GIS applications for poverty targeted aquaculture development in the lower Mekong Basin

Thesis submitted for the degree of
Doctor of Philosophy

by

Martin Louis Van Brakel

Institute of Aquaculture
University of Stirling
Stirling FK9 4LA
Scotland

February 2006

Originality Statement

I declare that the work contained in this dissertation is my own, and where the work of others has been used it has been properly cited

Martin Louis Van Brakel

28 February 2006

Dedication

To Claudia and Estella

Mis Amores y mi Vida

To my family, in loving memory of my father

Acknowledgements

I would like to thank my supervisors Prof. Lindsay Ross, who "discovered" me in Temuco, Chile, and Prof. James Muir for their support and strategic advice. I am also grateful for the excellent facilities and working environment provided to me in the GIS lab. I gratefully acknowledge the Institute of Aquaculture, University of Stirling and the DFID Aquaculture and Fish Genetics Research Programme for jointly financing this research.

I would like to thank Ernesto "Jack" Morales and Danai Turongruang for their friendship and hospitality. Their company made the "ground truthing" in Thailand and Cambodia a very enjoyable experience. I also would like to extend my gratitude to Dr. Harvey Demaine, Prof. Peter Edwards and Dr. Dave Little who were all of invaluable help in providing guidance, data and advice. I also express my gratitude to my friends and colleagues Krienkrai "Key" Satapornvanit, Jatuporn Bundit and Angus McNiven for their assistance in translating and facilitating my access to data, as well as to the many colleagues at AIT and staff at the Community Development Information Centre in Bangkok, Thailand. I wish to thank Khong Sophoan and Hav Viseth of DoF, Cambodia, and Mr. Boreak Sik, WFP Cambodia, as well as Mr. Dang Kieu Nhan and Dr. Le Thanh Duong, Can Tho University, for their support.

I also would like to thank my office mates, particularly Oscar Perez, Matias Del Campo, Mauro Gongora and Juan Navas for the pleasant company and friendship and their patience with my Españolandés. I extend my gratitude to all my friends at the Institute of Aquaculture and beyond, especially the "Mexican community" who helped maintain the "Latin rhythm" in my social life.

Finally I want to express my gratitude to Claudia and Estella for their love and patience.

Abstract

In the lower Mekong Basin, marginal socio-economic conditions prevail amongst rural small scale farming households which heavily depend on highly seasonal, rain-fed farming systems for their livelihood. Persistent rural poverty is aggravated by frequently occurring droughts and floods. A yearly flood-drought cycle, while essential to their household economy based on rice and fisheries, renders rural poor livelihoods vulnerable to recurrent periods of food insecurity.

This research demonstrates how a combination of publicly accessible Remote Sensing imagery and disaggregated poverty maps, within a comprehensive rural development framework, can provide an effective method to target pro-poor aquaculture development interventions at the local level. An agro-ecosystems analysis is performed in order to capture the seasonal dynamics of water- and aquatic resource exploitation. A holistic farming systems approach emphasises the potential of ponds in integrated rural smallholder systems to reduce poverty and vulnerability under rain fed conditions.

A Geographic Information System (GIS), an efficient spatial inventory tool and decision support system in resolving real world problems, is used to identify where rural poor households can potentially benefit from the integration of aquaculture into existing production systems. A time series of satellite derived vegetation index data reveals distinct agro-ecosystem seasonality over large parts of the study area, which is indicative for farming systems under rain fed conditions. The developed methodology is capable of identifying functionally different agro-ecosystems.

Socio-economic indicators for Cambodian parts of the lowland areas point to widespread rural poverty and vulnerability to recurrent food insecurity, which is

directly related to agro-ecosystems seasonality and annual climate variability. Dependence of farming households on low productivity rain fed rice agro-ecosystems in Cambodia's southern provinces is in stark contrast to the highly productive farming systems directly bordering it, in the freshwater fluvial zone of the Vietnamese Mekong Delta. A rapid increase in rice productivity in this densely populated area went hand-in-hand with a considerable reduction in rural poverty. In this flood-prone but fertile area, resource competition and falling market prices of rice may have prompted the development of a range of integrated farming systems. The incorporation of ponds on-farm in these systems facilitates reuse of nutrients from farm by-products for low-input aquatic resource production.

In Northeast Thailand, crop production and low-input aquaculture have been successfully integrated along a tradition of water- and living aquatic resources management in farmer managed systems under resource poor conditions. A spatially linked commune level rural development database for Sisaket province in Northeast Thailand provides a useful framework for planning of aquaculture development through systems that are appropriate and relevant to local socio-economic and agro-ecological conditions. It was concluded that the socio-economic and agro-ecological context of rural poverty in Southeast Cambodia offers scope for similar pathways to improve rural wellbeing and reduce vulnerability to poverty and food insecurity by integrating aquatic resources development in pond based systems as part of an interdisciplinary approach towards rural development.

List of Contents

List of Figures

List of Tables

Acronyms

ADB	Asian Development Bank
AFGRP	Aquaculture and Fish Genetics Research Programme (DFID)
AIT	Asian Institute of Technology
AOP	Aqua Outreach Program (AIT)
ASTER	Advanced Spaceborne Thermal Emission and reflection Radiometer
ATN	Advanced Television Infrared Observation Satellites (TIROS-N)
AVHRR	Advanced Very High Resolution Radiometer
CERES	Clouds and Earth's Radiant Energy System
CGIAR	Consultative Group on International Agricultural Research
CIIFAD	Cornell International Institute for Food and Agricultural Development
CLASS	Comprehensive Large Array-data Stewardship System
CPWF	Challenge Program on Water and Food
DAAC	Distributed Active Archive Center
DEM	Digital Elevation Model
DEWA	Division of Early Warning and Assessment (UNEP)

DFID	Department for International Development (UK)
EDC DAAC	Earth Resources Observations Systems (EROS) Data Center
EOS	Earth Observing Systems
EOSDIS	Earth Observing Systems Data and Information System
EROS	Earth Resources Observations Systems
ESDIS	Earth Science Data and Information System
ESE	Earth Science Enterprise
ETM+	Enhanced Thematic Mapper Plus (Landsat)
EVI	Enhanced Vegetation Index
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GIS	Geographic Information System
GLCC	Global Land Cover Characteristics database (IGBP)
GOES	Geostationary Operational Environmental Satellites
GPS	Global Positioning System
GRID	Global Resource Information Database (UNEP)
GSDI	Global Spatial Data Infrastructure

HDF	Hierarchical Data Format
IAAS	Integrated Agriculture / Aquaculture Systems
ICESat	Ice, Cloud and land Elevation Satellite
IFAD	International Fund for Agricultural Development
IFAS	Integrated Fisheries / Aquaculture Systems
IGBP	International Geosphere Biosphere Program
IIASA	International Institute for Applied System Analyses
IPAS	Integrated Peri-urban Aquaculture Systems
ISIN	Integerized Sinusoidal projection
IRBM	Integrated River Basin Management
IWRM	Integrated Water Resources Management
LAZEA	Lambert Azimuthal Equal Area projection
LPDAAC	Land Processes Distributed Active Archive Center
LWIR	Long-wave infrared
MAUP	Modifiable Areal Unit Problem
MISR	Multi-angle Imaging Spectro-Radiometer
MODIS	Moderate Resolution Imaging Spectro-Radiometer

MOPITT	Measurements of Pollution in the Troposphere
MRC	Mekong River Commission
MWIR	Medium-wave infrared
NACA	Network of Aquaculture Centres in Asia
NASA	National Aeronautics and Space Administration (USA)
NCSA	National Center for Supercomputing Applications (USA)
NDVI	Normally Differentiated Vegetation Index
NESDIS	National Environmental Satellite, Data and Information Service (USA)
NIR	Near-infrared
NOAA	National Oceanic and Atmospheric Administration (USA)
NPRS	National Poverty Reduction Strategy (Cambodia)
NRDP	National Rural Development Plan (Thailand)
NSIDC	National Snow and Ice Data Center (USA)
PAM	Poverty Aim Marker
PCA	Principal Components Analysis
POES	Polar Orbiting Environmental Satellites
PPP	Purchasing Power Parity

PRA	Participatory Rural Appraisal
READ	Rural Extension for Aquaculture Development project (MRC)
RGC	Royal Government of Cambodia
SRS	Self-recruiting species
SRTM	Shuttle Radar Topography Mission
SWIR	Short-wave infrared
TM	Thematic Mapper (Landsat)
TOVS	Tiros Operational Vertical Sounder
TRMM	Tropical Rainfall Measuring Mission
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
USGS	US Geological Survey
UTM	Universal Transverse Mercator projection
VAC	*Vuon* (garden), *ao* (pond), *chuong* (livestock) integrated farm (Vietnam)
VI	Vegetation Index
WFP	World Food Programme
WRS	World-wide Reference System

1 Introduction

1.1 General introduction

Poverty reduction, now an overarching goal for governments and international donors, only became the central theme of economic and social development efforts after it was placed on the global development agenda by the 1995 World Social Summit. Targets for decreasing malnourishment and halving global poverty by the year 2015 were internationally adopted and it is now generally acknowledged that growth can only be truly economically, politically and socially sustainable when poverty is explicitly taken into account (IFAD, 2002).

Despite this recognition, official development assistance apparently fails to acknowledge the fact that 75 percent of the world's 1.2 billion poor live in rural areas, where agriculture is their primary livelihood source. Only about 12 percent of total official development assistance is devoted to agricultural development (IFAD, 2002). The absolute value of aid to agriculture declined sharply, by two thirds in the period from 1987 to 1998 (IFAD, 2001; DFID, 2004). In the absence of greater commitment to investing in agricultural and rural development, the international development goal of halving poverty by 2015 will not be met (IFAD, 2002).

The general objective of poverty alleviation is to promote sustainable development that results in rapid poverty reduction. Adequate investment in the growth of productivity in areas of high rural population density can alleviate mass rural poverty, and provides a rationale for donors to focus their assistance on poverty with emphasis on support for sustainable rural development and improved management of natural resources. The development of sustainable agriculture with minimal adverse environmental impacts is particularly relevant for developing countries, where farms which are operated under rain fed conditions comprise about 70 to 80 percent of the total agricultural land. To be successful, poverty reduction policies must focus on such rural areas.

1.2 Poverty and rural development

1.2.1 Introduction

Poverty is multi-faceted. It is unlikely that the key processes that underlie poverty can be captured in one definition. The concept of human poverty goes beyond income poverty to encompass other forms of deprivation. Poverty manifests itself in deprivation of the three key dimensions of human development; longevity, knowledge and standard of living. Human poverty implies that the opportunities and choices essential to human development are denied (UNDP, 1997). Rural residents are often even more deprived in terms of health and education than they are in terms of income poverty, since access to facilities that deliver services is often limited. Other factors contributing to being poor and staying poor are vulnerability to economic shocks and a marginal role in decision-making.

Poverty in terms of a *capital asset framework* may be understood in terms of the set of capital assets which an individual or household possesses. Assets are highly significant as a determinant of the depth and severity of poverty, of the vulnerability of a household to destitution, and of the availability of a range of strategies to escape poverty. The sustainable livelihoods concept is defined in terms of the set of capabilities, assets and activities required for a means of living. The livelihood building blocks are in fact the set of capital assets which an individual or household possesses. A livelihood is sustainable "when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base"(Cox, Farrington, & Gilling, 1998).

The Department for International Development (DFID) has developed a Poverty Aim Marker (PAM), which is consistent with the multidimensional capital assets approach to poverty. It recognises that poverty reduction may be promoted through different levels and mechanisms. PAMs indicate that poverty reduction may be promoted through enabling, inclusive or focused actions. *Enabling actions* underpin policies for poverty reduction and lead to social, environmental or economic benefits for poor people. *Inclusive action*s, such as sector programmes, aim to benefit population groups (including poor people) and address issues of equity, barriers to participation or access of poor people. Finally, actions can be *focused* predominantly on the rights, interests and needs of poor people (Cox *et al.*, 1998).

1.2.2 Poverty indicators

The first step in measuring poverty or inequality is to choose an overall indicator of household welfare. Good indicators are household consumption expenditures per capita and household income per capita. Whilst there are several reasons to consider consumption-based welfare indicators to be superior to those based on income, household income data can yield interesting insights concerning a household's socio-economic status, particularly when disaggregated by the source of income. In addition to choosing a welfare indicator, poverty analysis involves some judgement regarding the level of income or expenditure that is absolutely necessary for a minimal standard of living. Households whose income or expenditure levels fall below this standard are then classified as poor. Common practice is to set a poverty line based on a basket of goods that provides enough calories to meet minimum energy requirements (Glewwe, Gragnolati, & Zaman, 2000).

A number of aggregate measures of poverty are in use. The most commonly used measure is the headcount index, as it is simple to construct and easy to understand. It simply measures the proportion of the population that is counted as poor. The headcount index does not take the intensity of poverty into account and implies that there is a jump in welfare, from poor to non-poor, at about the poverty line. Such a jump, which also implies that the easiest way to reduce the headcount index is to target benefits to people just below the poverty line in order to move them across the line, in practice does not exist. The headcount index does not change if people below the poverty line become poorer. Another drawback is that the headcount index calculates the percentage of individuals who are poor and not the percentage of households, making the critical assumption that within a household all members enjoy the same level of wellbeing (World Bank, 2005).

