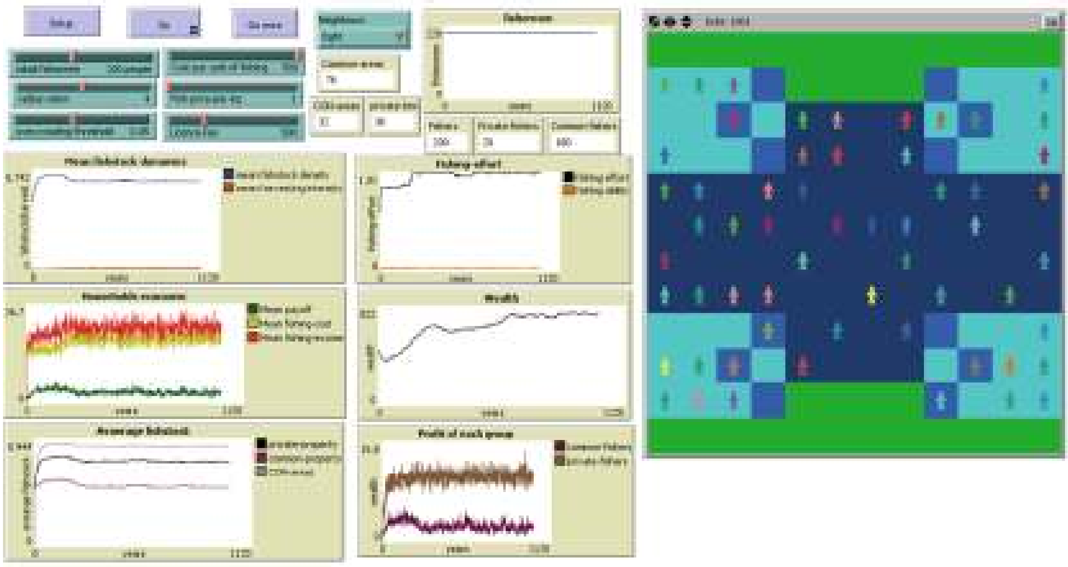


Figure 7-1 The user-model interface showing the changeable parameters, output plots and the emergence of the model at time, 1,000. Dark blue shows the common-property fishing grounds; light blue represents the common-property fishing grounds in good habitats; cyan (greenish-blue) shows the private fishing grounds; and green represents reserves.

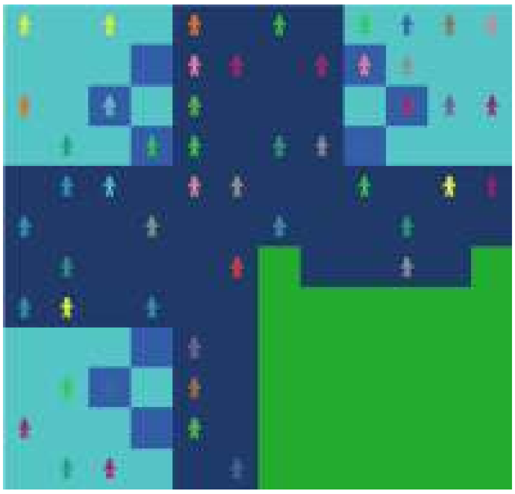
Different designs of reserves are made for the different analyses. For the analysis of reserve sizes, the reserves are designed to cover 11%, 22%, 33%, 44% and 55% of the total wetland. The maximum size is set at 55% of the total area because it seems unrealistic to have very large conservation areas for inland fisheries in developing countries with high densities of fishermen. The size of reserves depends on the number of cells that are converted from private or common areas to conservation areas. The scenarios are chosen to reflect the spatial layout in the case study and the variation in conservation sizes from other fisheries. E.g., in a study of marine reserves the conservation areas varied between 0.002 to 846 square kilometres (Halpern, 2003).

For the analysis of the spatial pattern of the reserve design, FISHCON investigates the effects of four different patterns of reserves (Figure 7-2). Two of them (*large single square* and *large single rectangular*) depict a large area of conservation reserve, whilst the other two patterns (*small fragmented cross* and *small fragmented line*) represent several small areas of conservation reserves. The *small fragmented cross* pattern represents a concentration of reserve areas in the centre of the wetland with fragmented areas coming out from the centre of the reserve. The design of the *small fragmented line* pattern represents a wetland with a large fragmented reserve area with no central reserve. Each design has the same distribution of habitat quality and similar patterns of property rights but they have reserves located in different patterns. This results in different combinations of private and common areas while the reserve area is the same (Table 7-1). This has to be taken into account when interpreting the effectiveness of the designs.

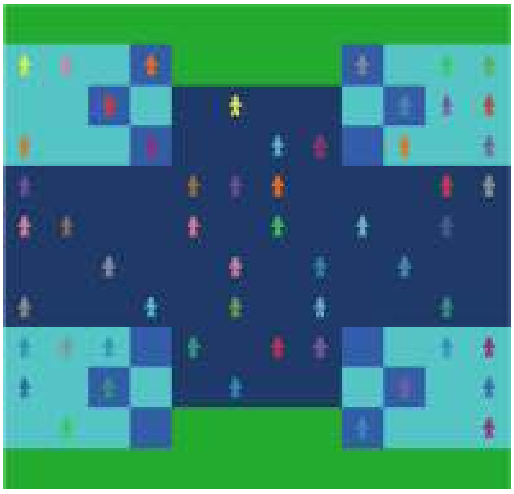
Table 7-1 The areas of reserves and private and common-property fishing grounds for the different model patterns

Patterns	Reserves (cells)	Private areas (cells)	Common areas (cells)
Large single square	32	39	73
Large single rectangular	32	36	76
Small fragmented cross	32	44	68
Small fragmented line	32	33	79

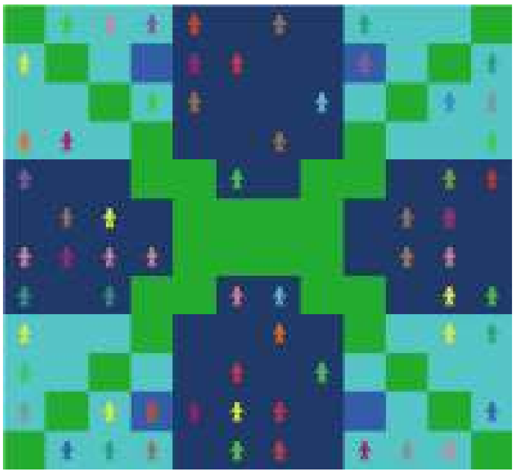
For an analysis of habitat qualities, reserves are placed in one of three qualities of habitats: baseline, mixed or good (Figure 7-3). Each design has a similar pattern of property rights and habitat quality reflecting the situation in Tonle Sap. The designs have the same area of reserve in different locations (Table 7-2). The number of patches of private and common ownership varies between the designs. The quality of habitats is measured by the reproduction rate of the fish biomass. The three scenarios have the same distribution of habitat qualities as is found in Tonle Sap, but the location of the conservation areas varies. For the baseline-habitat scenario, the reserve is located in normal habitats. For the mixed-habitat scenario, half of the reserve area is positioned in good habitats while the other half is located in normal habitats. And for the good-habitat scenario, all of the reserve is placed in good habitats.



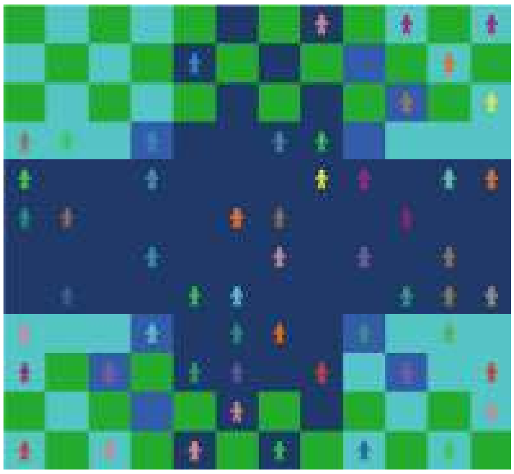
Large single square



Large single rectangular[17]



Small fragmented cross



Small fragmented line

Figure 7-2 Four different patterns of reserves. Dark blue shows common-property fishing grounds; light blue represents the common-property fishing grounds in good habitats; cyan (greenish-blue) shows the private fishing grounds; and green represents reserves.

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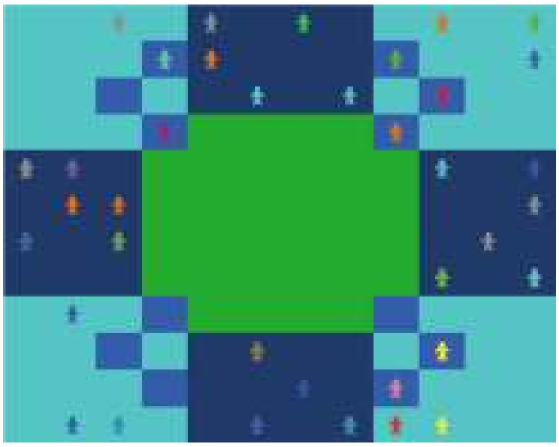
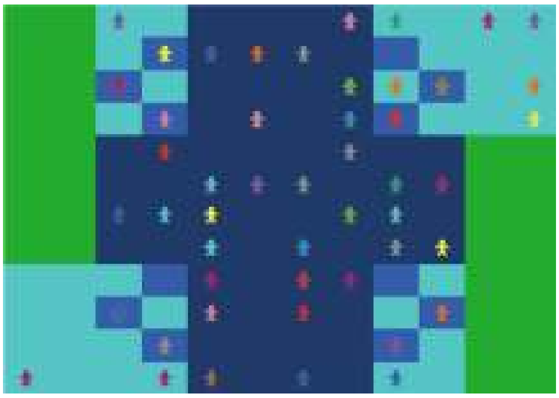
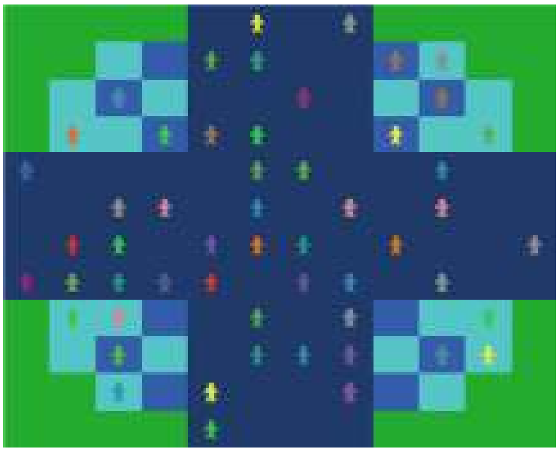
[17] The green areas (above and below) are specified as a continuous area in the model.



Baseline-habitat scenario



Mixed-habitat scenario



Good-habitat scenario

Figure 7-3 Three different allocation scenarios of reserves. Dark blue shows common-property fishing grounds; light blue represents the common-property fishing grounds in good habitats; cyan (greenish-blue) shows the private fishing grounds; and green represents reserves.

Table 7-2 The number of cells for reserves, private and common-property fishing grounds in different scenarios

Scenarios	Reserves (cells)	Private areas (cells)	Common areas (cells)
Baseline habitat	32	52	60
Mixed habitat	32	36	76
Good habitat	32	20	92

7.4 RESULTS

The FISHCON model demonstrates the interactions between harvesting intensity and the dynamics of fish biomass for 1,000 years. This is used to evaluate the effects of reserve design on the fishery. Reserve design is described in terms of reserve sizes, patterns and habitat qualities. The results are reported as the mean (as there was very little variation between runs) of one hundred repetitions for each parameter value. The average values of the variables of interests, e.g., profits and fish biomass, are compared and analysed. The default values of the model parameters are set at 200 fishermen, cost of fishing licence equal to 500 and radius of vision at four neighbouring cells.

7.4.1 Reserve size

The model investigates the effects of five different reserve sizes. The results show that the larger sizes of reserve lead to higher fish biomass, as shown in Figure 7-4. The trends of fish biomass increase in the beginning and then slightly decrease over time regardless of reserve size. The outcomes show that setting aside 55% of the total wetland as a reserve provides the highest fish biomass, followed by reserves of 44%, 33% and 22%, respectively. The lowest fish biomass results from reserve areas of 11%. The results show that the potential increase in fishing effort in the areas left out of the reserve does not eliminate the effect of the increase in fish biomass in the reserve.