The poverty gap index takes into account to what extent individuals fall below the poverty line, and is expressed as a percentage of the poverty line. The poverty gap for non-poor equals zero. Its virtue is that it does not imply that there is a discontinuity at the poverty line. However, it may not convincingly capture differences in the severity of poverty amongst the poor, as it measures the mean proportionate poverty gap in the population, such that it ignores inequality among the poor. The aggregate poverty gap expresses the cost of eliminating poverty by making perfectly targeted transfers to the poor. The poverty gap index can show the value of using survey information to identify the characteristics of the poor, and the smaller the poverty gap index, the greater can be the potential economy of targeting benefits and programs for a poverty alleviation budget. By squaring the poverty gap index a measure of poverty severity is obtained as it implicitly puts more weight on observations that fall well below the poverty line. It is a weighted sum of poverty gap values as a proportion of the poverty line, where the weights are the proportionate poverty gaps themselves (World Bank, 2005).

The measures of depth and severity of poverty provide complementary information on the incidence of poverty and can be disaggregated for population sub-groups. Hence, the contribution of each sub-group to national poverty can be calculated. It might be the case that some groups have a high poverty incidence but low poverty gap, when numerous members are just below the poverty line, while other groups have a low poverty incidence but a high poverty gap for those who are poor (World Bank, 2005).

1.2.3 Poverty targeting

Efficient allocation of resources is essential for making poverty alleviation effective. The formulation of a targeting policy such that the gap between current income or expenditure levels and the poverty line is just fulfilled, is unlikely to be possible in practice. But targeting often helps to make an allocation cost-effective as it can avoid wasting resources on the non-poor. There are two types of errors in targeting. First there is the error of exclusion, in which intended beneficiaries cannot benefit from the intervention, and the second is the error of inclusion, in which the benefits reach people who are not intended to be beneficiaries (Hoddinott, 1999). For a given geographic unit, targeting becomes increasingly costly if it moves below a certain administrative level. At a level at which the costs of targeting outweigh the benefits it may be more efficient to distribute allocations to everyone without targeting (Fujii, 2003).

Many detailed poverty assessments and participatory poverty appraisals do provide important insights into the nature of poverty. But when it comes to differentiating between poor groups, except from income, they provide little information on the correlation between levels of poverty and geographical location of livelihoods and their production systems. Identifying spatial patterns with poverty maps can provide new insights into the causes of poverty. Spatial determinants are important particularly in the area of natural resources, as natural capital asset holdings, including natural resource stocks and environmental quality, are difficult to characterize with conventional variables, and by definition are spatially distributed (Davis, 2003).

1.2.4 Poverty and natural resources

Vosti and Reardon, 1997, as cited in Cox *et al.* (1998) considered that rural poverty can be viewed as the product of various assets, made of the following components; private and commonly held natural resources, human resources, on- and off-farm resources, community-owned resources, and social and political capital. Natural resources provide fundamental support to life and economic processes in rural areas. Therefore rural residents are especially vulnerable to exogenous shocks related to adverse impacts on fragile natural resources. Inappropriate use of natural resources threatens rural livelihoods and degradation of the natural resource base affects the poor more than others. Improving social well-being, managing risk, and reducing vulnerability are key issues to improving the quality of life of rural people. These investments will also make substantial contributions towards increasing productivity, promoting the rural non-farm economy and enhancing economic growth (Csaki, 2001).

Sustainable natural resources management and poverty reduction are generally quite compatible. Natural resources research can be a potentially powerful, but also comparatively blunt instrument for addressing poverty. It can promote broad patterns of growth from which the poor can and often do benefit, but it is difficult to target in such a way that the poor disproportionately benefit. Its impact is highly dependent on a range of demand and supply-based variables which often do not favour the poor. In some cases, poverty reduction can be achieved by focusing on the types of commodity that are either produced or consumed specifically by the poor, or provide employment for them. But in many cases, natural resources are common to both the poor and less poor, so that the question of who gains from the research depends heavily on whether wider policy and institutional conditions favour the poor or less poor (Cox *et al.*, 1998).

When applied to natural resources research, *enabling* actions can improve the poverty impact of either existing or new research through changes in general conditioning factors such as the regulatory or incentive frameworks; *inclusive* actions, such as improving extension services or markets, address equity concerns and benefit the broad population; and *focused* actions through sector or sub-sector specific research, seek to target most of their benefits at poor groups (Cox *et al.*, 1998).

1.3 Agriculture and rural poverty in developing Asia

The "green revolution", regarded as the true Asian miracle in agriculture in the 1970s and 1980s, had a phenomenal impact on increasing food production and averting food insecurity in developing Asia. The impressive growth in the production of cereals, mainly rice, maize and wheat, was based on high input, high output technology, using three major production inputs: high-yielding varieties of cereal crops, irrigation water and chemical fertilizers. In countries with a "green revolution" agriculture accounted for between 25 and 40 percent of Gross Domestic Product (GDP). The "green revolution" kept food prices down and with increasing grain yields, employment per hectare increased (IFAD, 2002). Increases in farm income led to greater demand for rural non-farm products and services. The resulting growth in non-farm activity contributed to increased employment opportunities for the rural poor (Hazell & Haggblade, 1993; IFAD, 2001).

Despite this tremendous progress in agricultural development and its direct and indirect poverty reducing effect, poverty remains a rural phenomenon in most Asian developing countries (IFAD, 2002). According to IFAD (2001) more than two thirds of the world's poor are in Asia. Poverty in Asia is concentrated along social and geographical dimensions. Geographically it is concentrated in less favoured rural areas and socially in such areas it affects particularly women, indigenous people, pastoralists, the landless, and small- and marginal farmers (IFAD, 2002).

1.3.1 Rural poverty and water resources

The "green revolution" was fuelled by increased water resources for agriculture (CGIAR Challenge Program on Water & Food, 2002b). Green revolution technology normally succeeded in reducing rural poverty in areas where water control had been improved upon earlier, but there has been little progress in developing appropriate technologies for less favoured areas. Rice yields in rainfed areas are only half of those in irrigated areas, and yields are even lower in upland and deepwater areas. Competing demands for water for agricultural, industrial and domestic uses in a context of progressively less stable rainfall and higher evaporation result in water depletion, and alongside considerations of water quality this is now the single main environmental problem for the poor. Rural poverty reduction increasingly depends on better allocation and distribution of water (IFAD, 2001).

The World Water Council (Cosgrove & Rijsberman, 2000) suggested priorities for expanded water research funding for international and national agencies as more research on sustainable water use and supplementary systems is clearly needed in developing countries. In order to address some of the main agricultural production constraints of resource-poor farmers in low-potential areas, who have been bypassed by the green revolution technology, the needs of the rural poor must be integrated into such research. Increasing water availability, quality and water use efficiency for farmland, and some control over water, is vital for the rural poor. Yet the rural poor have even less access to assets for yielding and saving water, than they have to land (IFAD, 2001). The Consultative Group on International Agricultural Research (CGIAR) addresses this issue in its Challenge Program on Water and Food (CPWF). The development objective of this ambitious research, extension and capacity building programme is to increase the productivity of water for food and livelihoods in an environmentally sustainable and socially acceptable manner. It has a specific focus on low-income groups within rural and peri-urban areas in river basins with low average incomes and high physical, economic or environmental water scarcity or water stress (CGIAR Challenge Program on Water & Food, 2002b).

In the face of the increasing demand for water, important questions arise regarding the value and trade-offs amongst different water uses. One of these questions addresses the use of natural ecosystems and resources. Many of the policies, institutional and regulatory arrangements governing the use of ecosystems have led to inefficient and inequitable allocation of these resources, and consequently loss of their benefits to people. There are ecological thresholds beyond which land- and water use practices cannot be sustained by ecosystems. Therefore, future investments in water management need to consider how to sustain aquatic ecosystems as an integral aspect of approaches to improving water productivity at the basin level (CGIAR Challenge Program on Water & Food, 2002c).

1.3.2 Aquaculture and integrated rural development

Aquatic ecosystems provide a wide range of benefits to people, particularly so where aquatic resources such as fisheries are used intensively to sustain livelihoods of poor communities (CGIAR Challenge Program on Water & Food , 2002a). Secure access rights and control over common aquatic resources is of fundamental importance, especially to poor landless or near-landless households (Edwards, 2000). In many cases, the poorer people are, the more dependent they become on aquatic resources to satisfy basic needs (Friend & Funge-Smith , 2002). In order to reduce the pressure on aquatic resources, aquaculture can provide a sustainable alternative or complement to river- and floodplain fisheries. Fish farming in common water bodies may help to reduce poverty, provided that the poor have access. Water based systems may provide an opportunity for landless people and poor fishers to farm fish (Edwards, 2000).

Aquaculture has become the world's fastest growing form of food production. The integration of aquaculture into inland watershed management offers a huge potential to improve water productivity and aquatic resource utilisation and hence can contribute to sustainable livelihoods for the poor. It is an increasingly important contributor to food security and economic development. Aquaculture can complement other food production systems, for example through its integration with agriculture and fisheries, and can add value to the use of on-farm resources (NACA & FAO, 2000). Three broad categories of integrated aquaculture can be defined on the basis of system inputs. Integrated agriculture / aquaculture systems (IAAS) depend usually on limited inputs of fertilisers, green fodders and agricultural by-products on- or near farm. Integrated fisheries / aquaculture systems (IFAS) use small freshwater or marine fish as feed inputs, and integrated peri-urban / aquaculture systems (IPAS) use wastewater, and wastes from food- and food processing in cities and industry as inputs. Inputs to IPAS conceptually can include fertilisers from intensive feedlot livestock and effluents from intensive aquaculture. Integrated aquaculture can be practised both in ponds and cages, but traditional cage culture was probably developed as an activity integrated with fisheries rather than agriculture (Edwards & Allan, 2004).

Strategies to reach the goal of increasing the impact of aquaculture on rural development and poverty alleviation require integration into overall rural development programmes, in order to make efficient use of international donor resources. A programme approach to multi-sectoral development should be applied, under which donors and aquaculture developers adopt more cohesive approaches and procedures within a comprehensive planning and development framework. Taking into account the poverty focus, aquaculture development would be integrated effectively into poverty reduction programmes as a means to diversify production systems and reduce food insecurity in areas with generally low welfare levels and limited scope for alternative sustainable resource exploitation. This requires adequate focusing on areas where natural events and resource competition are threatening poor people whose livelihoods are dependent on aquatic resources. An analysis of the poverty processes which prevail in any such area should determine the strategy for pro-poor aquaculture development. Involvement of the poor in aquaculture must be based on a careful and realistic assessment of poor people's needs, capacity and access to resources, while minimising any potential adverse impacts on their livelihoods (NACA & FAO, 2000). The use of participatory approaches that empower the poor and local communities, rather than technology-driven approaches should lead to the adoption of aquaculture by new entrant poor farming households (Edwards, 2000).

1.3.3 Aquaculture and rural development in Asia

The scope for a promising contribution of aquaculture towards poverty reduction is possibly best in tropical and subtropical humid regions, as well as tropical climates with distinct wet and dry seasons, especially in Asia. Over the last decade aquaculture expansion has been faster in Asia than anywhere else in the world. China, the world's largest producer of farmed fish, has seen a sustained growth of inland aquaculture, averaging 11.5 percent per year between 1970 and 2000, compared to 7.0 percent in the rest of the world (FAO, 2002). In parts of Asia where it is traditional practice, aquaculture has contributed towards poverty reduction, and it continues to do so today. Fish forms an essential part of the diet of a large proportion of people in developing countries, hence aquaculture has the potential to become an important contributor to local food supplies and alleviate nutritional deficiencies (NACA & FAO, 2000). Land-based culture systems in inland areas have the greatest potential because aquaculture can be integrated with the existing agricultural practice of small-scale farming households. The full potential of aquaculture is in most countries unfulfilled and it is an often neglected option in rural development. Its impact has scarcely been assessed and few projects have specifically targeted the poor (Edwards, 2000).

1.3.4 Integrating aquaculture on-farm

Integrating aquaculture with crop and livestock production systems of resource poor small scale farmers, who have limited access to the off-farm inputs necessary to exploit modern farming technology, provides an effective means to produce fish by recycling by-products of agriculture and animal husbandry. Hence, production costs can be lower than in systems using inputs from agro-industry, while balancing risks among the various farming subsystems through increased diversity of produce.

In Asia, integration of aquaculture with agriculture is more developed than in other regions of the world (Edwards, Pullin, & Gartner, 1988). Land based systems are commonly integrated with agriculture, through stocking fish in rice fields and ponds. Most of the production is realized in semi-intensive pond farming systems, and is destined for local consumption. It has the potential to improve the efficiency of utilisation of the limited resource base of small-scale farmers (IFAD, 2002), and there is considerable evidence for its benefits to complex and diverse agricultural systems where external input is low or non-existent. Many of the poor in rural Asia are small scale or marginal farmers, having land holdings in risk prone and rainfed agricultural areas which are often environmentally degraded. Under such circumstances pond construction may provide a focal point for agricultural diversification and increased sustainability (Edwards, 2000). The pond provides a method of water storage in areas with variable topography and seasonally heavy rainfall, and can be used as an emergency water supply to the other subsystems in times of drought (Edwards *et al.*, 1988). Nutrient-rich pond water and sludge become potential organic fertiliser resources for adjacent crop products.

In most cases small-scale farming systems were created empirically by farmers themselves in response to local circumstances. Individual households make their own livelihood production decisions, based on appropriate indigenous technical knowledge (Edwards, Little, & Yakupitiyage, 1997). As a result a wide range of farming systems is in use. The extent of integration of aquaculture in these systems is highly variable, but it often fulfils an important role being one of the various livelihood production systems. Fish farming in rice paddies and growing vegetables on pond dikes can increase farm income by up to USD 240 per hectare (Cornell International Institute for Food and Agricultural Development (CIIFAD), 1999).

1.4 Study objectives and methodology

1.4.1 Study aim and conceptual framework

This study seeks to target poor rural areas with a potential to include aquaculture and aquatic resources development in a framework of wider rural development, as part of an integrated approach to reduce poverty and vulnerability. In order to reach intended beneficiaries, effective national poverty reduction strategies that incorporate aquatic resources development would benefit from ready access to sufficiently detailed and quantified information on the socio-economic benefits of aquatic resources. The aim of this study is therefore to offer a decision support tool based upon geographic information, in order to improve the targeting of benefits from aquatic resources development to rural poor people.

A conceptual framework (Figure 1.1), designed for this study, visualises the wider rural development context in which options and needs for aquaculture development at different scales are embedded. A transboundary river basin context was adopted in order to capture as broad as possible group of poor aquatic resource users who are potential beneficiaries from such a development approach. The framework incorporates levels at which policy decisions on the inclusion of aquaculture in poverty reduction strategies are likely to be made and outlines a decision support system in terms of policy levels (grey frames) and geographic scales (blue frames). Natural resources management and systems development ideally take place within this river basin management framework. Red linkages represent climate regulated factors and principal constraints, least controllable by human interventions. Linkages between natural assets and dependent livelihood production systems are in green. Blue links are population and socio-economic factors. Yellow integrates all factors at the systems level, where individual households make their own livelihood production decisions (Edwards *et al.*, 1997).

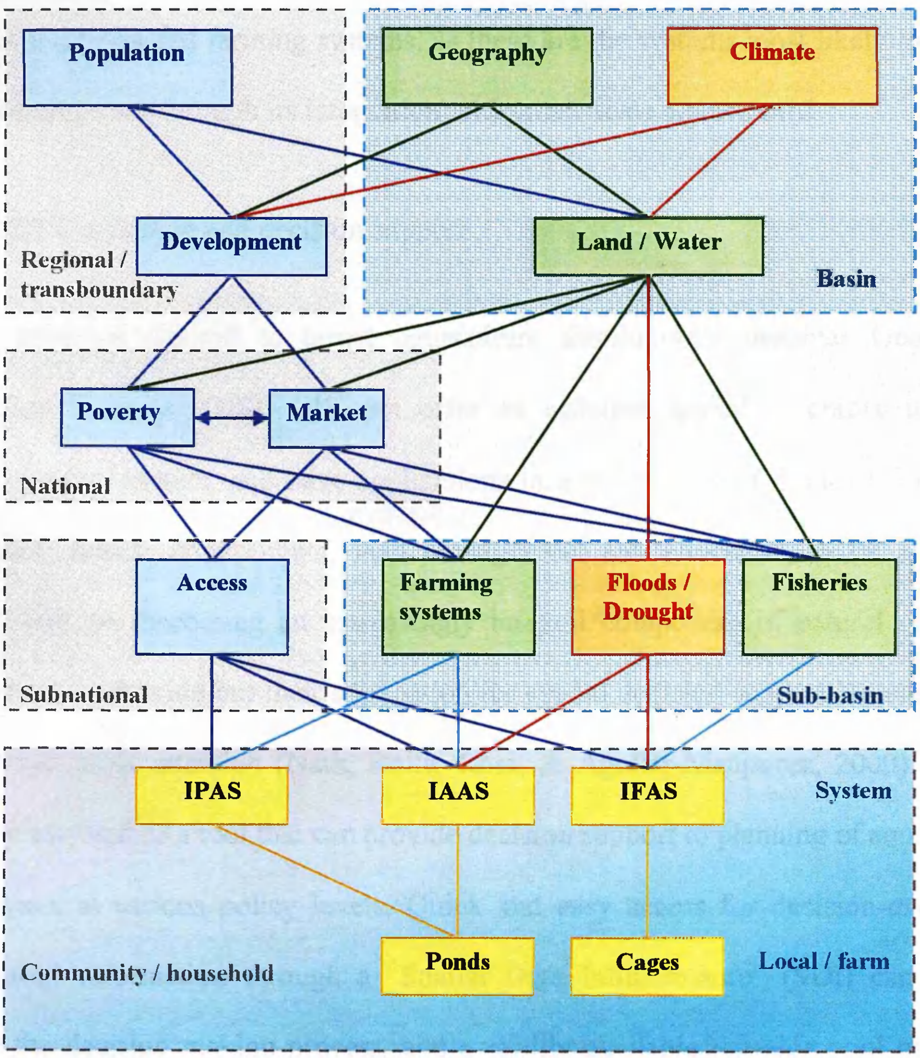


Figure 1.1 Aquaculture development decision framework, indicating multiple levels of decision making (grey outline) and geographic scales (blue outline), converging at the systems level. Boxes and linkages in red: climate related constraints, green: natural assets and production systems, blue: population and socio-economics, yellow: farmer managed systems

1.4.2 Systems focus

The policy focus and geographic focus of aquaculture development in this study finally converge in a holistic farming systems approach in order to capture the largest group of potential target beneficiaries, rural poor smallholder farmers. A systems approach of aquaculture addresses social, economic and environmental aspects as well as production technology in the narrow sense and is particularly relevant in characterising the great diversity of small scale production systems in the region (Edwards *et al.*, 1997). The emphasis is on rain-fed farming systems, as these are the systems most likely to benefit from diversification through its integration with small-scale aquaculture.

1.4.3 GIS in planning and decision support

A cost effective method to target aquaculture development involves Geographic Information Systems (GIS). GIS can offer an efficient spatial inventory tool and decision support system, and have applications in a wide range of domains, including governance, health, environment, land management and allocation, water and food security. GIS are becoming an increasingly integral component of natural resources management worldwide but their application for spatial decision support in aquaculture has received scant attention (Nath, Bolte, Ross, & Aguilar-Manjarrez, 2000). GIS in this study are used as a tool that can provide decision support to planning of aquaculture development at various policy levels. Quick and easy access for decision-makers to geographical information through a "Spatial Data Infrastructure" (SDI) can greatly enhance the decision making process, and a readily available reusable pool of spatial information is cost-effective as it avoids unnecessary and expensive recapture of existing geographic information (Global Spatial Data Infrastructure (GSDI), 2004). Publicly accessible geographical information is of increasing importance to support management and decision making at local, national, regional and global levels. Particularly in the developing world, its potential and practical benefits are not yet realised.

1.4.4 Rationale for spatial analysis

Within a spatial framework, time series of environmental data in combination with socio-economic indicators can provide new insights into where aquaculture related development will impact positively on poverty. Poverty targeting is increasingly used as a 'screen' at the project proposal stage to filter out those proposals having little or no prospect of poverty impact (Cox *et al.*, 1998). Therefore, a focus of aquaculture development in relation to poverty is explicitly taken into account. In the Mekong River Basin, Southeast Asia, living aquatic resources contribute significantly to food security, nutrition and income generation, but yield estimation using traditional production statistics is extremely difficult. Fisheries are highly diverse and widely dispersed and operate at various levels, ranging from large-scale commercial to household subsistence levels. Most aquaculture production is small-scale and run by rural households. Aquatic resources contribute to food supply and provide supplementary income through farm diversification, but there are large seasonal fluctuations in their availability. The lack of statistics on household level aquatic resource production leads to a serious underestimation of yields, and hence of its economic and nutritional importance (Phillips, 2002; Sverdrup-Jensen, 2002). Under such circumstances, an indirect approach is to estimate production via rural household consumption surveys and participatory rural appraisals (PRA's). The results can be extrapolated using secondary data on population density and rural socio-economics, including natural capital asset holdings. These data are by definition spatially distributed and can thus be spatially analysed in order to target aquaculture development on potential areas which are deficit in aquatic resources.

1.4.5 General methodology

This study consists of the seven phases ideally included in any GIS methodology as outlined by Nath *et al.* (2000). The first phase is the identification of the importance of living aquatic resources for food security and the rural economy within the context of the Mekong Basin, on the basis of literature data (Chapter 2). Then the study specifications and analytical framework are formulated with emphasis on the nature and distribution of rural poverty in the basin, and the potential for poverty reduction through sustainable aquaculture development. Sources of spatial information on the factors within the conceptual framework are identified in Chapter 3. The data are organised and manipulated for input in a general model for aquaculture suitability, which is developed at the basin level in Chapter 4. The general model outcome is verified against secondary data on current aquatic resource exploitation practice in the area. Finally, a target area with a high potential suitability for aquaculture development is defined on the basis of the model outcome and secondary data analysis.

The model is refined in two iterative steps. In the first step, the spatial distribution of poverty in Cambodia and the use of poverty data for aquaculture development targeting are explored in Chapter 5 on the basis of disaggregated poverty maps. A socio-economic submodel for accessibility of rural and urban markets to poor people is developed from the poverty data. For Sisaket province, Northeast Thailand, a spatial database is developed, by linking a national rural development database at village level to administrative boundary maps. The poverty and rural development data are used in an analysis of socio-economic variables that can explain the suitability of a target area for aquaculture development under varying scenarios and data availability.

In the second step the natural resource base in the target area is analysed in Chapter 6, with a focus on land use and flood related agro-ecosystems seasonality. Within the target area the availability of aquatic resources and suitability for aquaculture development also depends on access to private and commonly held natural resources. The outputs of the socio-economic analysis and the agro-ecosystems seasonality analysis are integrated and evaluated within a farming systems context. The evaluation is based on field verification of the socio-economic and agro-ecosystems seasonality data, supported by Landsat satellite imagery covering the field locations, as well as secondary GIS data and outputs from ongoing and past projects focusing on aquaculture and aquatic resource exploitation in those areas. It is discussed to what extent the outputs can explain patterns in rural poverty and whether or not they can be useful indicators to target aquaculture development at poor rural areas.

2 The Mekong River Basin

2.1 Target area

2.1.1 Introduction

The Mekong River Basin in Southeast Asia is the geographic unit targeted in this research. Fish is an important food commodity in the basin and the potential for increasing the beneficial impact of aquaculture on rural development and poverty reduction is therefore substantial. A basin-wide focus on environmentally sustainable aquaculture and aquatic resource development is adopted because it can provide a more systematic approach to target poverty and food insecurity through aquatic resources development. The Mekong River Basin is one of the most biologically diverse freshwater ecosystems in the world. It yields annual fish catches of up to 1.5 million tons, which are a major source of protein and basic livelihood for 65 million people (Visser and Poulson, 2001, as cited in McNally & Tognetti, 2002). Income is very low and the main development issue to be addressed is how to achieve sustainable economic development through increasing and safeguarding agricultural- and fisheries production, while alleviating poverty and preserving the unique basin environment and biodiversity. Within the basin, recent rapid agricultural and economic development has led to competition for water resources. High population density and agricultural activities are concentrated in the deltas, low-lying coastal areas and lower river valleys (Volker, 1983). Water scarcity is not yet severe, but rapid population and economic growth threaten water dependent ecosystems (CGIAR Challenge Program on Water & Food, n.d.).

2.1.2 The Mekong Basin development framework

A cooperative framework for integrated river basin management (IRBM) in the Mekong River Basin has been adopted between the lower Mekong Basin riparian countries, Cambodia, Lao People's Democratic Republic (Lao PDR), Thailand and Vietnam. The Mekong River Commission (MRC) was established by the 1995 Agreement on the cooperation for the sustainable development of the Mekong River Basin (Chenoweth, Malano, & Bird, 2001). The MRC proposes a catchment approach within the framework of one of its core programs, the Mekong Basin Development Plan. This plan will institutionalise a planning process for responsible management and sustainable development of the Basin's resources. It aims to achieve a balance between socio-economic development and environmental concerns (MRC, 2006).

2.2 Geography of the Mekong River Basin

The Mekong River is the dominant geo-hydrologic structure in mainland Southeast Asia (CGIAR Challenge Program on Water & Food, n.d.). It rises in Qing Hai province of China, in the Himalayas on the northeast rim of the great Tibetan Plateau at ca. 5000 m above mean sea level. Along its 4200 km course it flows southeastwardly through Tibet and Yunnan provinces of China and subsequently through or along the borders of five other countries, Myanmar, Lao PDR, Thailand, Cambodia and Vietnam (Figure 2.1). The point in southern Yunnan, where the river leaves China, defines the division between the upper Mekong Basin and the lower Mekong Basin (Hook, Novak, & Johnston, 2003). The total drainage basin of 783,000 km^2 includes ca. 160,000 km^2 in China, 12,000 km^2 in Myanmar and 611,000 km^2 in the lower Mekong Basin (Pantulu, 1986).