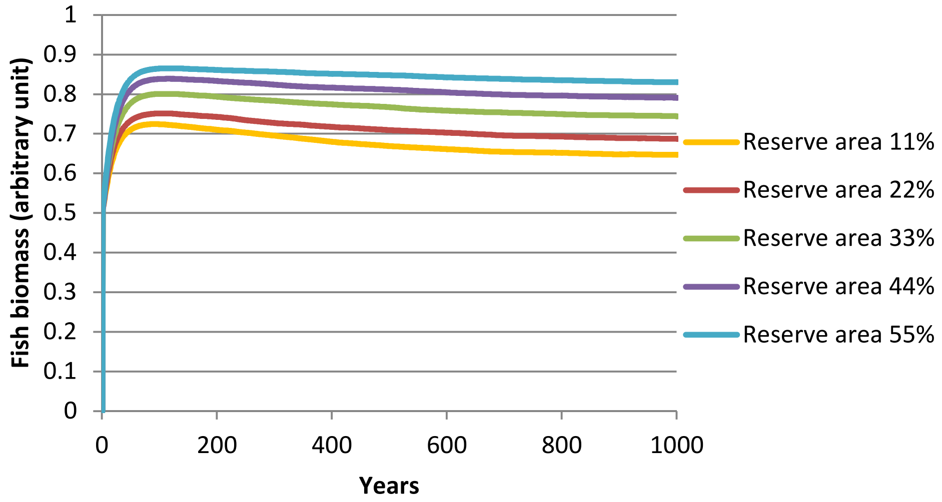


Figure 7-4 The dynamics of fish biomass for a thousand-year model run under reserve areas of 11%, 22%, 33%, 44% and 55% of the total wetland

In terms of socio-economics, overall, mean profits increase sharply for a short period at the beginning of the model run. Thereafter, profits decrease gradually throughout the simulation (Figure 7-5). Most scenarios with a larger size of conservation area result in higher profits per person.

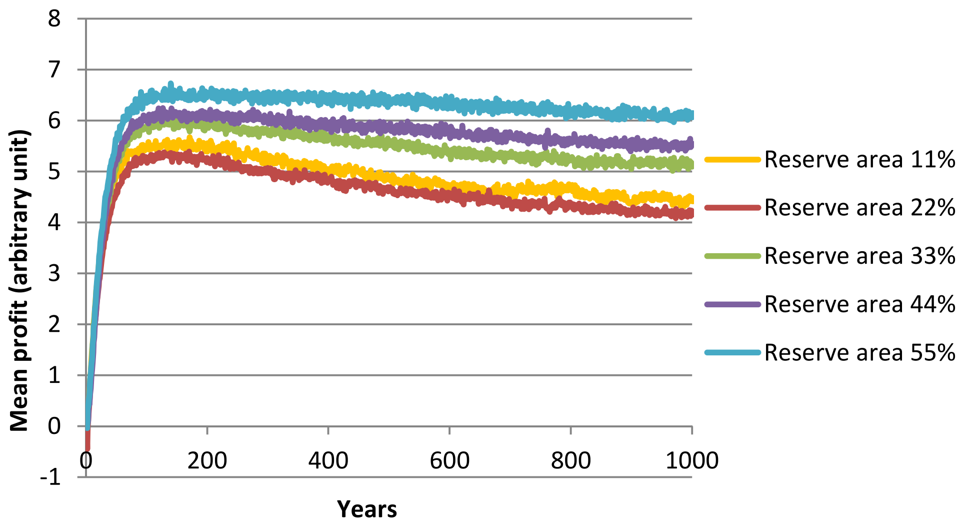


Figure 7-5 The dynamics of fishing profits per fisherman for a thousand-year model run under reserve areas of 11%, 22%, 33%, 44% and 55% of the total wetland

Figure 7-6 depicts the upward trend in the average level of fishing effort over the time period of the model. The fishing efforts are shown to be very similar regardless of the reserve size. The largest reserve area delivers the lowest level of fishing effort and it provides the highest mean profit (Figure 7-5), while the number of fishermen are the same. As the total profit of the fishing community is the aggregated profit of all fishermen, the largest reserve also provide better total community profit. This implies that catch per unit effort is higher when the larger reserve area is introduced. The smallest reserve size (11%) produces the highest mean fishing effort. However, the profit per person in this scenario is slightly higher than the 22% reserve size. In summary, larger areas of reserve contribute more to both fish stock conservation and profit creation than smaller areas. Fishermen invest lower fishing effort but earn more profit.

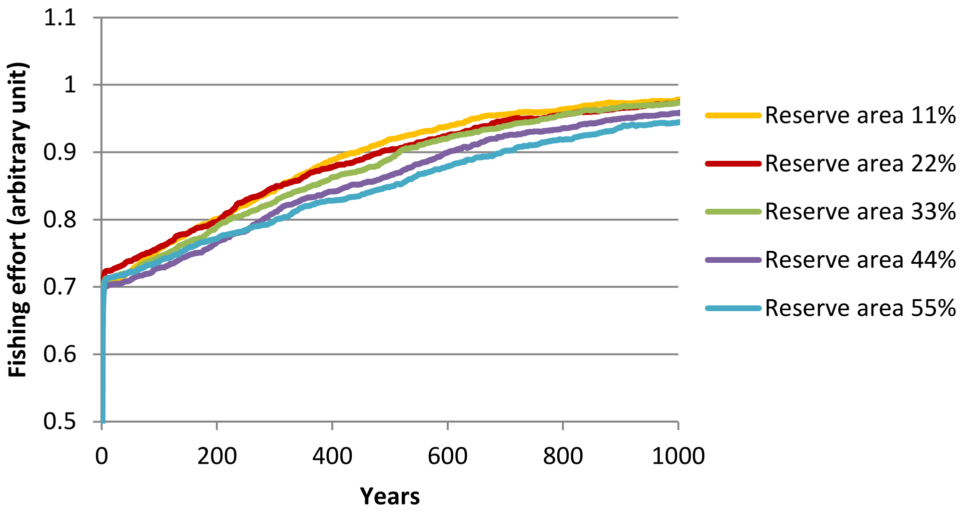


Figure 7-6 The dynamics of fishing effort values for a thousand-year model run under reserve areas of 11%, 22%, 33%, 44% and 55% of the total wetland

7.4.2 Patterns of the conservation reserves

Four different patterns of conservation reserve are simulated with the FISHCON model. Different patterns result in different fish biomass and levels of profit. The *large single square* pattern is the most successful in terms of fish biomass production, while the *large single rectangular* and *small fragmented cross* patterns are almost identical (Figure 7-7). Both the *large single square and small fragmented cross* pattern optimize the mean profit per fisherman.

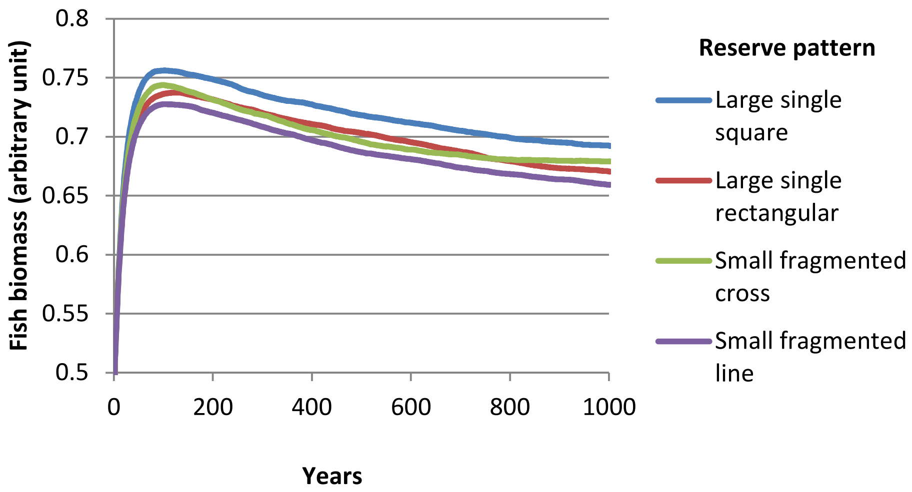


Figure 7-7 The dynamics of fish biomass for a thousand-year model run under the reserve patterns, *large single square*, *large single rectangular*, *small fragmented cross* and *small fragmented line*

The mean profit per fisherman is influenced by reserve pattern (Figure 7-8). For all patterns, the mean profit increases initially before decreasing (at varying rates). At the end of the model run, the greatest profits result from the *small fragmented cross* pattern and the *large single square* pattern. These two patterns have more of the reserve area adjacent to the common-property fishing grounds than do the other patterns and therefore benefit fishermen fishing on the common property. This increases the overall profit of the fishing community since private fishermen already have access to more fish (greater biomass) and so it is more effective to increase the biomass in the common-property area. In addition, these two patterns have the highest population of fishermen on private property, which contributes to higher overall profit per person.

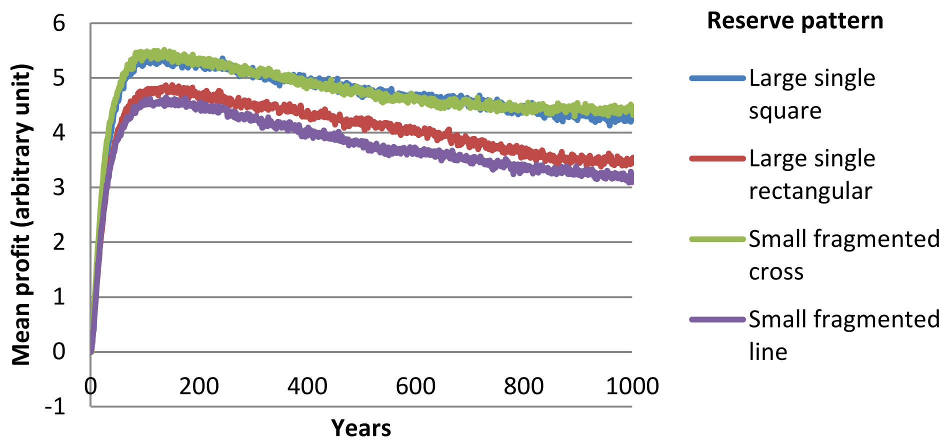


Figure 7-8 The dynamics of profit per fisherman for a thousand-year model run under the reserve patterns *large single square*, *large single rectangular*, *small fragmented cross* and *small fragmented line*

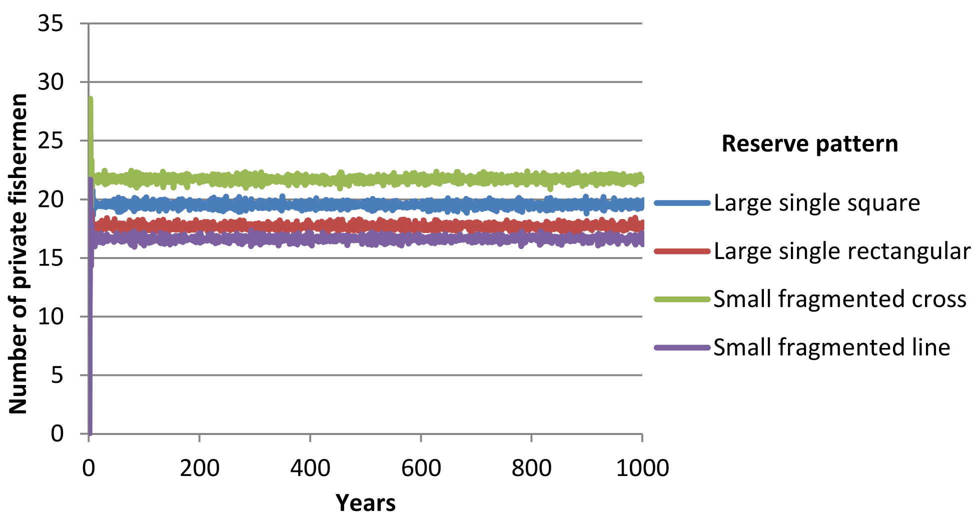


Figure 7-9 The dynamics of the number of private fishermen or the fishermen who purchase a fishing licence for a thousand-year model run under the reserve patterns, *large single square*, *large single rectangular*, *small fragmented cross* and *small fragmented line*

The number of fishermen who purchase a fishing licence in order to fish in the private fishing areas is also dependent on the pattern of reserve (Figure 7-9). The number of private fishermen is in the range of 16 to 23 (around 50% of licences were purchased). Fishermen buy the fishing licence less under the *small fragmented line* reserve pattern than with other patterns, whereas the *small fragmented cross* pattern provides the highest number of private fishermen.

Similar results are found for fishing effort (Figure 7-10). The *small fragmented cross* pattern gives the highest level of fishing effort, followed by the *large single square* pattern. These patterns are almost identical. The highest number of fishermen per common-property patch (around 2.6) results from the *small fragmented cross* pattern, while there are approximately 2.3–2.4 fishermen per common-property patch from other patterns.