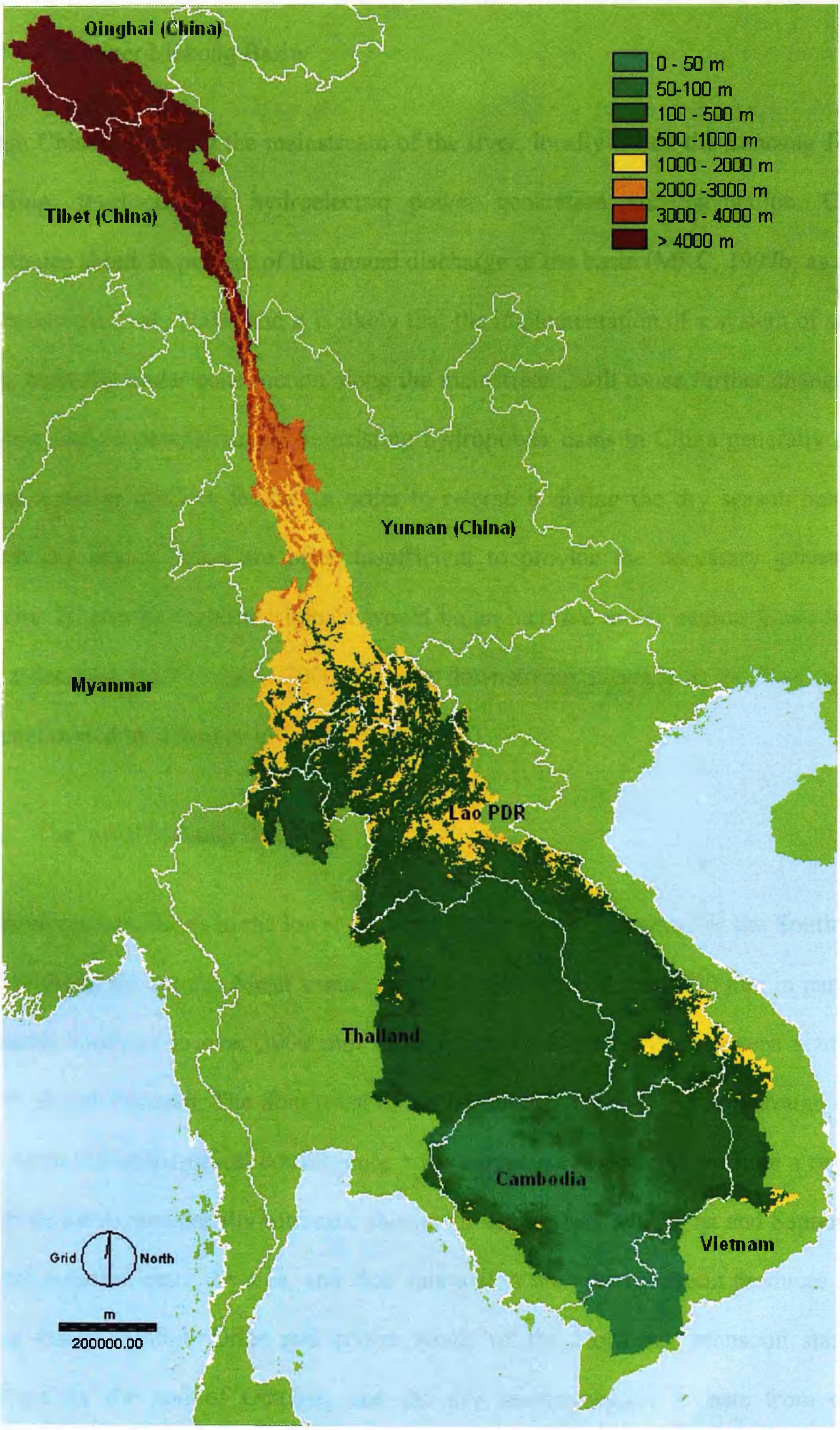


Figure 2.1 The Mekong River Basin

2.2.1 The upper Mekong Basin

Within Chinese territory the mainstream of the river, locally called the Lancang Jiang, is being developed for hydroelectric power generation and navigation. China contributes about 16 percent of the annual discharge of the basin (MRC, 1997b, as cited in Chenoweth *et al.*, 2001) and it is likely that the implementation of a system of seven dams, currently under construction along the mainstream, will cause further changes in the flow regime downstream. The existing hydropower dams in China generally store excess water in the wet season, in order to release it during the dry season because natural dry season flows are often insufficient to provide the necessary generating capacity. Hence, the expected impact would be an increase in dry season flows rather than a decrease (McCormack, 2000). Further downstream, changes in the flow regime are ameliorated by tributary inflows (MRC, 2004).

2.2.2 The lower Mekong Basin

Climatologic conditions in the lower Mekong Basin are characterised by the Southwest and Northeast monsoons. Mean annual rainfall ranges from about 1000 mm in parts of Northeast Thailand to over 3000 mm in mountainous border areas between southern Lao PDR and Vietnam. The Southwest monsoon initiates the rainy season around mid-May when the inter-tropical convergence zone moves northward and by June a regular pattern of local, occasionally torrential showers is established. In August and September tropical cyclones enter the area, and their interaction with the monsoon produces long lasting heavy rainfall. Drier and cooler winds of the Northeast monsoon start to dominate by the end of October, and the dry season begins. It lasts from early November to mid-March (Plate & Thanongdeth, n.d.). The lower Mekong Basin supplies more than 80 percent of the annual discharge of the river, and increases and decreases in river levels are strongly correlated with the annual rainfall pattern.

The lower Mekong Basin cuts across four riparian countries, Cambodia, Lao PDR, Thailand and Vietnam (Figure 2.2).

Figure 2.2 Lower Mekong Basin countries and physiographic units

Population densities vary greatly from lows of less than 10 inhabitants per km^2 to highs of more than 3500 inhabitants per km^2. These differences are mainly dictated by differences in geographical conditions. The northern part of the lower Mekong Basin, covering the northern part of Lao PDR and a small part of northern Thailand, is a mountainous region where remote and scattered settlements are found on the slopes and in valleys of the mountain range. The mountain range continues southward along eastern Lao PDR and the border of Vietnam, and terminates in the Central highlands of Vietnam and eastern uplands of Cambodia. In these thinly populated areas there is broad correlation between remoteness and poor social outcomes, particularly in terms of health and education (Hook *et al.*, 2003). Moving southwards the Mekong River forms the border between Lao PDR and Northeast Thailand. Along western central Lao PDR, a narrow strip of flat land, the Mekong Corridor, runs between the river and foothills of the mountains. The flat land continues into Northeast Thailand. This region, known as the Korat plateau, is inhabited by approximately 40 percent of the population of the lower Mekong Basin. To the south of the Korat plateau, the Mekong lowlands and Tonle Sap floodplain area of Cambodia form a vast expanse of flat land where 10 to 20 percent of the lower basin population lives. At Cambodia's capital Phnom Penh, the Mekong river divides into three arms, the lower Mekong, Bassac- and Tonle Sap rivers. The Tonle Sap river drains into the huge Tonle Sap lake as at Phnom Penh part of the river discharge is diverted into it during the early flood season. Usually in late September, the flow is reversed and the lake level starts to fall. The lake has an area of over 6,000 km^2 during the dry season, increasing up to 16,000 km^2 during extreme floods (Plate & Thanongdeth, n.d.). The Mekong Delta is the southernmost portion of the basin. Mostly within southern Vietnam (Hook *et al.*, 2003), it extends into the Mekong-Bassac floodplain and southern provinces of Cambodia. The Mekong Delta supports a dense population of around 17 million people within an area of around 40,000 km^2 (Poverty Task Force, 2003), accounting for approximately 25 percent of the population of the lower Mekong Basin (Hook *et al.*, 2003). Substantial numbers of poor live in areas of medium and high agriculture potential, but lack access to sufficient natural capital such as land or water. As a result of inequitable landholding patterns and population pressures, access to land is limited, especially for the poorest. The poor in well-endowed lowlands are often landless or near-landless.

2.3 Poverty and rural development

Across the lower Mekong Basin, marked differences exist in socio-economic conditions and levels of achievement for various indicators of human development. Although it is clear that a considerable proportion of the population in each country is poor, it is difficult to compare poverty as the political and economic systems differ among countries. Thailand and Vietnam increasingly become industrialised countries, while Cambodia and Lao PDR focus more on agricultural production. Thailand has established itself firmly in the ranks of middle income countries whereas Cambodia and Lao PDR are classified by the UN as least developed countries (Hook *et al.*, 2003).

Nevertheless there are also important commonalities that give the region coherence as a unit of socio-economic analysis as national territories are linked by the river, its watersheds and its drainage area. Perhaps the most important commonality is that the majority of the basin's population live in rural areas. Although the four riparian countries are at different levels of development, poverty and related low levels of health, education and other indicators of social wellbeing are common phenomena across the lower Mekong Basin. Most of the population live in rural areas and a considerable proportion is poor. The basin plays a vital role in their development and sustains the livelihoods of many of the rural poor living within its boundaries (Hook *et al.*, 2003). The needs for rural development are therefore likely to be similar. Aquaculture and aquatic resources development potentially can help satisfy these needs by generating alternative or supplementary production and diversification of the farmer economy. In this context, the potential impacts of aquaculture on poverty have to be assessed. A better targeted approach towards sustainable aquaculture development which helps to alleviate rural poverty has to be based on such an assessment.

2.3.1 Agriculture and flood-related seasonality

Fisheries and production of lowland rice, the staple diet and still the basis of the rural economy, are found primarily in the lower basin area. The agricultural pattern is adapted to the natural hydrological environment and productivity depends on both rainfall and flood characteristics (Volker, 1983). Proper water management plays a vital role in its development (Lesaca, 1983). Maintenance of the annual flood cycle is essential to the continued production of rice and fisheries, but floods also cause serious problems which are linked to recurrent food insecurity of rural populations within the affected areas. In August and September, flash floods in mountainous areas and inundation of fertile land in the lower floodplain areas are frequently occurring phenomena. Monsoon floods were particularly devastating in the year 2000 (CARE International, 2001; United Nations Resident Coordinator System in Cambodia, 2003), while 2003 was characterised by dryer than usual wet season conditions (MRC, 2004). The first half of 2004 has also been persistently drier.

2.3.2 Poverty and rural development in Cambodia

Cambodia is a post-conflict country which faces a formidable array of development challenges. Many of the foundations for growth and development have been shattered and need to be restored. The private sector is the driving force behind Cambodia's economic recovery (World Bank, n.d.). The expansion of small enterprise trade, the informal sector and services activities has allowed for employment of a large labour force that the market has not been able to absorb. Efforts continue to provide necessary incentives to encourage private initiative.

Sources of economic growth which have development potential in Cambodia are agriculture, natural resources, light industry and tourism. In 2001 the services sectors accounted for 43.2 percent of the economy, followed by agriculture at 37 percent and industry at 19.8 percent. Economic growth, fuelled by an expanding tourism sector and robust exports of which garments represent 90 percent, was estimated at 6.3 percent in 2001 (United Nations Resident Coordinator System in Cambodia, 2003). Cambodia's economy is showing resilience in spite of the challenging international economic environment (World Bank, n.d.). Expansion of exports, however, is jeopardised by China's accession to WTO and ending of preferential access for Cambodia's garments to US markets, which was scheduled for 2005 (United Nations Resident Coordinator System in Cambodia, 2003).

Despite its significant progress Cambodia remains one of the poorest countries in the world. It ranks 130th out of 175 in the Human Development Index (UNDP, 2003a). Among its neighbours, Lao PDR, Thailand and Vietnam it has the second lowest Purchasing Power Parity (PPP), per capita GDP and life expectancy. Purchasing power parity (PPP) measures the relative purchasing power of different countries' currencies over the same types of goods and services. This allows making more accurate comparisons of standards of living across countries (World Bank, 2003a). Annual per capita income is estimated at USD 290 in 2002.

Cambodia's economic recovery and poverty reduction is constrained by limited and high cost infrastructure, uncertain land and property rights, limited access to credit and a weak and unpredictable regulatory framework. The government lacks sufficient resources to invest adequately in health, education and basic physical infrastructure. Rates of maternal mortality and under-five mortality are high in comparison to neighbouring countries, except Lao PDR. Adult literacy (% age 15 and above) is far behind that of Thailand and Vietnam. The education and health sectors record progress in the improvement of services delivered to the population, but their geographic coverage is still insufficient (United Nations Resident Coordinator System in Cambodia, 2003).

Over the period of 1993 to 2001, agriculture has been the major sector of the Cambodian economy, sharing on average 46.4 percent in the total GDP. Growth of agricultural employment has been slow, at 1.6 percent between 1998 and 2000. Growth in secondary and tertiary sectors has been limited as well, and therefore the low productivity agricultural sector will continue to absorb the prospective labour force. About 46 percent of the labour force is categorised as unpaid family workers. In rural areas only 11 percent of the labour force was in wage employment in 1999. Households employed in the agricultural sector account for 79 percent of the poor. A well chosen poverty reduction strategy in the agricultural sector is thus critical for poverty reduction in Cambodia. The improvement of rural livelihoods is one of the proposed priority poverty reduction actions in the Royal Government of Cambodia (RGC) strategy for sustainable development, and an integral part of the National Poverty Reduction Strategy (NPRS), first presented in December 2002.

The goal set for the sector in the NPRS is to maximise food self-sufficiency of rural households through improved performance and increased productivity of agriculture, and ensure sustainable natural resources management, leading to increased food security and income generation. The strategic objectives are to "1) ensure an adequate legal framework and institutional environment, 2) strengthen capacity and improve the knowledge system within the Government, stakeholders and especially small-scale farmers, 3) promote intensification, diversification and security of agricultural production, 4) promote sustainable natural resources management and conservation, and 5) promote agricultural product processing and investment in agro-industries and strengthen the agricultural marketing system and market access" (Council for Social Development, 2002). In the context of Cambodian agriculture, modernisation is perceived as "to strengthen smallholders and promote dynamic agriculture by making use of appropriate technological innovations involving both the public and private sector with farmers having control over their production environment" (Council for Social Development, 2002).

Rice and fish and fish products, supplemented by seasonal fruits and vegetables, are staple foods in rural Cambodia. Rice is Cambodia's most important agricultural commodity and accounts for some 84 percent of annual food crop production. It occupies around 90 percent of the cropped area, along with maize, rubber, pulses, roots, groundnut, soybean and fruit and vegetables. It is mainly grown in the central Mekong Basin and Delta, and the Tonle Sap plain. Key producing provinces are Battambang, Siem Reap and Banteay Meanchey in the northwest and Takeo, Prey Veng and

Kampong Cham in the southeast. Other food crops account for some 10 percent of the total harvested area. Kampong Cham province accounts for 40 percent of non-rice crop area, being the main producer of soybean, maize, vegetables, mungbean, groundnut and sesame. Agriculture is predominantly rain-fed and depends heavily on natural conditions (WFP, 1996). Rice production fluctuates significantly with fluctuations in rainfall, and availability of vegetables and fruits can vary significantly during the dry season, depending on availability of sources of water. Of the five different rice systems practised in Cambodia, lowland rainfed rice is the main rice crop. It is cultivated during the wet season, which lasts approximately from May till December. The two other wet season rice systems are deep water- and floating rainfed rice, and rainfed upland rice. The dry season crop accounts for 10 percent of total planted area and close to 18 percent of output. It is cultivated from November till May and takes advantage of receding flood waters (FAO & WFP, 1999).

Natural disasters, particularly floods and drought, are direct threats to food security and transitory food insecurity occurs frequently. Major crop losses occur every three to four years. Poverty is closely linked to food insecurity and in rural Cambodia, having enough rice and other foodstuffs to eat 12 months per year is perceived as synonymous with not being poor or food insecure. Chronic food insecurity affects 30 percent of communes even within large rice producing provinces (Council for Social Development, 2002).

2.3.3 Poverty and rural development in Northeast Thailand

Thailand has had an impressive record of sustained economic growth for more than two decades, averaging 8 percent annually in the early 1990s. This growth was achieved mostly by a development strategy emphasising the role of the private sector and was backed by prudent macroeconomic management. Economic growth accelerated sharply, and was driven by a labour intensive export-led manufacturing boom which began in the second half of the 1980s and continued until 1996 (Siamwalla & Sobchokchai, 1998). The country was hit by a financial and economic crisis in July 1997. This brought about a severe depreciation of the national currency, the Baht. An expected impact of exchange-rate changes would be better performance of export sales, which would receive a higher Baht income. Indeed the price of rice and most other agricultural products turned sharply upwards in direct response to the rise in exchange rate. The price of rubber, at that time Thailand's second most important crop after rice, failed to respond to the depreciation. This reflected the simultaneous depreciation in the currencies of Indonesia and Malaysia, the other major suppliers of rubber to the world market.

Farmers in general appear to have benefited directly from the currency depreciation. A third of the poor households are headed by rice farmers and among the bottom decile of poor rural households a greater share of income is derived from farming than from wage labour. The direct impact of an increase in prices of rice, the staple food, on poorer households has probably been limited but the way the crisis could reach the poor was through a drop in employment. Demand for labour fell with the contraction of the economy and wage rates came down. The decline in employment started in the urban construction sector and was followed by a much larger decline in the rural sector. Manufacturing employment surprisingly was not severely affected, whereas agricultural employment declined, contrary to expectations. This decline was entirely among women as they returned to housework.

After an economic contraction by more than 10 percent in 1998, real GDP grew at 4.2 percent in 1999. Since, the economy gradually recovered, driven by strong exports and an accommodating fiscal policy. This recovery has gained momentum and real GDP grew at 6.7 percent in 2003, the highest rate since the crisis. GDP growth in 2004 is expected to be even higher, by around 0.5 percent. Total export earnings grew by 17 percent and export volume by 10 percent in 2003. Close to a fifth of total exports still comprise agriculture and resource based manufactures. Since 2001, prices of agricultural products continue to rise much faster than prices of manufactured goods. Agricultural export prices rose by 23 percent in 2003. Growing by 45.5 percent in 2003, natural rubber was the major agriculture export, contributing around 12 percent to total export growth. As a result of the rise in agriculture prices, real farm incomes have increased significantly over the past few years and rose by a record high of 26 percent in 2003. This helped boost real consumption growth. A further rise in agricultural export prices in 2004 will be led by those of fats, oils and grains. This is favourable for Thailand's key agricultural exports, particularly those of rice, maize and oils (World Bank, 2004).

Thailand succeeded in a rapid and sustained reduction of its poverty incidence. As a result of the significant drop in poverty rates, health, education and other aspects of social wellbeing have improved considerably. Since 1970 life expectancy has increased by ten years. The distribution of these gains however, lacked equity. The national average masks higher poverty incidences in specific parts of the country. One factor which helps to explain income disparities is that over 50 percent of the population remains in rural areas. Poverty is primarily a rural phenomenon and about 90 percent of the poor live in rural areas. The poverty situation is also characterised by gender inequities (Rodriguez, 1999). Income poverty in Thailand is highly related to geographic location and to the rural areas. At the regional level poverty is concentrated in the Northeast, where the five poorest provinces, with a poverty incidence greater than 35 percent, are located. While the Northeast as a whole is the poorest region in Thailand, there are large differences in poverty incidence across provinces (Figure 2.3 a). Provinces with the highest poverty incidence are generally also the ones with the highest concentration of numbers of poor people (Figure 2.3 b).

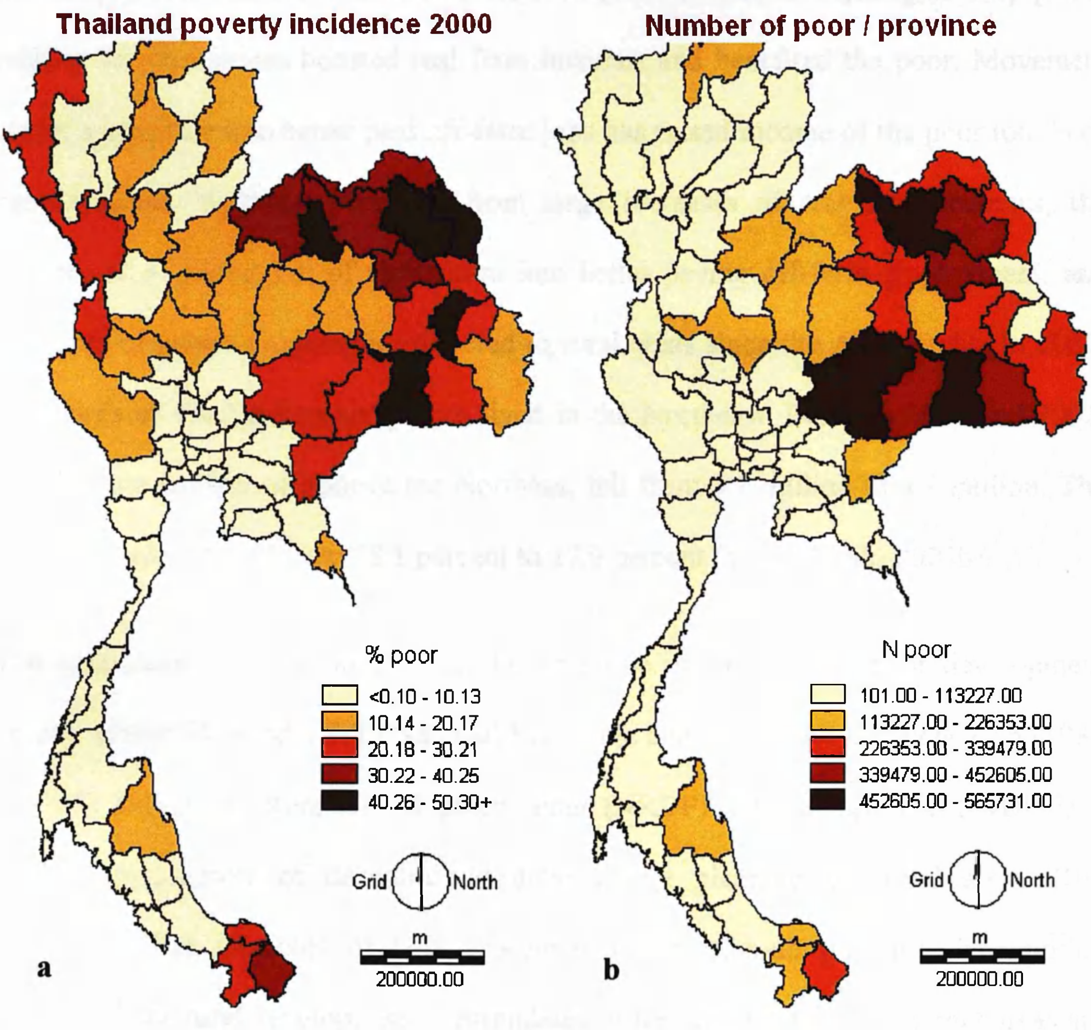


Figure 2.3 **a) Poverty incidence and b) number of poor people, Thailand (data source: UNDP, 2003b)**

Poverty is also closely related to the size of landholdings. Most poor own less than *5 rai*, equivalent to 0.8 ha (one rai equals 1600 square meters) of land. The Northeast is an area with limited arable land and water resources. Therefore, seasonal and permanent out-migration from the Northeast to Bangkok and other large cities is common. In terms of human poverty, including access to basic social services, regional variations do not coincide in all cases with regional variations in income poverty. The Northeast is better off in terms of human poverty than in terms of income poverty (Rodriguez, 1999).

Poverty in Thailand declined from a peak post-crisis level of 14.2 percent in 2000 to 9.8 percent in 2002, and has fallen further in 2004 (World Bank, 2004). Higher crop prices relative to other prices boosted real farm incomes and benefited the poor. Movement out of agriculture into better paid off-farm jobs has raised income of the poor too. Poor people in the Northeast benefited from large increases of real farm incomes, the movement of labour out of agriculture into better paying off-farm employment, and increases of public programmes directed to rural areas since the Asian crisis. In 2000, two-thirds of Thailand's poor people lived in the Northeast. Between 2000 and 2002, the absolute number of poor in the Northeast fell from 5.9 million to 3.8 million. The poverty headcount fell from 28.1 percent to 17.9 percent (World Bank, 2003b).

The eradication of rural poverty has become one of Thailand's major development targets. Under Thailand's Fifth National Economic and Social Development Plan (1982 – 1986) a National Rural Development Plan (NRDP) was set up. The NRDP is a national programme of decentralised development planning for rural areas. The programme has elements of both top-down and bottom-up planning. The policy framework for rural development is formulated at the national level but target areas are selected at the provincial level in response to problems and needs identified by the rural population. It is at this level that Tambon (sub-district) Development Plans are screened and coordinated in order to draw up District Development Plans and finally to formulate the Provincial Development Plan. Decentralisation of planning to the local level assures that local organisations and officials, involving the rural population, are to play a major role in offering solutions to particular problems and fulfilling real needs of particular areas. In order to achieve this objective, the classification of target areas and target groups and promotion of people's participation at the local level are important prerequisites (Kaojarern, 1986).

It has been realised that the lack of a single integrated framework in the past has led to poor coordination, both vertically and horizontally, between the various authorities and their agencies involved in the rural development programme, at all stages of the planning and implementation process. The lack of continuously and systematically collected data was among the several problems and bottlenecks which hindered information sharing and the effectiveness of planning. In response to this, a national rural development database at village level, known as the NRD-2C, was established in order to provide the basis for a more detailed identification of development needs. The use of this dataset among government agencies at various administrative levels and non-government field agencies will strengthen coordination among these agencies and will be conducive to the formulation of coherent rural development plans which will be carried out in a systematic way and over an extended period (Kaojarern, 1986).

2.3.4 Poverty and rural development in the Vietnamese Mekong Delta

Vietnam has achieved rapid economic growth during the 1990s and social- and other welfare indicators have improved significantly (World Bank, 1998). Remarkable progress has been made across a broad range of socio-economic development issues. Life expectancy has increased to 68 years and infant mortality has declined to 27 per 1000 live births in 2000. Adult literacy has been maintained at over 90 percent and primary school enrolment rates attained nearly 95 percent in 1998-99. Vietnam ranked

109th out of 175 in the Human Development Index 2003 (UNDP, 2003a). Vietnam's GDP per capita is estimated at USD 553.27 in 2004 and real growth of GDP stood at 7.69 percent in the same year. Industry and construction accounted for 40.1 percent of GDP, followed by services at 38.1 percent and agriculture at 21.8 percent (UNDP, 2005).