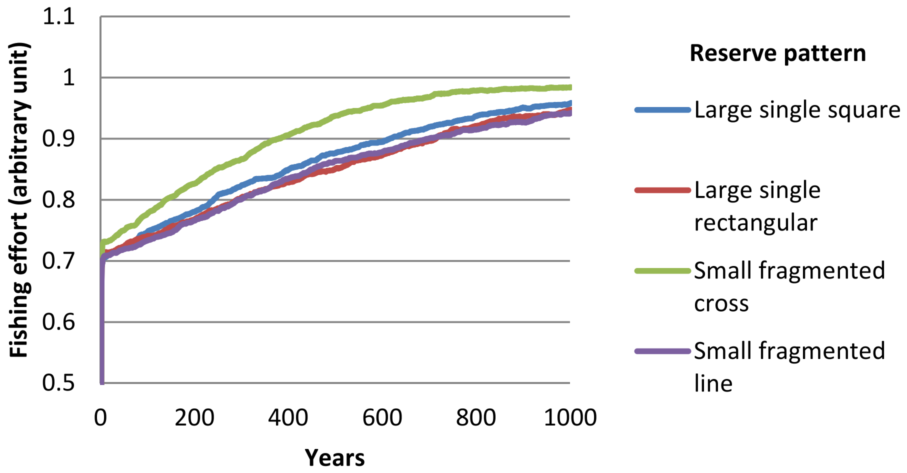


Figure 7-10 The dynamics of fishing effort values for a thousand-year model run under the reserve patterns, *large single square*, *large single rectangular*, *small fragmented cross* and *small fragmented line*

7.4.3 Location of conservation reserves

Using the FISHCON model, this section analyses the effects of habitat in combination with the spatial pattern of reserves on fish biomass production and fishermen's profits. The mean value of the parameters from hundred repetitions is calculated to synthesize the results.

Considering only fish biomass within the reserve areas (Figure 7-11), the results clearly show, unsurprisingly, that reserves in good habitats provide higher fish biomass than others. This implies that there is a higher spillover effect into fishing grounds from reserves with good habitats.

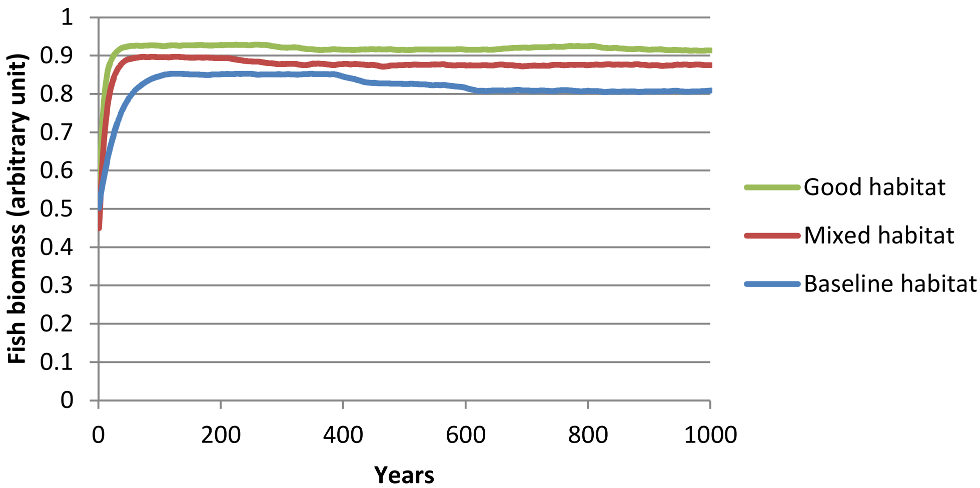


Figure 7-11 The dynamics of fish biomass in conservation reserves for a thousand-year model run under the reserve habitat qualities, baseline, mixed and good

However, in terms of reserve management, locating the reserves in good habitats provides lower fish biomass (Figure 7-12). The highest mean fish biomass results from locating the reserve in the baseline habitat. It is noted that the habitat analysis provides different spatial distributions of fish biomass to that of the reserve pattern analysis although the habitat qualities of the reserves cover the same amount of area. Different combinations for each scenario were given for the three different zones, as shown in Table 7-2. The baseline habitat scenario consists of the highest number of private fishing grounds (52 cells) but the good habitat scenario consists of only 20 private fishing grounds. As the unsold private fishing grounds have a similar function as the reserves, the private patches in the baseline scenario help to increase the amount of fish biomass. In addition, the biomass level in sold private fishing grounds also produces higher fish biomass than common-property fishing grounds. In contrast, the high common-property fishing area (92 cells) in the good habitat scenario also results in the highest number of common-property fishermen fishing under open-access conditions (leading to lower fish biomass). Even though the productivity of the fish stocks is higher in the good-habitat reserve, the allocation of reserves between the fishing zones in the good-habitat reserve results in a lower level of fish biomass.

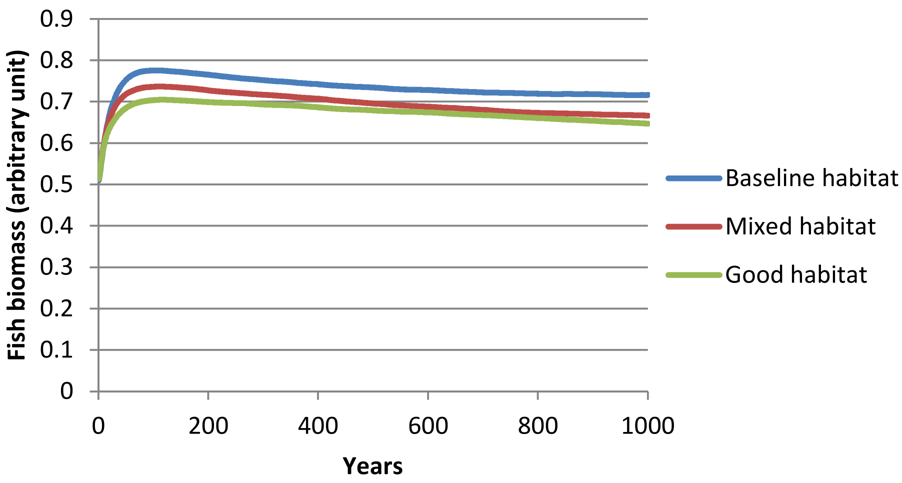


Figure 7-12 The dynamics of fish biomass for a thousand-year model run under the reserve habitat scenarios, baseline, mixed and good

There are significant differences between the profits from the three different habitat scenarios (Figure 7-13). The baseline habitat generates the highest socio-economic benefit to the fishing community. The profit from baseline-habitat scenario is almost triple the profit from the good-habitat scenario. In addition, there are a higher number of private fishermen in the baseline-habitat simulations (Figure 7-14) than in the good-habitat scenarios, where fewer fishermen purchase fishing licences due to their lack of availability.

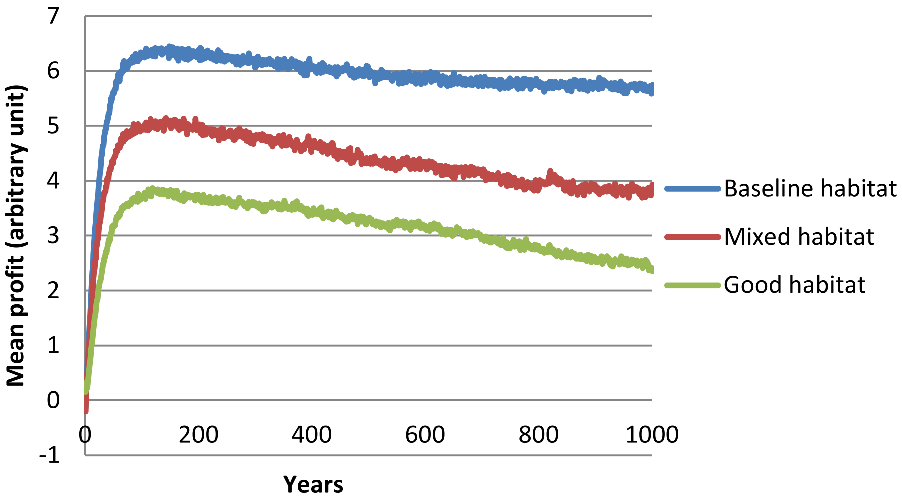


Figure 7-13 The dynamics of profit for a thousand-year model run under the reserve habitat qualities, baseline, mixed and good

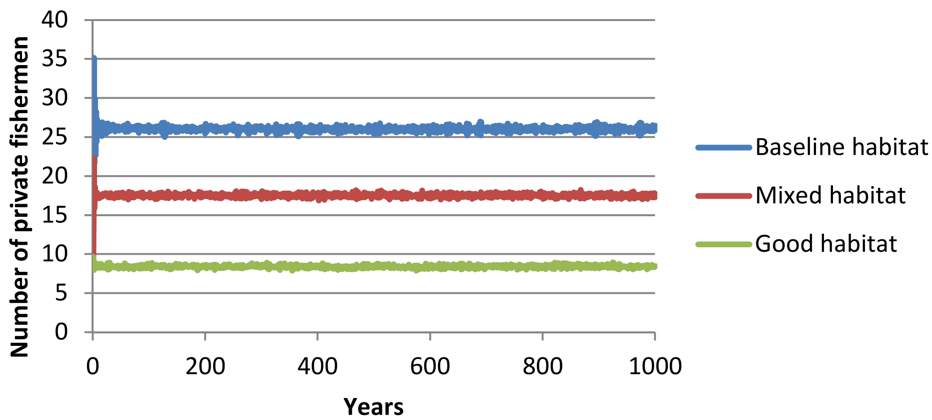


Figure 7-14 The dynamics of licence holders for a thousand-year model run under the reserve habitat qualities, baseline, mixed and good

7.5 DISCUSSION AND CONCLUSIONS

This chapter uses ABM to investigate the effects of various aspects of conservation reserves (size, pattern and habitat quality) on biological and socio-economic indicators in a wetland fishery. Fish biomass and fishermen's profits are used as indicators of biological and socio-economic sustainability of the fishery, respectively. The model captures variations in the size of private, common-property and reserve areas. The results illustrate the effects from a conservation management perspective as well as partially in terms of privatisation of fishing rights. The main finding is that bigger reserve sizes, in a pattern of one solid block and located in a habitat of baseline quality, are favoured when considering both biological sustainability and the private profits of fishermen. However, a fragmented reserve pattern is as favourable as a one-block pattern if only the private profits of fishermen are considered. In the model, the fishing capacity (i.e., the number of fishermen) is assumed to be fixed. This means that long-term adjustments in the numbers of fishermen in response to the productivity of the resource are not taken into account.

7.5.1 Implications for conservation biology

The findings of this chapter are relevant to the debates in conservation biology relating to the size, pattern, and type of habitat of conservation reserves. The discussions in this thesis focus on fish biomass rather than species diversity as in the single-large-or-several-small debate about reserve size. Larger reserve sizes have been argued to provide higher fish biomass in the long term because the bigger size reduces mortality pressure within the conservation areas (Halpern, 2003) and the spillover benefits fishable areas as well (Russ and Alcala, 1996).

In this chapter, trends in patterns of reserve area do not display large differences in fish biomass between patterns. However, the large one-block pattern seems to be the most desirable design as it produces the greatest fish biomass.

Variations in qualities of habitat sites produce different effects on fish biology. The model outcomes show that good habitats produce the most fish biomass in the reserve area compared to other habitats. This explanation is in accordance with Polunin and Roberts (1993) and Hawkins *et al.* (2006). However, considering the overall area (common-property, private and conservation zones together), locating reserves in good habitats does not necessarily provide the highest mean fish biomass to the fishery system as a whole. In this case, the baseline-habitat scenario produces more fish biomass. This can be understood by a joint interpretation of the habitat effect and the effect of the private-property-right allocation. Higher numbers of licences are sold in the baseline-habitat scenario, which leads to lower harvesting intensity competing in small common-property areas and higher mean profit per fisherman. Secondly, the combined effects of conservation and unsold private fishing grounds have a similar spillover effect as conservation. The good-habitat scenario comprises only 20 private fishing grounds, while the baseline-habitat scenario has 52 private fishing grounds. If half of the private licences have not been purchased for both scenarios, the baseline scenario would have a larger area (approximately 58 cells) that do not have harvesting pressure.

7.5.2 Socio-economic implications of conservation

This section focuses on the setting up of reserves in terms of profit for the fishing community. This socio-economic indicator is important when considering reserve allocation as it is often set as a priority when reserves are established due to the comparatively high management costs associated with the presence a reserve compared to the potential economic benefits of conservation (Soulé and Simberloff, 1986).

The findings show that larger reserve sizes not only produce more fish biomass but also higher profit. These results are supported by other research (Russ and Alcala, 1996a; Wantiez *et al.*, 1997) suggesting significant spillover effects of conservation. It seems that the loss of fishable areas from the establishment of larger reserves does not impact the profit of fishermen. This finding is in contrast with the discussions of Batista *et al.* (2011) stating that profits decrease after the creation of MPAs because of the loss of fishing areas. They argue that the loss in area results in high harvesting pressure on the smaller remaining fishable area and decreases in captures per vessel because the spillover effects from the reserve are not large enough to reverse this tendency. However, the findings in this chapter show that there is an overall higher level of fish biomass in the fishable areas of the fishery when larger reserves are implemented. This results from the migration of fish from reserves to fishing grounds and leads to higher catch per unit effort and, in turn, higher fishing profits.