Vietnam has managed to avoid the worst of the Asian economic crisis, which started in 1997, through prudent management of its economy. It achieved solid growth and poverty reduction throughout the recession (World Bank, 2002). The Asian Development Bank (ADB) estimates GDP growth at 5.5 percent yearly from 1998 to 2002. Export growth, though falling to 2 percent in 1998, averaged over 12 percent per year. Its value rose from USD 9.1 billion in 1997 to 16.5 billion in 2002. Vietnam took a growing share in global exports of garments and shoes. In the same period manufacturing growth averaged about 10 percent yearly, in real GDP terms and gross industrial output grew at an even faster pace of about 14 percent yearly. The fast growth in manufacturing has been of uncertain quality. A lot of the output gains have come from highly protected state sponsored heavy industry. Private investment has been the most dynamic sector since 2000. Industry under private ownership has experienced nearly 20 percent yearly growth since 1999. The entire formal private sector created 1.75 million new jobs from 2000 to 2002 while there was near zero growth in jobs for the entire public sector (Dapice, 2003).

Vietnam has achieved major progress in poverty reduction. The poverty rate dropped from well over 70 percent of the population in the mid 1980s to around 37 percent of the population in 1998. The remarkable decline in the incidence of poverty from 58.2 percent in 1992-93 to 37.4 percent in 1997-98 is one of the sharpest of any developing country on record. Much of the poverty reduction results from Vietnam's high economic growth rates at 8 to 9 percent in the early 1990s, and specifically from its strong agricultural performance since the late 1980s. Reforms in the agricultural sector transformed Vietnam from a country experiencing profound food shortages into one of the world's leading exporters of rice, coffee and other agricultural commodities. Life in rural areas, where nearly 90 percent of poor people live, has improved significantly. The promotion of rural development is a key component of a comprehensive strategy to enhance human development in Vietnam (UNDP, 2001).

Poverty has dropped further from its previous level of 37 percent of the population in 1998 to 29 percent in 2002, but income data by province and urban authority demonstrate that income inequality has risen significantly from 1995 (UNDP, 2001). Poverty continued to be a largely rural phenomenon. Almost 30 million people, around one-third of the population, still live in poverty and millions are still vulnerable to fall back into poverty. The poorest rural households are those whose livelihoods rely on farming only, while those who diversify into off-farm employment do better. Around 25 million people, 60 percent of the labour force, are underemployed in rural areas and rapid growth of rural and urban off-farm employment is essential. Domestic private sector development is perceived to be best placed to provide necessary new jobs, also in rural areas (Dapice, 2003; UNDP, 2001).

Nevertheless, absolute poverty is still high. Fifteen percent of the population is so poor that consumption is inadequate to meet nutritional needs (Turk, 2001). The rural population constitutes 80 percent of the total population and rural poverty incidence is much higher than in urban areas. Ninety percent of the poor live in rural areas, thus rural development is essential for growth and poverty reduction. The largest poverty reduction effect has come from the increase in paddy production, as a result of land reform from collective to household tenure and the liberalisation of prices, which stimulated farmer investments. The main reduction in poverty has as a result been in the rice-growing areas. Rice is still the basis of the rural economy. Seventy percent of Vietnamese households grow rice and rice accounts for three-quarters of the caloric intake of the average Vietnamese household. The rural poor in the lowland and midland provinces perceive an increase in rice productivity as the first priority for increased food security.

Although the extent of poverty declined across the seven regions of Vietnam during the period 1993-98, economic growth has not been equitable across regions (Poverty Working Group, 2000). Geographically, the poorest provinces are found in the North Central Coast region, the Northern Uplands and the Mekong Delta region. The nature of poverty in the lowland delta areas is heterogeneous in comparison to poverty in the mountain areas and north central coastal areas. It is found in the midst of better-off rural areas. There are pockets of poverty in all communities and inequalities are emerging between individuals and households in the same communities based on age, gender, ethnicity and access to land and capital. There is sometimes a connection between poverty and social exclusion. Social marginalisation is more common for the poor in market-integrated areas. The poor in relatively well-off communities are often excluded from services and activities.

The Mekong Delta is notable for being relatively land abundant and highly irrigated. This contributes to its per capita food production which is substantially higher than that of any other region. Most of its districts are relatively well off except for a few coastal districts and one on the Cambodian border. Of all seven economic regions poverty reductions were nevertheless smallest in the Mekong Delta, experiencing only moderate declines of about 10 percentage points in overall poverty during the period 1993-98. Nearly 9 percent of households slipped into poverty and only 19 percent escaped poverty. Many of the newly non-poor households are still nearly poor, hovering close to the poverty line. Their vulnerability to shocks and crises coupled with the recent slowdown in economic growth means that the gains in poverty reduction cannot yet be considered robust (Turk, 2001). Poverty is connected very closely with vulnerability. Floods and drought occur frequently, and this contributes to a general level of vulnerability. The relatively poor performance of the Mekong Delta may reflect the fact that Typhoon Linda struck the Mekong Delta in November 1997, causing many previously non-poor households to fall into poverty, which underscores the vulnerability of Vietnamese households to risk (Glewwe *et al.*, 2000).

Poverty is increasingly connected with dependence on a rice monoculture and seasonal unemployment. Rice production for income generation is becoming less attractive with decreasing profitability. The poor who are dependent on rice are becoming more vulnerable to seasonal crises than people in the hilly areas, who have more diversified sources of income, even though they are often poorer than those in the paddy-growing areas. Poverty is associated with having less land per capita, lower food production per capita, and a smaller share of land allocated to perennial crops. Farmers have to meet essential needs out of tiny, fragmented plots of agricultural land, on average less than 0.2 hectare per capita (Oxfam, 2001). The most common poverty indicator used in Vietnam is food production per capita, expressed in paddy equivalent (Anh, 1997 and Huu, 1997 as cited in Minot, 2000). Minot & Baulch (2002) showed in their study on geographically disaggregated estimates of poverty, that it is not a particularly good indicator. The results demonstrated that many household characteristics are, individually, fairly weak predictors of poverty, but, when combined they are more accurate predictors. The proportion of rural households having farming as their main occupation (78.4 percent of rural households), was highest among the two poorer of four expenditure categories (Poorest 25 percent, 2nd quartile, 3rd quartile, Richest 25 percent), the two richer categories presumably having more household income from non-farm self-employment and wages. The proportion of fishing households (2.4 percent of rural households) was found to be highest among these two richer expenditure categories, which suggests that farming households are more likely to be poor than fishing households.

The nature of poverty in Vietnam is changing and there is need for more carefully targeted measures of poverty alleviation. Before, policies for rural development and poverty reduction have focused on overall growth and development of the rural economy, aiming at raising the living standards of the rural population as a whole. The relatively even distribution of resources in the rural areas, especially land, has resulted in a positive relation between economic growth and poverty reduction (Beckman, 2001).

The initial redistribution of land as a result of land reform has in general been equitable, but concerns arise about increases in landlessness, particularly in the South. Many poor people in the South are landless labourers, because of the skewed access to land. The majority of poor households have little or no land. Non-agricultural supplementary incomes are not yet widespread. Non-agricultural small-scale enterprises are becoming more common, but there is a lack of advisory services to provide the knowledge and information required to venture into new types of enterprise (Beckman, 2001). The slow development of local businesses and job opportunities currently poses the greatest constraint for sustainable poverty reduction in the Mekong Delta (Poverty Task Force, 2003).

The policy focus has shifted from concentrating on securing rice production for food security and export during the 1990s to rural agro-based industrialisation and employment creation. Revenues from non-rice production are playing an increasingly significant role in the household economy. In the lowlands, a diversification of sources of income is needed, and households which are able to generate a surplus invest it in diversification through other crops, animal husbandry and small rural businesses. Animal husbandry has been the most common way for farmers to diversify their income. Pig rearing is extremely important in the household economy, especially for rice farmers to bridge the long gap between the autumn and spring harvests. However, profitability is not very high and pig rearing continues to be mainly an occupation for the poor. Many people suffered considerable losses because of repeated failures of investment in animal husbandry after the floods, when disease removed a lot of animals. People are gradually orienting themselves to domestic markets for vegetables and meat (Beckman, 2001). Farming household revenues from livestock and aquaculture increased by 53 percent during the period 1993-98, whereas real revenues from rice production increased only by 21 percent (Poverty Working Group, 2000).

2.3.5 Summary

The lower Mekong Basin areas linking Cambodia, Northeast Thailand and the Vietnamese Mekong Delta vary in poverty levels and are in different stages of rural development. Nonetheless, poverty reduction and rural development face a number of common challenges. Poverty is connected with low agriculture productivity, seasonal unemployment, and vulnerability to shocks and crises. Poverty is also closely related to the limited size of landholdings, and many of the poor are landless. Developments in Northeast Thailand and Vietnam have shown that initially, impressive results in rural poverty reduction can be achieved through investments in public programmes directed to rural areas, for example through equitable land distribution policies and infrastructure development. However, such programmes alone are probably not sufficient for sustainable rural development and poverty reduction. Sustainable rural development can benefit from diversification out of the rice-based economy and generation of income and employment opportunities through private sector development and rural agro-based industrialisation. Pro-poor aquatic resources development has to take these factors into account in order to realise its potentially significant contribution to rural development.

2.4 Status and trends in aquatic resource exploitation

Freshwater ecosystem diversity is huge in the Mekong Basin, and is supported by a wide range of available permanent and seasonal habitats. Vast seasonal floodplains, which are highly productive in terms of fish and other aquatic animals, are a result of the annual flood pulse caused by monsoon rains, and in the dry season fish seek refuge in permanent water bodies such as lakes and deep pools, or within river channels. Capture fisheries are highly diversified, and adapted to the complex and diverse environments in the basin. Participation in capture fisheries is high throughout the basin, and capture fisheries contribute significantly to food security, nutrition and income generation. On a seasonal basis, fishing is a part time activity for virtually all farming households, and the number of rural dwellers active in the fishery is estimated at about 40 million. In many areas of the lower Mekong Basin, community fisheries management traditions are long standing, and are established to sustain local resource levels and to ensure equitable distribution of benefits amongst local resource users.

Growing political interest in such schemes has recently led to the establishment of co-management arrangements within the riparian countries, through which fisheries are jointly managed by public authorities, resource users and other stakeholders at various administrative levels. At the national level, inland fisheries management varies from country to country. Several species stocks are transboundary but few institutional arrangements exist at the regional level for the joint management of these resources. Impacts of other sectors on fisheries are generally negative, as they result in changes in the aquatic environment which affect the integrity of the natural resource base as well as socio-economic conditions. Environmental degradation poses a major threat to sustaining capture fisheries. Water availability is increasingly affected by development activities at all levels, and conflicts about the allocation of water between various sectors are escalating (Sverdrup-Jensen, 2002).

2.4.1 Yields and economics of aquatic resource exploitation

Demand for fish is high throughout the lower Mekong region. A 20 percent increase in fish demand over the next 10 years is predicted due to population growth. The true economic value of the natural aquatic resources of the Mekong Basin is difficult to estimate through a cost-benefit analysis, as economic values for food security and informal employment, as well as non-consumption and ecosystem values, are difficult to assess. Based on an average farm gate price of USD 1.05 per kg of cultured fish and an average initial sale price of USD 0.68 per kg of captured fish, the total market value of aquatic production in the basin is about 1,400 million USD. Expansion of aquaculture could contribute significantly to meet the increasing demand for fish products in the basin. Most aquaculture production comes from small-scale fish farms, run by rural households, where it contributes to food supply and provides supplementary income through farm diversification. Ponds and rice fields are the most common means of producing fish throughout the basin, except in Cambodia. There are distinct differences between fish culture operations in peri-urban areas close to markets and fish seed supplies, and systems in rural areas far from markets and support services. Peri-urban systems have better access to agricultural inputs, and can be integrated with intensive livestock production, particularly pigs and poultry, which provides wastes useable in aquaculture. Small scale rural aquaculture has considerable potential to reduce food insecurity, particularly in areas where wild fish stocks are insufficient to meet demand (Sverdrup-Jensen, 2002).

Aquaculture and capture fisheries in the Mekong basin are closely interrelated (Phillips, 2002; Sverdrup-Jensen, 2002). Capture fisheries supply wild seed and feed fish as inputs to aquaculture, and in rice fish culture wild fish enters into the field during the flood season, and is retained by a system of dikes and trenches around the rice field as floods recede. Alternative methods comprise trapping fish in the major irrigation canals or keeping fish and stocking juveniles in ponds, or in deep-flooded areas, within a system of fences. Constraints to the development of aquaculture are of an institutional rather than technical nature. A shift from a sectoral approach towards an integrated approach for natural resources management, in which aquaculture, capture fisheries and water resources are considered as a holistic system is required. The integration of aquaculture and fisheries into wider rural development strategies for alleviating poverty and increasing food security is essential. Aquaculture products are becoming more important in the basin's fish markets but reliable data on fish marketing in the lower Mekong Basin are scarce. Fish marketing data provide clues about potential supply, demand and distribution channels for fish, and are therefore vital for aquaculture development planners. The supply infrastructure and the availability of wild fish have an important influence on markets for aquaculture products. Cultured fish can be marketed during the dry season when there is insufficient wild fish and market prices are favourable, and it can be marketed live, providing a fresher product (Naret, Viryak, & Griffiths, 2003).