The best reserve patterns in terms of profit are the ones where the reserve areas lie in close proximity to the common-property areas, i.e., the spillover effects of the *large single square* and *small fragmented cross* reserves are greater and are more quickly realised in common-property fishing areas than elsewhere. The majority of the fishermen fish in common-property areas so these patterns will give more fishing benefits to the most fishermen. In terms of habitat quality of reserves, the results reveal that it is more favourable to locate a reserve in a baseline habitat because it increases the biomass in the common-property fishing grounds (by reducing overexploitation, which is common in most common-property fishing grounds). Secondly, when a reserve is set in a less productive area, fishermen will not be losing their productive fishing grounds. Furthermore, if more private licences are available, more fishermen may end up being private fishermen (with higher profits), and the fishing intensity in the common-property areas will be reduced.

To summarise, setting aside areas of conservation can potentially be used as a management tool to meet a goal of fishery sustainability in terms of both biology and socio-economics. The designs and decisions on the creation of a reserve depend on which of the biology or socio-economic aspects are a priority. For small-scale fishery communities who are usually not well-off, socio-economic success and improvement of the livelihoods of small-scale fishermen will often be a priority. However, this should be carried out in conjunction with consideration for biological criteria in order to avoid collapse of fish populations. These findings are similar to other studies (e.g., Soulé and Simberloff, 1986; Roberts, 2000) indicating that the social, political, and economic criteria should be prioritised before the biological criteria when the reserve location needs to be decided. The results of this chapter suggest that reserves can be designed to improve both socio-economic and biological indicators. Choosing the favourable design in terms of socio-economic output is not detrimental to the sustainability of fish stocks.

7.5.3 Agent-based modelling applications for fishery conservation

This is the first research using ABM to study the effects of conservation under the designation of three different management zones; private, common-property and conservation. Some studies on fishery conservation issues do use simulation tools, e.g., Armstrong and Skonhoft (2006) and Hannesson (1998). However, using ABM to investigate the effects of the various designs of conservation areas is a new contribution to the literature on fishery conservation. The agent-based model allows policy makers to use spatial and dynamic information to test the impact of alternative management strategies. This enables analysis of far more realistic and complicated systems in spatial fishery management that cannot be analysed using traditional bio-economic models due to the complex and heterogeneous agents involved. The prediction of fishery dynamics under different what-if conditions provides information for policy makers to develop conservation plans. However, the agent-based model necessarily simplifies the complexities of fishery systems. When complex fisheries are simplified, alternative zoning arrangements can be tested against the objectives of the conservation plans. Simple models, with easily changeable assumptions and scenarios, can be a useful tool for decision-making. Agent-based models have been used in decision-making processes to ease the dialog between decision-makers and other stakeholders (Boulanger and Bréchet, 2005). Further development of FISHCON can potentially be used for this purpose.

Chapter 8

CONCLUSIONS AND RECOMMENDATIONS

This chapter summarises the main findings presented in the empirical chapters (4, 6 and 7) and discusses the potential implications for fishery management. Following an overview of the key issues addressed in the thesis, the main findings related to the thesis objectives are presented. First, the implications of distributing fishing rights using auctions are discussed. Secondly, the effects of property rights and conservation efforts on fishery sustainability are examined. The chapter then summarise the empirical and methodological contributions of the research. Finally, the limitations of the approach taken in this thesis are discussed before making recommendations for future studies.

8.1 INTRODUCTION

Degradation of fish stocks and their habitats have been raised as major global problems (Hilborn *et al.*, 2003; Worm *et al.*, 2009; FAO, 2012), and this is also the case for the Tonle Sap wetlands (Nuorteva *et al.*, 2010). Fishery management tools have not been successful in ensuring fishery sustainability. This is particularly the case for inland tropical fisheries where enforcement of rules is often limited. This thesis aims to improve our understanding of the management of small-scale tropical fisheries in developing countries using the Tonle Sap fisheries in Cambodia as a case study. This wetland provides a case to study the use of zonal management to regulate access to fishing grounds. To improve fishery management, past failures need to be understood, and the analysis of the effects of different potential designs of fishery management can provide an important input for development of new policies. The thesis used a combination of choice modelling and agent-based modelling. Choice modelling, based on choice experiment data, has been used to model fishermen behaviour in a hypothetical auction market. An agent-based model is employed to assess the complexity of fishery dynamics including the spatio-temporal interactions among fishermen, dynamic fish biomass, and fishery regulations. Different policy scenarios have been simulated from micro level activities (i.e., individual fishing) but the model outcomes are presented at the macro level (i.e., dynamics of biomass and profit for the fishing community).

The results of the choice experiment analysis identified different socio-demographic groups of fishermen according to their preferences. The results also enable a specification of the relative importance of individual characteristics of the fishing lots. The fishermen behaviours can be characterised dividing the fishermen into two distinct groups, revealing a different behaviour in the hypothetical market. The results also reveal a possible connection between property rights and conservation behaviours, as fishermen associate higher values to private fishing grounds under conservation management restrictions. Secondly, the thesis investigates the property rights system in Tonle Sap in a spatial context. Finally, the thesis studies the use of conservation areas as a tool for managing fisheries, by modelling the spillover effects on the fisheries from conservation areas. The spatial analyses using agent-based models depict the consequences of the spatial interactions of three main components in fishery (fishery regulations, fishermen and fish biology). The simulations uncover the potential for using property rights and conservation as fishery management tools to enhance fishing profitability and ensure sustainability. The model shows a positive effect from using both property rights allocation and conservation.

8.2 SYNOPSES OF THESIS FINDINGS

8.2.1 The implications of the distribution of fishing rights

To evaluate the auction-based system, the thesis investigates how fishery management systems affect different groups of small-scale fishermen and how different characteristics of fishing lots affect their bidding behaviour. A choice experiment approach is used to model fishermen's choices in a hypothetical auction market by offering fishermen the choice between purchasing different potential fishing lots and a no purchase option, implying fishing only in the public fishing grounds. Small-scale fishermen are shown to be willing to bid for exclusive fishing rights in the Tonle Sap wetlands rather than choosing to fish only in the open access fishing grounds. In particular, flexible finance schemes (or micro finance operation) are shown to increase the likelihood of participation in potential future auctions.

The thesis finds that fishermen have heterogeneous preferences for fishing lot characteristics and the fishing community consists of two segments, as the best model is a 2-segment latent class model. One segment expressed consistently higher willingness to pay for fishing privileges through ownership of private lots. This implies that the other segment of the small-scale fishing community is unlikely to gain access to private fishing grounds under an auction system. The results reveal preferences for contracts with longer leasing periods. This is interpreted as an interest in securing longer term fishing rights to avoid the uncertainty of future auction outcomes. This is an encouraging finding as this indicates that it may be possible to encourage fishermen to consider long-term profits as opposed to short-term resource exploitation.

8.2.2 Spatial dynamics of fishing intensity and fish stocks: A combination of private property and common property rights

With regards to linking conservation and private property rights indicated from choice experiment estimates, the second part of this thesis examines the spatial effects of different combinations of different resource extraction rights. In doing this, Agent-based modelling is used to identify the effects of property rights, i.e. the consequences of the various combinations of private and common areas, on fishery productivity and sustainability. The agent-based modelling is also used to analyse what parameters influence the performance under different property rights. The behaviour of the systems is modelled at the micro level by investigating the spatial interactions between heterogeneous fishermen, the dynamics of harvesting intensity and this fish stock response at each location. The outcomes however are presented at macro level in terms of overall fish biomass and socio-economics of the small-scale fishing community.

The results of the agent-based modelling confirm that allocating private property rights will generate resource rents and conserve fish (Sinclair *et al.*, 2002; Grafton *et al.*, 2006). However, it is often not possible to assign private ownership to a whole fishing area because of the imbalance between resource availability and the population of fishermen. In addition, if all fishing grounds are converted to private areas, the lack of fish migration may have serious impacts on fish biology. A combination of private and common areas in a fishing season might provide a more sustainable solution. The results show that those designs where common areas dominate provide greater benefits to the fishing community as a whole. This result may be influenced by a number of factors, particularly by the number of fishermen. For instance, when fishermen population is high (which reflects the real situation in many developing countries), and fishing grounds are dominated by private areas, there will be more competition over a smaller common area. This has a negative impact on the majority of the fishermen. Overall, a management system where private property rights dominate does not offer better conditions for fish conservation or socio-economic benefits to the community as a whole.

8.2.3 Spatial effects of conservation in fishery dynamics

The third part of this thesis investigates the consequences of different designs of conservation zones (sizes, patterns and locations). This complements the findings from choice experiment analysis showed that some small-scale fishermen are willing to participate in conservation management. Conservation areas are used as a fishery management tool in Tonle Sap wetlands, where fishing grounds have been divided into private, common and reserve areas. Effective conservation can potentially result in higher fish productivity (Roberts, 1995; Rodwell *et al.*, 2002) and can also offer a buffer zone against increases in fishing-efforts (Botsford *et al.*, 2003) and habitat degradation. An agent-based model is used to simulate the interactions between fishermen and fish biomass in the zonal management systems in which different regulations are assigned to each zone.

The results show that conservation areas contribute to fishery sustainability and a higher level of socio-economic performance for the fishing communities. The types and amounts of benefits vary and are determined by the design of conservation areas. Conserving a large proportion of the wetland, in large individual areas, located in the least productive areas provide the best improvement for fishery sustainability. However, conservation will not be successful if implemented without other management tools (Roberts *et al.*, 2005); for example, fishing effort also needs to be controlled at an appropriate level.

8.3 CONTRIBUTIONS

This thesis represents the first time that both choice experiments and agent-based models have been used to analyse the dynamics of small-scale fisheries in Tonle Sap Lake. In addition, this thesis contributes to the knowledge of inland fishery management, which have received less attention compared to marine fisheries. The contributions of the thesis can be split into empirical and methodological contributions.

8.3.1 Empirical contributions

The findings improve our understanding of the dynamics of complex fisheries such as those in Tonle Sap wetlands. The empirical results contribute to debates on alternative approaches to inland fishery management, in particular property rights based approaches and approaches based on zonal management.

8.3.1.1 Institutional and policy recommendations

First, understanding sources of heterogeneity when selecting which types of fishing grounds to put on auction, can assist fishery managers in regulating fishing. For example, offering a variety of fishing lots' characteristics can provide more opportunities in the auction market for small-scale fishing households. This is important for reducing the problem of unequal access to valuable fishing grounds among different groups of fishermen. Other methods might need to be considered apart from an auction-based system in order to better allocate exclusive fishing licences such as rotation or other administrative methods. This is because the poorest group of small-scale fishermen are not able to compete with richer fishermen using only an auction-based method. This is also supported by other research (Beck and Nesmith, 2001; Meinzen-Dick and Mwangi, 2008; Working Group on Property Rights, 2008) stating the difficulty of poorer groups in accessing resources.

Second, a property rights approach can be used as a part of a wider fishery management scheme, but the management plans for small-scale or subsistence fisheries needs to be considered separately from the commercial fisheries. For example, the price of the exclusive fishing licences should be set based on socio-economic characteristics of small-scale households such as households' incomes. In addition, sizes of private fishing grounds also need to be set appropriately, to match the fishing gear of small-scale fishermen.

Third, the effects of conservation areas may benefit the overall fishery system, however it may not achieve the goal of fishery sustainability if other management restrictions are not in place (Hannesson, 1998) and enforced (Hilborn *et al.*, 2004). Similarly, property rights can also be used to improve sustainable fisheries but fishing regulations such as gear restrictions and effective monitoring are also needed (Grafton *et al.*, 2006).

Fourth, the fishing areas that are predominantly common property are very important for fishery sustainability in terms of fish biomass and socio-economic outcomes. Although private property rights offer more fish and socio-economic benefits for the licence holders, this might not apply to the fishing society overall, when there is a high population of poor fishermen. So, the designs or combinations of commons and private areas should be considered along with the fishermen population in order to improve fishery sustainability. When the common fishing grounds are too small, these areas can get overexploited. The simulation results provide a guideline which suggests how conservation can be designed to support fishery sustainability. However decisions on the reserve locations also need to consider other information such as species biodiversity and investment and maintaining costs.

Fifth, a comparision of the effects of long- versus short-periods of property rights allocation is not included in the analysis. In this study, private rights are assigned as short-term contracts. Nevertheless, the ABM results show a potential for private property rights allocation to contribute to maintain fish biomass. This contrasts with Yandle (2007) who states that the security of long-term property rights is important for developing biologically and socially sustainable resource management. In addition, the choice experiment outcome shows the preference for long-term property rights. However, other factors might influence fishery sustainability more than the lengths of ownership period, such as the spatial distributions of fishing efforts.

Sixth, fish conservation zones will perform better when the reserves are large, and located in good habitat quality. The superiority of large reserves is consistent with other studies, for example, Le Quesne and Codling (2009) and Hannesson (1998) indicating higher achievement of conservation from large reserve areas. The good quality habitats provide a high level of fish biomass (Polunin and Roberts, 1993). Nevertheless creation of freshwater protected areas are often established when an opportunity emerges and based on social criteria rather than biological scientific research (Roberts, 2000). The model result suggests that this might be wise as the reserves which are located in the least productive habitats generate a higher benefit for the community in terms of socio-economic and biological sustainability. This is both because of the higher spillover effect but also because this leaves more areas as private property when the spatial distribution of habitats is as in Tonle Sap. In conclusion, it is not the valuable habitat that should be reserved to promote productivity. Collectively the fishery is better off with higher spill-overs from productive reserves and a larger fraction of fishermen with licenses, as this controls effort.

8.3.1.2 Additional supports for small-scale fisheries

The results show that small-scale fishermen are interested in bidding for fishing lots; however, finance is still a constraint for the poorest small-scale fishermen. This finding is supported by other studies (e.g., Beck and Nesmith, 2001; Meinzen-Dick and Mwangi, 2008; Working Group on Property Rights, 2008) showing that poorer groups in a community have more difficulty in accessing and exercising property rights.

Different financial supports might be needed in order to enhance the interest in auction participation for small-scale fishermen. As such accessing a credit market and increasing levels of education might help the poorer group to participate in auctions. This is because auctioning of fishing lots requires capital to invest in the exclusive fishing licenses and maintenance for lot operation, as well as literacy to deal with formal government documents.

8.3.2 Methodological contributions

This research offers a new application of, and a new set of approaches to fishery management, in the contexts of small-scale inland fisheries in developing countries. It contributes to the understanding of property rights regimes and conservation in complex fishery system by exploring choice modelling and spatial simulations. The choice experiments and agent-based modelling enhance the understanding of harvesting pressures and dynamics of fisheries overall. The combination of the techniques provides an in-depth analysis of fishermen behaviours in auction markets and the spatial dynamics of fisheries.

The thesis enhances the limited literature on the application of choice experiments approach in the context of wetlands in developing world. There are challenges in using a choice experiment approach in a developing country context (Bennett and Birol, 2010) as respondents are unfamiliar with filling out questionnaires due to, among other factors, limited education. To date, very few papers have applied choice experiments for wetlands valuation in developing countries (e.g., Do and Bennett, 2009), and for valuation of fisheries and watersheds in the context of a developing country (Agimass and Mekonnen, 2011). So far, no publication has yet, to the authors' knowledge, applied choice modelling to simulate behaviour in auction markets. This thesis therefore enriches the literature on choice experiment applications in fishery management in the developing world.

The thesis provides a new application to assessment of the zonal designations integrating property rights and conservations. It is the first time an agent-based model has been used to simulate the effects of property rights and conservation for small-scale fisheries. Qualitative methods have been widely used to study property rights in fishery contexts (Toufique, 1997; Basurto, 2005; Ahmed *et al.*, 2008). These methods can be suitable for evaluation of existing system of property rights but may not be appropriate to assess alternative designs of fisheries management. Other studies have investigated the effects of establishment of the protected areas in freshwater fisheries using different methods. These have been based both on field studies of existing protected areas (e.g., Cucherousset *et al.*, 2007; Sarkar *et al.*, 2008) and on identifying optimal locations in terms of species conservation objectives (e.g., Roux *et al.*, 2008; Nel *et al.*, 2009). Simulation approaches are not new to the study of fishery conservation, e.g., Armstrong and Skonhoft (2006) and Hannesson (1998). However, ABM offers a different perspective on the analysis of property rights issue by using a spatial context. A novel contribution of this research is the use of ABM to study the effects of conservation in small-scale fisheries under different allocations of property rights.

8.4 RECOMMENDATIONS FOR FURTHER RESEARCH

This section discusses the potential for further developing the research reported in this thesis. Therefore the discussion departs from the shortcomings of the approach taken in this thesis.

First, commercial fisheries have been operating as a part of the Tonle Sap fisheries, but they are not included in this study. This is because the focus in this work has been on small-scale fishermen as the majority group in Tonle Sap. However, including large-scale fishing operations in the research would add more realism and complexity to the models. For a more accurate assessment of potential regulations, this would be an important aspect to include in further studies. Such a model will provide a more complete picture of the Tonle Sap fisheries. This would allow a comparison of bidding behaviours between the large-scale fishermen who have participated in auctions in the past and small-scale fishermen who have traditionally not participated in auctions. Such an analysis can potentially reveal further segmentation of resource users which also need to be considered in the design of a future auction-based system. For ABM, other groups of lot owners could be included as other types of agents. Other features in the zonal management, such as different sizes of private areas, could also be included in the FISH and FISHCON models. Second, as the ABMs are very flexible they can be extended by modifying the model code for other purposes. Future studies can include other activities in Tonle Sap to analysis the overall ecosystem services of Tonle Sap wetlands such as agriculture, energy exploration and recreational activities. Furthermore, the geographical features can be enhanced by integrating GIS information (e.g., land used data) into the model (e.g., Robinson and Brown, 2009).

Third, the number of fishermen for each simulation was assumed to be fixed in the ABMs. This does not allow for any new fishermen to enter or for unsuccessful fishermen to leave the fishing sector. However, providing flexibility in entering or leaving the fishing sector can be included in future work in order to investigate the development of the fishing communities. Relaxing this assumption will allow the fishermen who does not make profit anymore to leave the fisheries, and the remaining fishermen will be better-off. Weninger and Just (2002) provide an example of considering entry and exist behaviours for tradable output permits analysing the evolution of the permit price (costs of owning permit rights) and market efficiency (costs of productive capital).

Fourth, the choice estimates show that the auction method might not be able to provide equal access for small-scale fishermen, due to the clustering of preferences and willingness to invest in exclusive rights. In order to suggest fairer methods for allocating fishing licences, further analyses need to evaluate various allocation methods, such as auctions, lotteries, rotation systems or some other forms of licences.

Fifth, there is no modelling of preferences for conservation in the agent-based models. Nevertheless, a more explicit integration of the behavioural choice model and the agent-based model could be developed, by including choice experiment parameters as a way of characterising agents in the agent-based modelling (e.g., Chapman *et al.*, 2009). For example, valuations of each attributes and their levels of fishing lots for different types of fishermen could be simulated in the future.

8.5 CONCLUDING REMARKS

Fisheries management is complex as it must deal with multiple users as well as biological and socio-economic uncertainties. In order to improve management systems, past management and current fishery dynamics need to be evaluated at the individual level, with policy suggestions made from the model outcomes at the society level. Combining the choice experiment approach and agent-based simulation can provide a better understanding of complex fisheries at both individual and societal level. This thesis suggests that it is possible to use property rights allocation and conservation areas combined with other fishery regulations, enforcement and monitoring systems to create effective management tools for small-scale fisheries.

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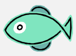
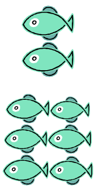
Appendix A:
SETS OF CHOICE CARDS

(There are two different sets of choice cards)

Choice set Version 1

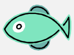
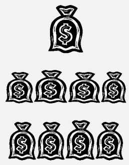
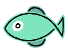
Q 2.1 Please choose ONLY ONE OPTION after considering the following three options.

Which option would you like to choose?

Attributes **Options**	**Annual fish catch** (tonnes)	**Floor prices** (USD/ year)	**A flexible payment scheme**	**Leasing periods** (years)	**Distance** (kms)	**A conservation management plan**	**My choice** (tick only ONE)
Option A			<u>Without a flexible payment scheme</u>	10	10	Include a CONSERVATION plan	
	Catch 5 tonnes of fish per year	**The minimum additional annual Payment is 1600 USD.**	**You do not have a flexible payment scheme**	**You have 10 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located 10 km from your house.**	**A conservation management plan needs to be included in the lot operation.**	
Option B			With a flexible payment scheme	10	10	No restrictions	
	Catch 45 tonnes of fish per year	**The minimum additional annual Payment is 1600 USD.**	**You have a flexible payment scheme**	**You have 10 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located 10 km from your house.**	**There are no restrictions.**	
Option C	**I do <u>NOT</u> want to bid or pay for any of these options.**						

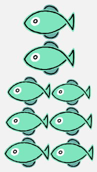
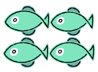
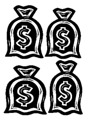
Q 2.2 Please choose <u>ONLY ONE OPTION</u> after considering the following three options.

Which option would you like to choose?

Attributes / **Options**	**Annual fish catch** (tonnes)	**Floor prices** (USD / year)	**A flexible payment scheme**	**Leasing periods** (years)	**Distance** (kms)	**A conservation management plan**	**My choice is** (tick only ONE)
Option A			With a flexible payment scheme	**10**	**≤2**	Include a **CONSERVATION** plan	
	Catch 5 tonnes of fish per year	**The minimum additional annual Payment is 3,500 USD.**	**You have flexible payment scheme**	**You have 10 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located less than or equal to 2 km from your house.**	**A conservation management plan needs to be included in the lot operation.**	
Option B			<u>Without a flexible payment scheme</u>	**2**	**10**	Include a **CONSERVATION** plan	
	Catch 5 tonnes of fish per year	**The minimum additional annual Payment is 1,600 USD.**	**You do not have a flexible payment scheme**	**You have 2 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located 10 km from your house.**	**A conservation management plan needs to be included in the lot operation.**	
Option C	**I do <u>NOT</u> want to bid or pay for any of these options.**						

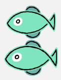
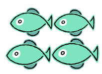
Q 2.3 Please choose <u>ONLY ONE OPTION</u> after considering the following three options.

Which option would you like to choose?

Attributes **Options**	**Annual fish catch** (tonnes)	**Floor prices** (USD/ year)	**A flexible payment scheme**	**Leasing periods** (years)	**Distance** (kms)	**A conservation management plan**	**My choice is** (tick only ONE)
Option A			**With a flexible payment scheme**	**2**	**10**	**No restrictions**	
	Catch 45 tonnes of fish per year	**The minimum additional annual Payment is 800 USD.**	**You have a flexible payment scheme**	**You have 2 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located 10 km from your house.**	**There are no restrictions.**	
Option B			**With a flexible payment scheme**	**2**	**10**	**Include a CONSERVATION plan**	
	Catch 20 tonnes of fish per year	**The minimum additional annual Payment is 1,600 USD.**	**You have a flexible payment scheme**	**You have 2 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located 10 km from your house.**	**A conservation management plan needs to be included in the lot operation.**	
Option C	**I do <u>NOT</u> want to bid or pay for any of these options.**						

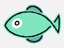
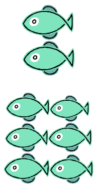
Q 2.4 Please choose <u>ONLY ONE OPTION</u> after considering the following three options.

Which option would you like to choose?

Attributes / Options	Annual fish catch (tonnes)	Floor prices (USD/year)	A flexible payment scheme	Leasing periods (years)	Distance (kms)	A conservation management plan	My choice is (tick only ONE)
Option A			With a flexible payment scheme	10	≤2	No restrictions	
	Catch 10 tonnes of fish per year	The minimum additional annual Payment is 1,600 USD.	You have a flexible payment scheme	You have 10 years guarantee for exclusive fishing rights over the lot.	The fishing lot is located less than or equal to 2 km from your house.	There are no restrictions.	
Option B			With a flexible payment scheme	10	≤2	Include a CONSERVATION plan	
	Catch 20 tonnes of fish per year	The minimum additional annual Payment is 800 USD.	You have a flexible payment scheme	You have 10 years guarantee for exclusive fishing rights over the lot.	The fishing lot is located less than or equal to 2 km from your house.	A conservation management plan needs to be included in the lot operation.	
Option C	I do <u>NOT</u> want to bid or pay for any of these options.						

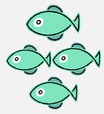
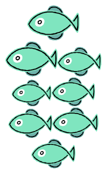
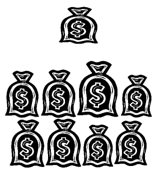
Q 2.5 Please choose ONLY ONE OPTION after considering the following three options.

Which option would you like to choose?

Attributes / **Options**	**Annual fish catch** (tonnes)	**Floor prices** (USD/ year)	**A flexible payment scheme**	**Leasing periods** (years)	**Distance** (kms)	**A conservation management plan**	**My choice is** (tick only ONE)
Option A			**With a flexible payment scheme**	**2**	**10**	**No restrictions**	
	Catch 5 tonnes of fish per year	**The minimum additiona l annual Payment is 800 USD.**	**You have a flexible payment scheme**	**You have 2 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located 10 km from your house.**	**There are no restrictions.**	
Option B			**Without a flexible payment scheme**	**10**	**10**	**No restrictions**	
	Catch 45 tonnes of fish per year	**The minimum additiona l annual Payment is 800 USD.**	**You do not have a flexible payment scheme**	**You have 10 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located 10 km from your house.**	**There are no restrictions.**	
Option C	**I do NOT want to bid or pay for any of these options.**						

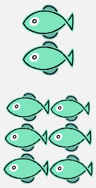
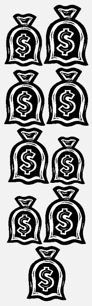
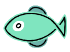
Q 2.6 Please choose ONLY ONE OPTION after considering the following three options.