Aquatic resources are an important source of food and income in the lower Mekong Basin. The fishery production from natural freshwater bodies in the basin is estimated at approximately 1.5 million tonnes per year, with an additional 240,000 tonnes of reservoir fisheries catches. Given the total of 10 million ha of wetlands in the basin, the total catch from natural water bodies corresponds to a fairly realistic catch estimate of 150 kg per ha per year from such areas. Mekong fisheries yield estimation using traditional fisheries statistics collection is extremely difficult, as fisheries are highly diverse and widely dispersed. There are no centralised landing ports, and catches vary seasonally. Numerous species are fished with a wide variety of gears, and, most importantly, fisheries operate at various levels, ranging from large-scale commercial to household subsistence levels. The lack of statistics on household level or subsistence fisheries leads to a serious underestimation of yields, and hence of its economic and nutritional importance (Sverdrup-Jensen, 2002).

Under such circumstances, an indirect approach to collect fisheries data is via rural household consumption surveys, which have been conducted in 15 of the 87 provinces in the lower Mekong. These surveys suggest that annual fish consumption ranges from 20 kg per person in mountainous areas with limited access to fish resources, to 70 kg per person in floodplain areas of Cambodia and Vietnam where fish is abundant during most of the year. Annual fish consumption in Northeast Thailand is estimated at about 36 kg per person. Most fish supply comes from local, inland areas. Extrapolation of household survey findings provides a conservative estimate of 2 million tonnes annual consumption of fish and other aquatic animals in the basin. The bulk is consumed locally or traded fresh at village, district or provincial markets. Seasonal peaks in fisheries catches have stimulated the development of a considerable processing industry, which produces dried and fermented fish products, fish sauce and fish paste. This industry adds value to the catch and generates employment. Hence economic and nutritional benefits from fisheries are extended over the full year (Sverdrup-Jensen, 2002).

2.4.2 Aquaculture product demand and marketing

Aquaculture production increased nearly five-fold over a 10-year period in the lower Mekong Basin, from around 60,000 tonnes in 1990 to around 260,000 tonnes in 2000, excluding brackish water prawn culture. Based on an average price of USD 1.05 per kg of cultured fish it has a farm gate value of about 270 million USD. Market demand strongly influences the development of aquaculture. Low per capita income may limit the scope for aquaculture in some areas of the basin, for example in Lao PDR where economic factors, including a poorly developed market economy outside major towns and lack of access to credit, pose a major constraint to its development (Sverdrup-Jensen, 2002).

The spectrum of people involved in aquaculture is wide and includes poor people as well as the better off. For the better off, aquaculture can offer a lucrative return on investment (Phillips, 2002). Aquaculture is a source of employment, cash and food for rural households. Poor farmers adopt aquaculture where certain predisposing conditions are met. One of these is that consumers, including the farmers themselves, must perceive the value of fish, and this must be reflected in market demand. Early attempts to promote small scale aquaculture which solely focused on household food security often have failed (Edwards, 2000). Nevertheless, small scale farm household contributions to aquaculture are increasing throughout the basin. Except for cage farming of catfish in the Bassac River and large integrated fish farms near urban centres in Northeast Thailand, there are relatively few large scale aquaculture operations in the basin (Phillips, 2002; Sverdrup-Jensen, 2002).

3 Methodology and data sources for spatial analysis

3.1 Data sources and use in the spatial analysis

3.1.1 Spatial information sources

The extent and scope of poverty oriented aquatic resources management and aquaculture in the target area is explored on the basis of three broad sources of spatial information. First, satellite imagery and derived products in this study are used to identify natural assets, population distribution and vulnerability of rural residents to exogenous shocks related to adverse impacts on natural resources. Socio-economic data are not inherently of a spatial nature but can be expressed as spatial information through linkage of the database to administrative boundary vector layers. Thus a spatially referenced database is created by mapping secondary data and used to model the geographical distribution of poverty and rural socio-economic factors. This information is verified through field visits to specific target provinces within the area.

Spatial analysis of the target area employs a range of satellite derived data, extracted from global spatial databases on climate, population, land use and land cover. Satellite derived data used in this study are pre-processed, public domain resources and are accessible through the Internet (Appendix I). The satellite derived information is verified by means of a set of Landsat TM and ETM+ satellite imagery covering the target area. Most of the employed Landsat satellite imagery is available on the Internet, but some additional Landsat ETM+ scenes were purchased through the United Nations Environment Program (UNEP) Regional Office for East Asia and the Pacific.

The accuracy of satellite derived information was verified by field visits. The farming systems under consideration were geolocated by registering their geographic coordinates with the aid of a hand held GARMIN GPS III global positioning system (GPS). At each field location photographs were taken with a Canon PowerShot A40 digital camera and a Fujicolor ISO 800/30° QuickSnap SUPERIA X-TRA 800 disposable camera.

3.1.2 GIS software and hardware

Two versions of the IDRISI software package (Clark Labs, USA) were used throughout the project; IDRISI32 Version 32.02 and IDRISI Kilimanjaro Version 14.02. IDRISI is a raster analytical system but it also employs vector data structures. Raster systems graphically represent features and their attributes into a fine mesh of grid cells which record the condition or attribute of the earth surface at that point. As a result of the uniform definition of geographical space in a simple and predictable fashion, these systems have substantial analytical power in the analysis of continuous space. The basic data structure of vector systems is a network. Vector systems tend to be more database management oriented (Eastman, 1999).

The image processing and modelling of satellite derived information was performed entirely within the IDRISI environment. Vector data interchange was performed initially with ERDAS IMAGINE v8.3.1 and later substituted by ArcView 3.x. in order to convert the ESRI proprietary .e00 vector file format to shape files (.shp) that can be imported by IDRISI. For digitising purposes a spatial data builder, CartaLinx V. 1.2 (Clark Labs, USA) was employed. The spatial data builder was mainly used for topological editing of imported vector files and the preparation of point vector files from geographic coordinates collected during the field visits. The GIS software was operated on a DELL PWS 360 workstation with 1.00 Gb of RAM and 111 Gb hard disk. Display was via a DELL UltraSharp 21" colour monitor.

3.1.3 Scale effects

Spatial information incorporates space or location as an explanatory variable, and is inherently scale sensitive. Structural heterogeneity is the norm within ecosystems and a systems approach requires explicit identification of spatial and temporal variability of climate- and agro-ecological as well as socio-economic factors. Scale effects are prevalent in spatial analysis, and most spatial data are available in some aggregated form (Nelson, 2001). The results of spatial analysis do not only depend on the degree of data aggregation but also on the areal unit chosen. This is known as the modifiable areal unit problem (MAUP), described by (Openshaw, 1984). The multiple scales employed in this study range in resolution from ca. 55 km for coarse scale climate models to a 15 m resolution of the Landsat ETM+ satellite panchromatic band.

The spatial resolution of data based on administrative area units is dependent on the administrative level at which the data are collected and the surface area of each unit. The coarsest resolution employed in this study is the province level, but the level targeted for analysis is the commune level. Where village level data are available, these are extrapolated or averaged at the commune level. Individual household data were not available at the scale of this study; hence the smallest unit of analysis is the village, which is spatially represented as a vector point, located by a single pair of coordinates. Larger administrative units are represented as vector polygons. Rural poverty and livelihood production data are visualised at the commune level.

3.2 Earth observation

3.2.1 Earth science data and observation

Public access to remotely sensed Earth observation data is available through the Earth Observing System Data and Information System (EOSDIS). EOSDIS has been developed by the Earth Science Data and Information (ESDIS) Project for the National Aeronautics and Space Administration (NASA, USA) Earth Science Enterprise (ESE) and has been operating since August 1994 at 8 Distributed Active Archive Centers (DAACs) around the United States. It interoperates with 6 foreign sites. The system manages data from NASA's earth science research satellites and field measurement programs, and provides data archiving, distribution and information management services. The ESE operates six larger spacecraft; the Tropical Rainfall Measuring Mission (TRMM), Landsat-7, Terra, Aqua, the Ice, Cloud and land Elevation Satellite (ICESat), and Aura. The EOS Terra, Aqua and Aura spacecraft orbits are 98.2 degree inclined, 705 km, 16 day, 233 orbit repeat cycles. The Landsat-7 orbit and position is very close to the Terra orbit and position (EOSDIS, 2004).

The National Oceanic and Atmospheric Administration (NOAA, USA) operates the National Environmental Satellite, Data and Information Service (NESDIS). NOAA's environmental satellite system is composed of geostationary operational environmental satellites (GOES) and polar orbiting environmental satellites (POES), providing together a complete global weather monitoring system. GOES provide short-range warning, and POES provide longer term forecasting. The geosynchronous plane of GOES is about 35,800 km above the Earth. POES offer daily global coverage, by flying nearly polar orbits roughly 14.1 times daily (NESDIS, n.d.). NOAA offers on-line access to its environmental data through its electronic library, the Comprehensive Large Array-data Stewardship System (CLASS).

Remotely sensed data of relevance to this research was accessed through the EOS Data Gateway and the Land Processes (LP) Distributed Active Archive Center (DAAC), both established as part of NASA's EOSDIS initiative. The satellite platforms and instruments that generated the data used in this study are described below.

3.2.2 EOS Terra

Terra has a polar, Sun-synchronous orbit, and the mean local solar time at the descending equatorial crossing is at 10:30 a.m., when daily cloud cover is typically at a minimum over land, and surface features can be more easily observed. The payload consists of five instruments; Advanced Spaceborne Thermal Emission and reflection Radiometer (ASTER), Clouds and Earth's Radiant Energy System (CERES), Multi-angle Imaging Spectro-Radiometer (MISR), Moderate Resolution Imaging Spectro-Radiometer (MODIS) and Measurements of Pollution in the Troposphere (MOPITT) (Maurer, 2001).

MODIS is playing a vital role in the development of validated, global, interactive Earth systems models which contribute to a better understanding of global dynamics and processes occurring on the land, in the oceans, and in the lower atmosphere. The MODIS instrument is a whisk-broom scanning radiometer which provides high radiometric sensitivity (12 bit) and acquires data in 36 spectral bands, ranging in wavelength from 0.4 μm to 14.4 μm, covering the visual (VIS), near-infrared (NIR), short- and medium-wave infrared (SWIR/MWIR) and long-wave infrared (LWIR) spectral regions. Two bands are imaged at a nominal resolution of 250 m at nadir, five bands at 500 m, and the remaining 29 bands at 1 km. The Scan Mirror Assembly (SMA) uses a continuously rotating double-sided scan mirror and depending on a the location of a target within the MODIS swath, the view zenith angle varies from nadir (0°) to 55° (Diner *et al.*, 1999). At the EOS orbit of 705 km it achieves a 2,330 km swath and the instrument provides global coverage every one to two days.

3.2.3 Landsat-7

Landsat-7 is a three-axis stabilised platform that carries a single nadir pointed instrument, the Enhanced Thematic Mapper Plus (ETM+). The mean local solar time at its descending equatorial crossing is at 10:00 (± 15 min) a.m. It has a swath width of 185 km and provides full coverage of the Earth every 16 days. The ground track of the spacecraft follows the standard World-wide Reference System (WRS) used by Landsat 4 and 5. The Landsat-7 sensor (ETM+) is designed as a nadir-viewing, eight-band (Table 3-1) multispectral scanning radiometer capable of providing high resolution imagery of the earth surface.

Table 3-1 Landsat-7 spectral bands, range and resolution

Band Number	Spectral Range(μm)		Ground Resolution(m)
	ETM+	TM	
1	0.45 to 0.52	0.45 to 0.52	30
2	0.53 to 0.61	0.52 to 0.60	30
3	0.63 to 0.69	0.63 to 0.69	30
4	0.75 to 0.90	0.75 to 0.90	30
5	1.55 to 1.75	1.55 to 1.75	30
6	10.4 to 12.5	10.4 to 12.5	60
7	2.09 to 2.35	2.08 to 2.35	30
Pan	0.52 to 0.90	N/A	15

The primary performance related changes over the Thematic Mapper (TM) sensors flown aboard the Landsat-4 and -5 satellites, are the addition of the panchromatic band and two gain ranges, the improved spatial resolution for the thermal band, and the addition of two solar calibrators (NASA, 1998).

3.2.4 NOAA polar-orbiting satellite series

NOAA's polar-orbiting satellites are known as Advanced Television Infrared Observation Satellites (TIROS-N or ATN) and its data supports a broad range of environmental monitoring applications. Its payload includes the Advanced Very High Resolution Radiometer (AVHRR), which is a radiation detection imager that can be used for remotely sensing cloud cover and surface temperature (Table 3-2), and the Tiros Operational Vertical Sounder (TOVS).

Table 3-2 AVHRR/3 Channel Characteristics (Source: NOAA, 2003)

Channel Number	Resolution at Nadir	Wavelength (um)	Typical Use
1	1.09 km	0.58 - 0.68	Daytime cloud and surface mapping
2	1.09 km	0.725 - 1.00	Land-water boundaries
3A	1.09 km	1.58 - 1.64	Snow and ice detection
3B	1.09 km	3.55 - 3.93	Night cloud mapping, sea surface temperature
4	1.09 km	10.30 - 11.30	Night cloud mapping, sea surface temperature
5	1.09 km	11.50 - 12.50	Sea surface temperature

Currently, NOAA is operating five polar orbiters. NOAA-12, NOAA-14 and NOAA-15 all continue transmitting data as stand-by satellites. NOAA-16 and NOAA-17 are classified as the operational satellites. NOAA-15 is the first of a new series of orbiters with improved sensors, carrying the latest version of the AVHRR sensor, the AVHRR/3 with 6 channels, permitting improved multi-spectral analysis (NOAA, n.d.).