Which option would you like to choose?

Attributes / **Options**	**Annual fish catch** (tonnes)	**Floor prices** (USD / year)	**A flexible payment scheme**	**Leasing periods** (years)	**Distance** (kms)	**A conservation management plan**	**My choice is** (tick only ONE)
Option A			**Without a flexible payment scheme**	**2**	**≤ 2**	**Include a CONSERVATION plan**	
	Catch 20 tonnes of fish per year	**The minimum additional annual Payment is400 USD.**	**You do not have a flexible payment scheme**	**You have 2 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located less than or equal to 2 km from your house.**	**A conservation management plan needs to be included in the lot operation.**	
Option B			**With a flexible payment scheme**	**2**	**≤ 2**	**Include a CONSERVATION plan**	
	Catch 45 tonnes of fish per year	**The minimum additional annual Payment is 3,500 USD.**	**You have a flexible payment scheme**	**You have 2 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located less than or equal to 2 km from your house.**	**A conservation management plan needs to be included in the lot operation.**	
Option C	**I do NOT want to bid or pay for any of these options.**						

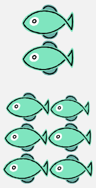
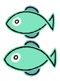
Q 2.7 Please choose ONLY ONE OPTION after considering the following three options.

Which option would you like to choose?

Attributes / **Options**	**Annual fish catch** (tonnes)	**Floor prices** (USD / year)	**A flexible payment scheme**	**Leasing periods** (years)	**Distance** (kms)	**A conservation management plan**	**My choice is** (tick only ONE)
Option A			**Without a flexible payment scheme**	**2**	**10**	Include a **CONSERVATION plan**	
	Catch 45 tonnes of fish per year	**The minimum additional annual Payment is 3,500 USD.**	**You do not have a flexible payment scheme**	**You have 2 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located 10 km from your house.**	**A conservation management plan needs to be included in the lot operation.**	
Option B			**Without a flexible payment scheme**	**10**	**≤2**	**No restrictions**	
	Catch 5 tonnes of fish per year	**The minimum additional annual Payment is 800 USD.**	**You do not have a flexible payment scheme**	**You have 10 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located less than or equal to 2 km from your house.**	**There are no restrictions.**	
Option C	**I do NOT want to bid or pay for any of these options.**						

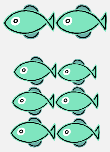
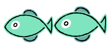
Q 2.8 Please choose <u>ONLY ONE OPTION</u> after considering the following three options.

Which option would you like to choose?

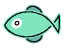
Attributes / Options	Annual fish catch (tonnes)	Floor prices (USD / year)	A flexible payment scheme	Leasing periods (years)	Distance (kms)	A conservation management plan	My choice is (tick only ONE)
Option A			**Without a flexible payment scheme**	**10**	**≤2**	**No restrictions**	
	Catch 45 tonnes of fish per year	**The minimum additional annual Payment is 1,600 USD.**	**You do not have a flexible payment scheme**	**You have 10 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located less than or equal to 2 km from your house.**	**There are no restrictions.**	
Option B			**With a flexible payment scheme**	**2**	**10**	**No restrictions**	
	Catch 10 tonnes of fish per year	**The minimum additional annual Payment is400 USD.**	**You have a flexible payment scheme**	**You have 2 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located 10 km from your house.**	**There are no restrictions.**	
Option C	**I do NOT want to bid or pay for any of these options.**						

Q 2.9 Please choose ONLY ONE OPTION after considering the following three options.

Which option would you like to choose?

Attributes / Options	Annual fish catch (tonnes)	Floor prices (USD/ year)	A flexible payment scheme	Leasing periods (years)	Distance (kms)	A conservation management plan	My choice is (tick only ONE)
Option A			With a flexible payment scheme	10	10	Include a CONSERVATION plan	
	Catch 45 tonnes of fish per year	The minimum additional annual Payment is 400 USD.	You have a flexible payment scheme	You have 10 years guarantee for exclusive fishing rights over the lot.	The fishing lot is located 10 km from your house.	A conservation management plan needs to be included in the lot operation.	
Option B			Without a flexible payment scheme	10	≤2	Include a CONSERVATION plan	
	Catch 10 tonnes of fish per year	The minimum additional annual Payment is 400 USD.	You do not have a flexible payment scheme	You have 10 years guarantee for exclusive fishing rights over the lot.	The fishing lot is located less than or equal to 2 km from your house.	A conservation management plan needs to be included in the lot operation.	
Option C	I do NOT want to bid or pay for any of these options.						

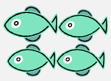
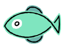
Q 2.10 Please choose <u>ONLY ONE OPTION</u> after considering the following three options. Which option would you like to choose?

Attributes **Options**	**Annual fish catch** (tonnes)	**Floor prices** (USD/ year)	**A flexible payment scheme**	**Leasing periods** (years)	**Distance** (kms)	**A conservation management plan**	**My choice is** (tick only ONE)
Option B			**<u>Without a flexible payment scheme</u>**	**2**	**≤2**	**No restrictions**	
	Catch 5 tonnes of fish per year	**The minimum additional annual Payment is 400 USD.**	**You do not have a flexible payment scheme**	**You have 2 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located less than or equal to 2 km from your house.**	**There are no restrictions.**	
Option C	**do <u>NOT</u> want to bid or pay for any of these options.**						

Choice set Version 2

Q 2.1 Please choose ONLY ONE OPTION after considering the following three options.

Which option would you like to choose?

Attributes / **Options**	**Annual fish catch** (tonnes)	**Floor prices** (USD / year)	**A flexible payment scheme**	**Leasing periods** (years)	**Distance** (kms)	**A conservation management plan**	**My choice is** (tick only ONE)
Option A			Without a flexible payment scheme	2	10	No restrictions	
	Catch 20 tonnes of fish per year	The minimum additional annual Payment is 1,600 USD.	You do not have a flexible payment scheme	You have 2 years guarantee for exclusive fishing rights over the lot.	The fishing lot is located 10 km from your house.	There are no restrictions.	
Option B			With a flexible payment scheme	10	10	Include a CONSERVATION plan	
	Catch 5 tonnes of fish per year	The minimum additional annual Payment is 400 USD.	You have a flexible payment scheme	You have 10 years guarantee for exclusive fishing rights over the lot.	The fishing lot is located 10 km from your house.	A conservation management plan needs to be included in the lot operation.	
Option C	I do NOT want to bid or pay for any of these options.						

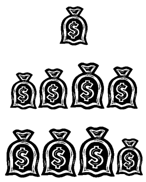
Q 2.2 Please choose ONLY ONE OPTION after considering the following three options.

Which option would you like to choose?

Attributes / Options	Annual fish catch (tonnes)	Floor prices (USD / year)	A flexible payment scheme	Leasing periods (years)	Distance (kms)	A conservation management plan	My choice is (tick only ONE)
Option A			Without a flexible payment scheme	2	≤2	No restrictions	
	Catch 10 tonnes of fish per year	The minimum additional annual Payment is 3,500 USD.	You do not have a flexible payment scheme	You have 2 years guarantee for exclusive fishing rights over the lot.	The fishing lot is located less than or equal to 2 km from your house.	There are no restrictions.	
Option B			Without a flexible payment scheme	10	≤2	Include a CONSERVATION plan	
	Catch 45 tonnes of fish per year	The minimum additional annual Payment is1,600 USD.	You do not have a flexible payment scheme	You have 10 years guarantee for exclusive fishing rights over the lot.	The fishing lot is located less than or equal to 2 km from your house.	A conservation management plan needs to be included in the lot operation.	
Option C	I do NOT want to bid or pay for any of these options.						

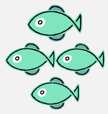
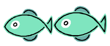
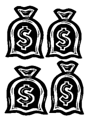
Q 2.3 Please choose <u>ONLY ONE OPTION</u> after considering the following three options.

Which option would you like to choose?

Attributes / Options	Annual fish catch (tonnes)	Floor prices (USD / year)	A flexible payment scheme	Leasing periods (years)	Distance (kms)	A conservation management plan	My choice is (tick only ONE)
Option A			With a flexible payment scheme	2	≤2	Include a CONSERVATION plan	
	Catch 10 tonnes of fish per year	The minimum additional annual Payment is400 USD.	You have a flexible payment scheme	You have 2 years guarantee for exclusive fishing rights over the lot.	The fishing lot is located less than or equal to 2 km from your house.	A conservation management plan needs to be included in the lot operation.	
Option B			With a flexible payment scheme	10	10	No restrictions	
	Catch 5 tonnes of fish per year	The minimum additional annual Payment is 3,500 USD.	You have a flexible payment scheme	You have 10 years guarantee for exclusive fishing rights over the lot.	The fishing lot is located 10 km from your house.	There are no restrictions.	
Option C	I do <u>NOT</u> want to bid or pay for any of these options.						

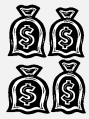
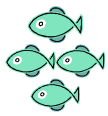
Q 2.4 Please choose ONLY ONE OPTION after considering the following three options.

Which option would you like to choose?

Attributes / Options	Annual fish catch (tonnes)	Floor prices (USD / year)	A flexible payment scheme	Leasing periods (years)	Distance (kms)	A conservation management plan	My choice is (tick only ONE)
Option A			With a flexible payment scheme	10	≤2	No restrictions	
	Catch 20 tonnes of fish per year	The minimum additional annual Payment is 800 USD.	You have a flexible payment scheme	You have 10 years guarantee for exclusive fishing rights over the lot.	The fishing lot is located less than or equal to 2 km from your house.	There are no restrictions.	
Option B			With a flexible payment scheme	10	≤2	No restrictions	
	Catch 10 tonnes of fish per year	The minimum additional annual Payment is 1,600 USD.	You have a flexible payment scheme	You have 10 years guarantee for exclusive fishing rights over the lot.	The fishing lot is located less than or equal to 2 km from your house.	There are no restrictions.	
Option C	I do NOT want to bid or pay for any of these options.						

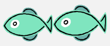
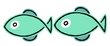
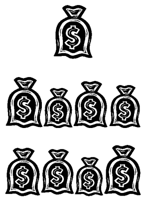
Q 2.5 Please choose <u>ONLY ONE OPTION</u> after considering the following three options.

Which option would you like to choose?

Attributes / Options	Annual fish catch (tonnes)	Floor prices (USD/year)	A flexible payment scheme	Leasing periods (years)	Distance (kms)	A conservation management plan	My choice is (tick only ONE)
Option A			<u>Without a flexible payment scheme</u>	10	10	Include a CONSERVATION plan	
	Catch 10 tonnes of fish per year	The minimum additional annual Payment is 1,600 USD.	You do not have a flexible payment scheme	You have 10 years guarantee for exclusive fishing rights over the lot.	The fishing lot is located 10 km from your house.	A conservation management plan needs to be included in the lot operation.	
Option B			With a flexible payment scheme	2	≤2	No restrictions	
	Catch 20 tonnes of fish per year	The minimum additional annual Payment is 400 USD.	You have a flexible payment scheme	You have 2 years guarantee for exclusive fishing rights over the lot.	The fishing lot is located less than or equal to 2 km from your house.	There are no restrictions.	
Option C	I do <u>NOT</u> want to bid or pay for any of these options.						

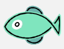
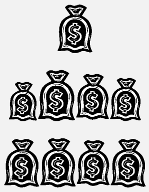
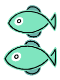
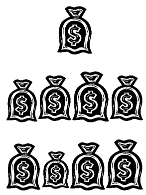
Q 2.6 Please choose <u>ONLY ONE OPTION</u> after considering the following three options.

Which option would you like to choose?

Attributes / **Options**	**Annual fish catch** (tonnes)	**Floor prices** (USD/year)	**A flexible payment scheme**	**Leasing periods** (years)	**Distance** (kms)	**A conservation management plan**	**My choice is** (tick only ONE)
Option A			**<u>Without a flexible payment scheme</u>**	**10**	**10**	**No restrictions**	
	Catch 10 tonnes of fish per year	**The minimum additional annual Payment is400 USD.**	**You do not have a flexible payment scheme**	**You have 10 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located 10 km from your house.**	**There are no restrictions.**	
Option B			**<u>Without a flexible payment scheme</u>**	**2**	**10**	**Include a CONSERVATION plan**	
	Catch 10 tonnes of fish per year	**The minimum additional annual Payment is 3,500 USD.**	**You do not have a flexible payment scheme**	**You have 2 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located 10 km from your house.**	**A conservation management plan needs to be included in the lot operation.**	
Option C	**I do <u>NOT</u> want to bid or pay for any of these options.**						

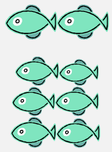
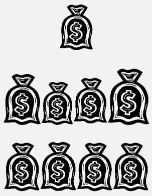
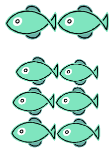
Q 2.7 Please choose <u>ONLY ONE OPTION</u> after considering the following three options.

Which option would you like to choose?

Attributes / **Options**	**Annual fish catch** (tonnes)	**Floor prices** (USD / year)	**A flexible payment scheme**	**Leasing periods** (years)	**Distance** (kms)	**A conservation management plan**	**My choice is** (tick only ONE)
Option A			**With a flexible payment scheme**	**2**	**10**	**Include a CONSERVATION plan**	
	Catch 5 tonnes of fish per year	**The minimum additional annual Payment is 3,500 USD.**	**You have a flexible payment scheme**	**You have 2 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located 10 km from your house.**	**A conservation management plan needs to be included in the lot operation.**	
Option B			**With a flexible payment scheme**	**2**	**≤2**	**Include a CONSERVATION plan**	
	Catch 10 tonnes of fish per year	**The minimum additional annual Payment is 3,500 USD.**	**You have a flexible payment scheme**	**You have 2 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located less than or equal to 2 km from your house.**	**A conservation management plan needs to be included in the lot operation.**	
Option C	**I do <u>NOT</u> want to bid or pay for any of these options.**						

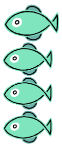
Q 2.8 Please choose <u>ONLY ONE OPTION</u> after considering the following three options.

Which option would you like to choose?

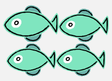
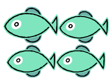
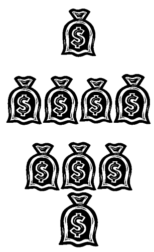
Attributes / Options	**Annual fish catch** (tonnes)	**Floor prices** (USD / year)	**A flexible payment scheme**	**Leasing periods** (years)	**Distance** (kms)	**A conservation management plan**	**My choice is** (tick only ONE)
Option A			With a flexible payment scheme	2	≤2	Include a CONSERVATION plan	
	Catch 45 tonnes of fish per year	**The minimum additional annual Payment is 3,500 USD.**	**You have a flexible payment scheme**	**You have 2 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located less than or equal to 2 km from your house.**	**A conservation management plan needs to be included in the lot operation.**	
Option B			<u>Without a flexible payment scheme</u>	2	10	No restrictions	
	Catch 45 tonnes of fish per year	**The minimum additional annual Payment is 800 USD.**	**You do not have a flexible payment scheme**	**You have 2 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located 10 km from your house.**	**There are no restrictions.**	
Option C	**I do <u>NOT</u> want to bid or pay for any of these options.**						

Q 2.9 Please choose <u>ONLY ONE OPTION</u> after considering the following three options.

Which option would you like to choose?

Attributes **Options**	**Annual fish catch** (tonnes)	**Floor prices** (USD / year)	**A flexible payment scheme**	**Leasing periods** (years)	**Distance** (kms)	**A conservation management plan**	**My choice is** (tick only ONE)
Option A			<u>Without a flexible payment scheme</u>	**10**	**≤2**	Include a CONSERVATION plan	
	Catch 20 tonnes of fish per year	**The minimum additional annual Payment is 800 USD.**	**You do not have a flexible payment scheme**	**You have 10 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located less than or equal to 2 km from your house.**	**A conservation management plan needs to be included in the lot operation.**	
Option B			<u>Without a flexible payment scheme</u>	**10**	**10**	Include a CONSERVATION plan	
	Catch 20 tonnes of fish per year	**The minimum additional annual Payment is 800 USD.**	**You do not have a flexible payment scheme**	**You have 10 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located 10 km from your house.**	**A conservation management plan needs to be included in the lot operation.**	
Option C	**I do <u>NOT</u> want to bid or pay for any of these options.**						

Q 2.10 Please choose <u>ONLY ONE OPTION</u> after considering the following three options. Which option would you like to choose?

Attributes **Options**	**Annual fish catch** (tonnes)	**Floor prices** (USD / year)	**A flexible payment scheme**	**Leasing periods** (years)	**Distance** (kms)	**A conservation management plan**	**My choice is** (tick only ONE)
Option A			**With a flexible payment scheme**	**10**	**10**	**No restrictions**	
	Catch 20 tonnes of fish per year	**The minimum additional annual Payment is 1,600 USD.**	**You have a flexible payment scheme**	**You have 10 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located 10 km from your house.**	**There are no restrictions.**	
Option B			**<u>Without a flexible payment scheme</u>**	**2**	**≤2**	**No restrictions**	
	Catch 20 tonnes of fish per year	**The minimum additional annual Payment is 3,500 USD.**	**You do not have a flexible payment scheme**	**You have 2 years guarantee for exclusive fishing rights over the lot.**	**The fishing lot is located less than or equal to 2 km from your house.**	**There are no restrictions.**	
Option C	**I do <u>NOT</u> want to bid or pay for any of these options.**						

Appendix B:

QUESTIONNAIRES

Date ……/…../2011

Interviewer's name …………………………………..……………..….

Time Start / Time Finish…………….……….……………….

Province …………………………… Village…..……………………

A Survey of fishermen's attitudes toward fishing regulation through auction based allocation of fishing rights.(Version 1)

Section 1 Introduction

(How familiar the respondents are)

Question 1

1.1 How many years have you fished in the Tonle Sap wetland? ………

1.2 How far (from your house) you normally go for fishing? …..……Km 1.3 How many boats do you have? ………………………………… Boats

1.4 Approximately, how many tonnes do you catch per year? ……………………………………………………………………….....Tonnes

1.5 How many people help you when fishing? …………………………..

1.6 Do you pay any of these helpers? Yes ◯ ◯

If YES how many paid helpers? ……………………………………

1.7 What types of fishing gear are you using? (Please list)

1) ……………………………… 3)…………………………………

2) ……………………………… 4) ………………………………….

Section 2 Choice cards

As a part of this study we would like to know how important different characteristics of the fishing lots are to you. So in the following questions, I will ask you to make some choices between 3 alternative options. I am going to describe the different characteristics of the hypothetical fishing lots which are available for you to purchase. I would like you to tell me which ONE lot you would be willing to bid for. On each of the cards you will see and you must choose ONE option on EACH card.

A hypothetical fishing lot is described by 5 attributes;

1) ***"Annual fish catch"*** means the 'official record' of the average of fish caught per year for the past few years in the fishing lot.
2) ***"Floor price"*** is a minimum bidding price in an auction in order to get exclusive fishing rights. In other words, the minimum additional annual payment that you have to pay while you are operating the fishing lot.
3) ***"Flexible payment schemes"*** means a scheme which allows you to pay (a bid price) for a fishing lot after the fishing season ends. In other words, you do not to pay any money in order to own a fishing lot on the auction day but you can pay after fish has been sold.
4) ***"A leasing period"*** is the number of years that you have an exclusive fishing right in the lot.
5) ***"Distance"*** means the distance between your house and the fishing lot.
6) ***"Conservation management plans"*** means that the activities in the fishing lots need to comply strictly with fishery law so that pumping water for fishing and electro-fishing activity are prohibited, and you can only use nets with mash sizes bigger than 4 centimeters.

Your choices involve **3** options.

- Option **A** and **B** involve a purchase of a hypothetical fishing lot.
- Option **C** is the current situation, no new action is involved; no new payment but no new fishing opportunity either.

As you prepare to answer the next few questions, before you make a decision please consider;

- Each card has **3 options** from which can select only **ONE.**
- You should consider **each card independently.**
- Please remember the following **3 things**:

First, I would like to remind you about your own household budget; at what price would your household be able to buy a fishing lot? The payment for a chosen lot option would be made annually and you also have other expenses. **Second,** keep in mind that there are alternative fishing grounds, such as the public fishing areas. And **third**, please keep in mind that in the previous surveys we have found that people CHOSE options that they ACTUALLY would not be able or willing to purchase. For this reason, please imagine that your household is actually paying for the selected option.

Now is time to choose (present choice cards)

Question 2 Please choose ONLY ONE OPTION after considering the following three options. Which option would you like to choose?

Q2	My choice is (tick only ONE)	Attributes / Options	Annual fish catch (tonnes)	Floor price (USD / year)	A flexible payment scheme	A leasing periods (years)	Distance (kilometers)	A conservation management plan
2.1		Option A	5	1,600	Without	10	10	With
		Option B	45	1,600	With	10	10	Without
		Option C	I do NOT want to bid or pay for any of these options.					
2.2		Option A	5	3,500	With	10	≤2	With
		Option B	5	1,600	Without	2	10	With
		Option C	I do NOT want to bid or pay for any of these options.					
2.3		Option A	45	800	With	2	10	Without
		Option B	20	1,600	With	2	10	With
		Option C	I do NOT want to bid or pay for any of these options.					
2.4		Option A	10	1,600	With	10	≤2	Without
		Option B	20	800	With	10	≤2	With
		Option C	I do NOT want to bid or pay for any of these options.					
2.5		Option A	5	800	With	2	10	Without
		Option B	45	800	Without	10	10	Without
		Option C	I do NOT want to bid or pay for any of these options.					

Question 2 (continue)

Q2	My choice is (tick only ONE)	Attributes / Options	Annual fish catch (tonnes)	Floor price (USD / year)	A Flexible payment scheme	A leasing periods (years)	Distance (kilometers)	A conservation management plan
2.6		Option A	20	400	Without	2	≤2	With
		Option B	45	3,500	With	2	≤2	With
		Option C	I do NOT want to bid or pay for any of these options.					
2.7		Option A	45	3,500	Without	2	10	With
		Option B	5	3,500	Without	10	≤2	Without
		Option C	I do NOT want to bid or pay for any of these options.					
2.8		Option A	45	3,500	Without	10	≤2	Without
		Option B	10	800	With	2	10	Without
		Option C	I do NOT want to bid or pay for any of these options.					
2.9		Option A	45	400	With	10	10	With
		Option B	10	400	Without	10	≤2	With
		Option C	I do NOT want to bid or pay for any of these options.					
2.10		Option B	5	400	without	2	≤2	Without
		Option C	I do NOT want to bid or pay for any of these options.					

Section 3 Follow-up questions

I would like to ask a few further questions about the options that you have just chosen. You can be ensured that this information is strictly confidential.

Question 3

3.1 Were any of the attributes NOT important to you? If so, which? (several ticks are acceptable)

◯ Fish catch ◯ Floor price
◯ Distance ◯ A flexible payment scheme
◯ Leasing period ◯ A conservation management plan

Why they were not important to you?...

……………………………………………………………………………………

3.2 I was confused when I answered the choice questions (question 2).

◯	◯	◯	◯	◯
Strongly	Agree	Disagree	Strongly	Not sure

3.3 Did you always select option C which is the no purchase option?

◯ Yes ◯ (please go to Question 4)

If YES, which of the following most accurately explain your reasons for choosing this option? (please select only ONE)

◯ I am not supporting the fishing lot system.

◯ I am supporting the fishing lot system but I could not afford any of the options.

◯ I am supporting the fishing lot system and I could afford a payment for a lot but I cannot get into the system because I do not have a supporter ("knong") to introduce me.

◯ I cannot decide which option is the best and would prefer to stay with my current situation.

◯ I was not sure what I was being asked to do.

◯ I have other reasons, please identify:…………………………..

Question 4

Please specify how strongly you agree or disagree with each of the following statements.

4.1 The fishing lot system depletes fish stocks.

◯	◯	◯	◯	◯
Strongly	Agree	Disagree	Strongly	Not sure

4.2 The fishing lot system is an unfair allocation system.

○ Strongly agree ○ Agree ○ Disagree ○ Strongly disagree ○ Not sure

4.3 Lot owners always have conflicts with the fishery community and I support the fishery community and I believe that all lots should be abolished.

○ Strongly agree ○ Agree ○ Disagree ○ Strongly disagree ○ Not sure

4.4 Owner of lots should be able to sub lease some areas.

○ Strongly agree ○ Agree ○ Disagree ○ Strongly disagree ○ Not sure

4.5 The fishing lot system is the best system because the fishery resources can be used in the best way.

○ Strongly agree ○ Agree ○ Disagree ○ Strongly disagree ○ Not sure

4.6 Fishing lot operations help to protect bird species and flooded forests which are nursing grounds for fish.

○ Strongly agree ○ Agree ○ Disagree ○ Strongly ○ Not sure

Question 5

Could you please indicate how you feel about the following statements?

5.1 An auction system is the best way to allocate fishing right.

○ Strongly agree ○ Agree ○ Disagree ○ Strongly disagree ○ Not sure

5.2 The auction system for allocating fishing lots in Cambodia should be improved.

○ Strongly agree ○ Agree ○ Disagree ○ Strongly disagree ○ Not sure

Please suggest how to improve the system.

……………………………………………………………………………………

……………………………………………………………………………………

Section 4 Demographic information

I would like to ask you some questions about your household which will help me understand why respondents select different options.

Q 5.Gender ◯ Male ◯ Female

Q 6. House number …………… Village name……………………

◯ Land-based village or ◯ Floating village

Q 7.Name of respondents …………………….………………………

Q 8.Age ……….. years

Q 9 Nationality Khmer Vietnamese

Other please specify ……………………………

Q 10 The number of household members ………………………and

the number of them who are under 15 years old ………………….and over 70…………..

Q 11 The education level

◯ Illiterate ◯ Literate but never went to school

◯ Primary ◯ Secondary ◯ Diploma or Certificate

◯ Bachelor ◯ Postgraduate ◯ Other, please specify……………………………………..…..

Q 12 Please specify all sources of household income

12.1)……................... 12.3)…………………… 12.5)………………..

12.2)………………… 12.4)………………….. 12.6)………………

Q 13 Annual household income (approximate income from last year according to Q12) Total income USD………………

13.1)……................... 13.3)…………………… 13.5)………………..

13.2)………………… 13.4)………………….. 13.6)………………

Q 14 Typical annual profit from current fishing activities? USD/year……….

14.1) Income from fishing activities……………………..USD/day

(A number of days/month……….and a number of months/year…………)

14.2) Fishing costs 14.2.1) investment costs USD/year…………………….

14.2.2) maintenance costs USD/year …………………

Q15 Would you like to make other comments?

………………………………………………………………………………………..…….

………………………………………………………………………………………

………………………………………………………………………………………

Thank you very much for your participation.

Appendix C:
SURVEY INSTRUCTION

Survey instructions for the questionnaire interviewers

1. Please sign your name in the record sheet and indicate the number of the questionnaires which you are taking with you on that day.
2. Please indicate the province/village or area in the record sheet.
3. Go to the targeted area.
4. Please write down the "number of questionnaire" in each page of the questionnaires.
5. Visit fishermen who are household leaders
6. In order to provide an ethical proof, please use the recorder for your interview (later on, please rename the record files in order following the number of questionnaire).
7. Introduce yourself;

"I am helping to conduct a survey about fishery management for a PhD student at Leeds University in the United Kingdom. The aim of the study is to generate knowledge to improve the fishing management in the Tonle Sap wetland.

The study tries to improve understanding of how access to fishing grounds managed through the fishing lot system affects fishermen in the Tonle Sap wetland. The study will ask you about your opinion on the fishing lot system. We will also try to find out which aspects of the fishing lot system are of most importance to you. You do not need to have any experience with purchasing fishing lots as we also want to find out why some fishermen only fish in the communal fishing ground. You will be asked to choose between different alternatives representing hypothetical fishing lots. You need to imagine that these hypothetical fishing lots are real fishing lots and you need to choose whether or not you would find it attractive to bid for any of them. If so, you need to choose which fishing lot is most attractive.

Your answers and your name are "strictly confidential" and all of your answers and information will not be linked to your name. Also, you are free to refuse to answer any of the questions."

Would you like to participate in this survey? If not please say thank you and find the next person.

8. If yes, thank you for agreeing to take part in the survey. And emphasise that ***"the data will be kept strictly confidential and will be available only to members of the research team. Excerpts from the interview/ individual***

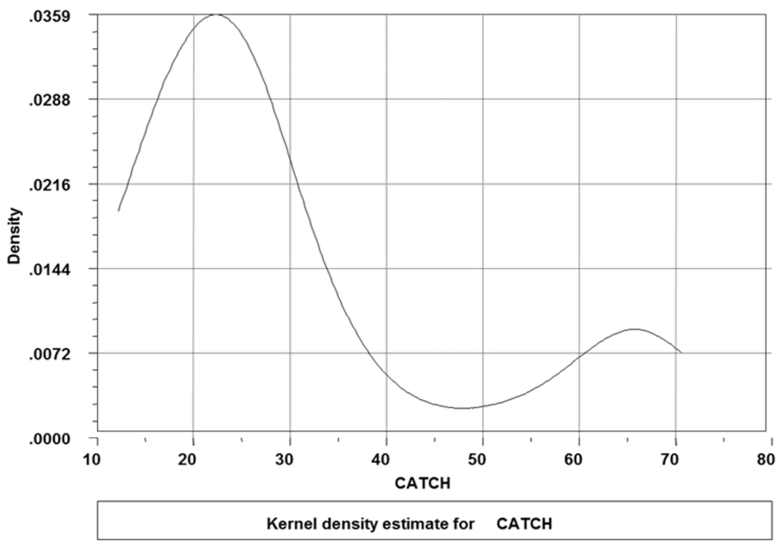
results may be made part of the final report, but under no circumstances will your name or identifying characteristics be included in the report. Would you mind if I use a recorder?"

And, if you have enquiries please contact Yingluk Kanchanaroek at Sustainability Research Institute, School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, the United Kingdom, Email: eeyk@leeds.ac.uk, Tel: +44(0)7541224348.

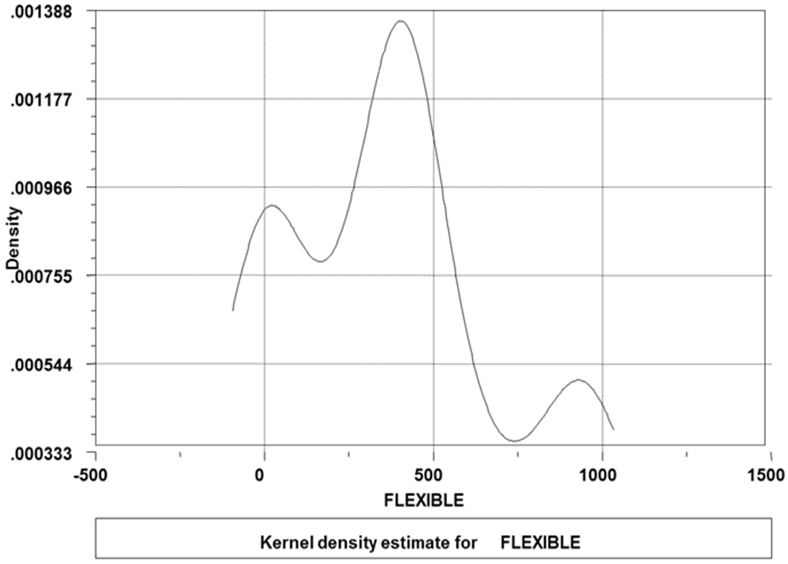
9. Please tick ◯ to show that the respondent understands the contents.

Appendix D:
THE KERNEL DENSITY OF 3-SEGMENT LATENT CLASS MODEL

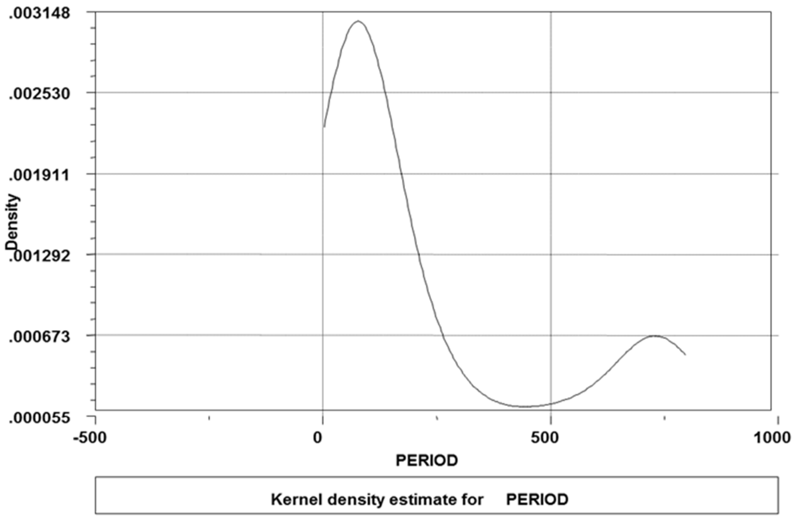
The figures below show Kernel density estimates for each attribute of 3-segment Latent Class Model.



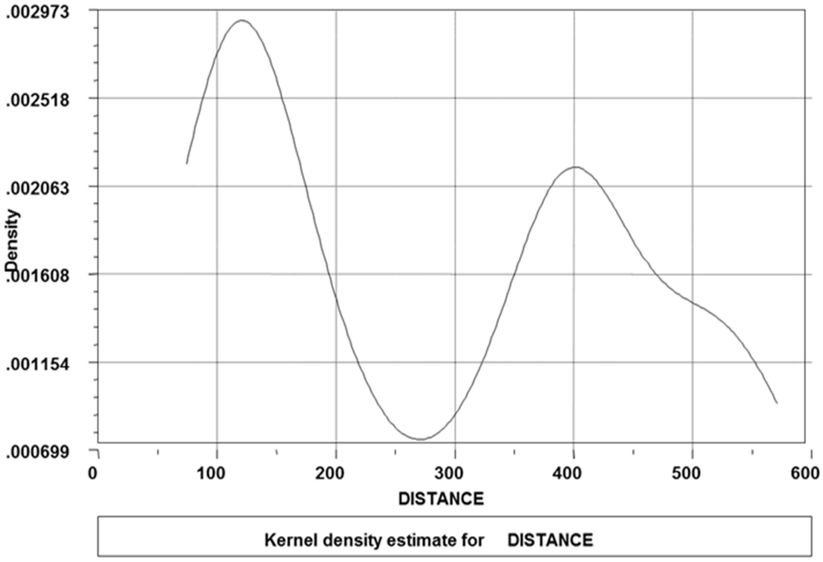
(a) Value of fish catch



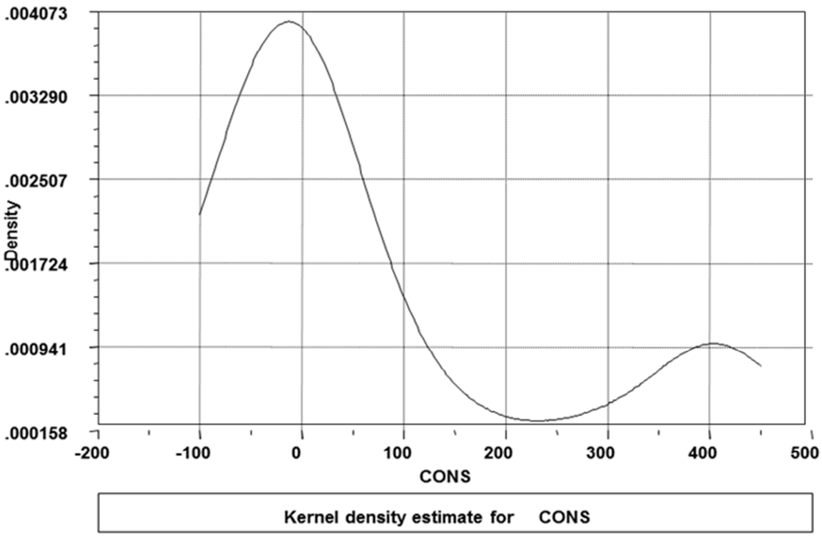
(b) Value of flexible finance schemes



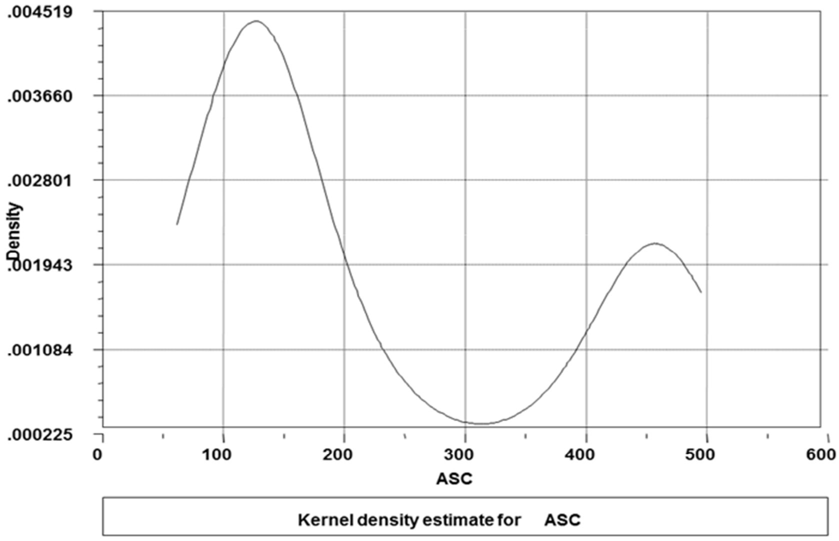
(c) Value of leasing period



(d) Value of distance from home to a fishing ground



(e) Value of Conservation management plans



(f) Value of ASC (status Quo)