3.3 Remote sensing for environmental resource management

3.3.1 Introduction

Vegetation, land cover, and land use change provide the basis for understanding land and water resource management. The analysis of these factors is a major application of remote sensing for environmental resource management. Applications include agricultural monitoring and forecasting, land use planning, hydrologic modelling, land cover characterization and land cover change detection (NASA, 1997).

3.3.2 Vegetation indices

Vegetation Indices (VI) are radiometric measures of the amount of vegetation present on the ground in a particular pixel, and are robust, empirical measures of vegetation activity at the land surface (Huete, Justice, & van Leeuwen, 1999). The quantitative assessment of green vegetation from measured spectral responses is based upon the very distinctive interaction that healthy green vegetation has with energy in the visible and near-infrared regions of the electromagnetic spectrum. In the visible regions, plant pigments cause strong absorption of energy, primarily for the purpose of photosynthesis. Energy in the near-infrared region is not used in photosynthesis and is strongly scattered by the internal structure of leaves, leading to a very high apparent reflectance in the near-infrared. Vegetation index (VI) models make use of this feature by combining two or more different wavebands, normally in the red (0.6 μm to 0.7 μm) and NIR 0.7 μm to 1.1 μm) wavelengths (Huete *et al.*, 1999). Slope based VIs are simple arithmetic combinations of the visible red and the near infrared bands. The most commonly used VI is the Normally Differentiated Vegetation Index (NDVI). It is expressed as the difference between the near infrared (ρ_{NIR}) and red (ρ_{RED}) bands, normalised by the sum of those bands.

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}$$

The measurement scale ranges from -1 to 1, with 0 being the approximate value of no vegetation. Negative values represent non-vegetated surfaces (Thiam & Eastman, 1999). In order to minimise data volume and optimise analysis and display it is recommended to scale computed NDVI results to 8-bit range. The USGS Earth Resources Observation Systems (EROS) Data Center (EDC) routinely scales the NDVI from -1.0 to 1.0 as integers from 0 to 200, where each value represents 1 percent of the total possible range (Eidenshink & Faundeen, 1994). That routine was adopted for this study because image analysis and computational modules in IDRISI often require the data to be in byte binary format.

MODIS Vegetation Index (VI) products provide new and improved tools for moderate resolution land vegetation condition monitoring. The emphasis has shifted to operational external noise removal through improved calibration, atmospheric correction, cloud and cloud shadow removal, and standardization of sun-surface-sensor geometries with bidirectional reflectance distribution function models. In addition to the standard NDVI, which is referred to as the "continuity index" to the existing NOAA-AVHRR derived NDVI, an enhanced vegetation index (EVI) has been developed, which has improved sensitivity with regard to high biomass regions. The EVI provides improved vegetation monitoring through a de-coupling of the canopy background signal and a reduction in atmospheric influences.

$$EVI = G * \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + C_1 * \rho_{RED} - C_2 * \rho_{BLUE} + L}$$

where ρ_{NIR} = NIR reflectance, ρ_{RED} = red reflectance, ρ_{BLUE} = blue reflectance, C_1 = atmosphere resistance red correction coefficient, C_2 = atmosphere resistance blue correction coefficient, L = canopy background brightness correction factor, and G = gain factor. The coefficients adopted in the EVI algorithm are $L = 1$, $C_1 = 6$, $C_2 = 7.5$, and $G = 2.5$. C_1 and C_2 are the coefficients of the aerosol resistance term, which uses the more atmosphere sensitive blue band to correct for aerosol influences in the red band based on the concept of wavelength dependency of aerosol effects. The canopy background adjustment factor L addresses non-linear, differential NIR and red radiant transfer through a canopy and renders the EVI insensitive to most canopy backgrounds. Canopy backgrounds exhibit low- and high frequency spatial and temporal variations that can greatly influence the vegetation index signal. Canopy background correction is relevant for vegetation monitoring since 70 percent of the terrestrial Earth surface consists of open canopies with significant canopy background signals exerting some effect on the canopy reflectance properties (Didan & Yin, 2002).

Currently released MODIS land data products represent provisional (V003) and validated (V004) Terra and Aqua data sets. The V004 product is currently in stage 2 validation and has been subjected to several ground truth and validation efforts. Product accuracy has been assessed over a widely distributed set of locations and time periods (NASA, 2003). MODIS Gridded Vegetation Indices are currently produced at 16-day intervals at high resolution (500 m, labelled as MOD13A1 and 250 m, labelled as MOD13Q1), and at standard 1 km resolution 16-day (MOD13A2) intervals (NASA, 2003). Recently, starting from the 1st of March 2004, monthly (MOD13A3) intervals at 1 km became available.

3.3.3 Land cover and land use

The US Geological Survey (USGS) hosts a global land cover characteristics database (GLCC), at a nominal spatial resolution of one kilometre. The methodology for developing the database was based primarily on a continent-by-continent unsupervised classification of a one-year time series of NDVI monthly composites. The 1-km AVHRR source imagery covers a period from April 1992 to March 1993. The heterogeneous preliminary greenness classes resulting from the unsupervised classification were stratified into seasonal land cover regions. This process involved extensive post-classification refinement by at least three interpreters. Seasonal land cover regions have similar mosaics of land cover types and common seasonal properties, and are continent-specific (USGS, 2005).

GLCC classifications, as well as monthly NDVI composites are provided on a continent by continent basis or as Global data. All GLCC files are provided in a flat headerless raster format. For every dataset two versions are available. Version 1 has undergone complete accuracy assessment. Version 2 is updated with additional data and sources, but accuracy assessment has not been completed. As the global land cover database lacks standardisation, it should be used with caution in scientific applications.

The total number of Eurasia seasonal land cover regions was constrained to 255 in order to keep the number of classes in an 8-bit range, so that the data set could be used in most image processing and geographic information systems (Loveland *et al.*, 1999). The GLCC Eurasia Version 2 seasonal land cover classification was used in the current study. A subset (Figure 3.1, white rectangle) covering mainland Southeast Asia, was subjected to a classification verification procedure which was based upon the April 1992 - March 1993 time series of NDVI composites. Additional AVHRR NDVI 10-day composites, covering two periods from April 1992 till September 1993 and from February 1995 till January 1996, were downloaded from the USGS Land Processes Distributed Active Archive Center (LPDAAC).

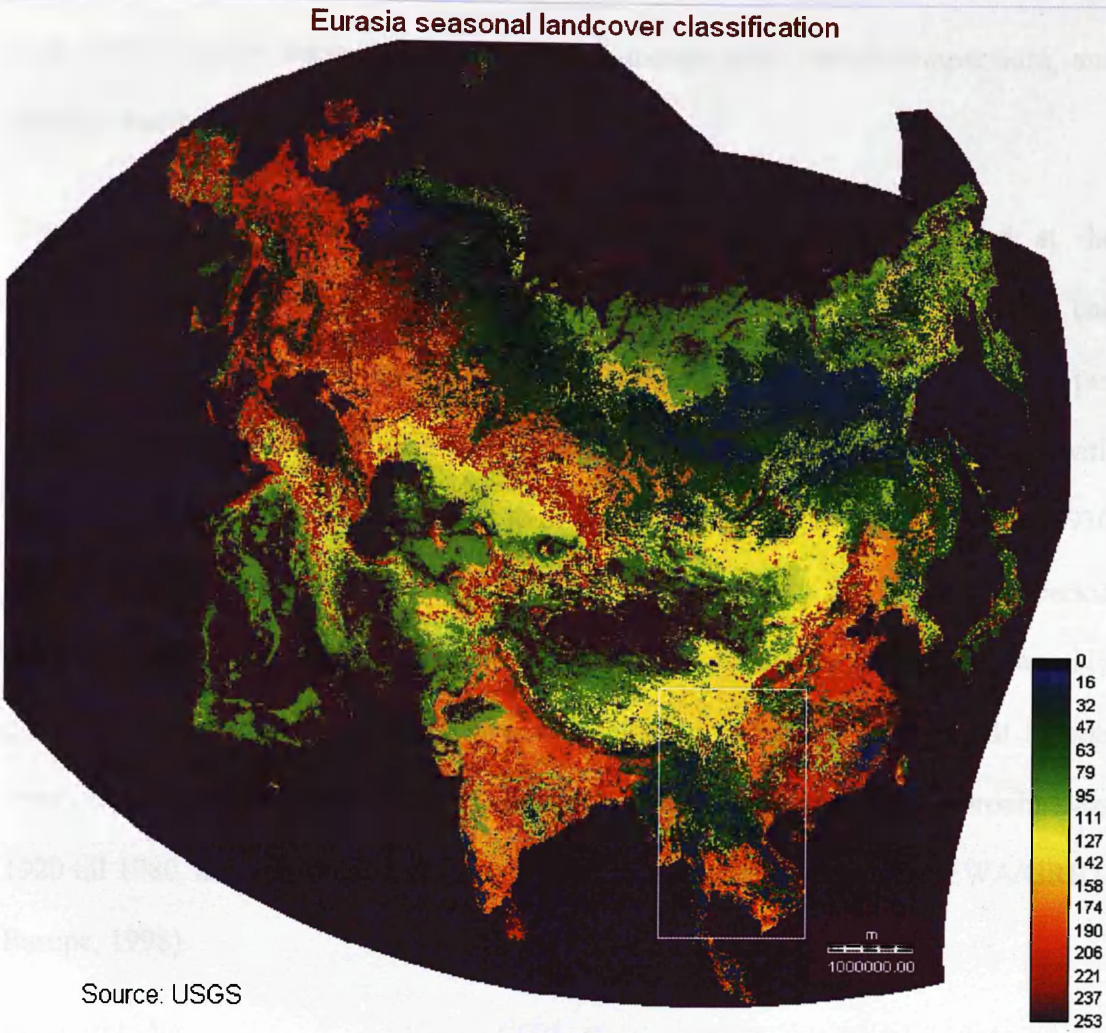


Figure 3.1 GLCC Eurasia seasonal land cover

3.4 Satellite derived spatial information products

3.4.1 Climate

Climate data were downloaded from the United Nations Environment Programme (UNEP) Global Resource Information Database (GRID), Geneva, Switzerland. GRID provides a set of global historical climate data at a resolution of 0.5 degrees (approximately 55 km). The GRID datasets employed for the climate sub-model in this study were monthly mean precipitation, evapo-transpiration and air temperature, and annual water balance.

The climate database represents current global climate and was created at the International Institute for Applied System Analyses (IIASA), Laxenberg, Austria. The variables for global monthly mean temperature and precipitation, 12 monthly values per variable, originate from existing historical weather records of a diverse nature, but with the common feature that most cover at least five years during the period between 1930 and 1960. The climate variables were assumed to be relatively stable over that period and to not have changed significantly over time. The dataset for annual and monthly potential evapotranspiration, actual evapotranspiration and water balance (all in mm units) consists of 39 raster maps representative of a time period from approximately 1920 till 1980, and was published in 1994 by C.H. Ahn and R. Tateishi (DEWA/GRID-Europe, 1998).

3.4.2 Population

Data on human population were obtained from the LandScan 2002 dataset, a worldwide population database developed by Oak Ridge National Laboratory (ORNL), Oakridge TN, USA, for estimating ambient populations at risk. The dataset is based upon best available census counts (usually at province level), distributed to a 30-arcsecond (approximately 1 km) latitude/longitude grid. Probability coefficients are assigned to each cell based on the relative likelihood of population occurrence due to road proximity, slope, land cover, and night time lights. A composite probability coefficient is calculated for each cell through a "smart" interpolation (Dobson, Bright, Coleman, Durfee, & Worley, 2000).

3.5 Image processing

3.5.1 Global image projections

The process of transforming earth surface locations to plane coordinate positions on a map is known as projection (Eastman, 1999). The development of a unified GIS database commonly requires re-projection of the various input layers to a common projection. Processing of remotely sensed data to Global projections has become increasingly important as a result of the growing emphasis on global monitoring. Interrupted equal area projections are a particularly useful class of projections for that purpose, but special processing of raster imagery is required because of the discontinuities caused by the interrupted areas of the map. Several equal area projections have been suggested for Global and continental studies (Steinwand, 1994).

The Interrupted Goode Homolosine projection, developed by J.P. Goode in 1923, is often used for the purpose of Global studies because it has visual appeal and because it reduces distortion in the major land masses. This projection, further referred to as "Goode's projection", is an equal area pseudo-cylindrical composite map projection, which leaves all the major continents, with the exception of Antarctica, intact (Figure 3.2). It merges the Mollweide projection, which is more accurate for higher latitudes, and the Sinusoidal projection, which is more accurate for lower latitudes. The advantage of its use in relation to data processing is that the projection can be treated as a single projection or for processing regions as separate maps on different computer systems at different times, which reduces the amount of disk space required (Steinwand, 1994).

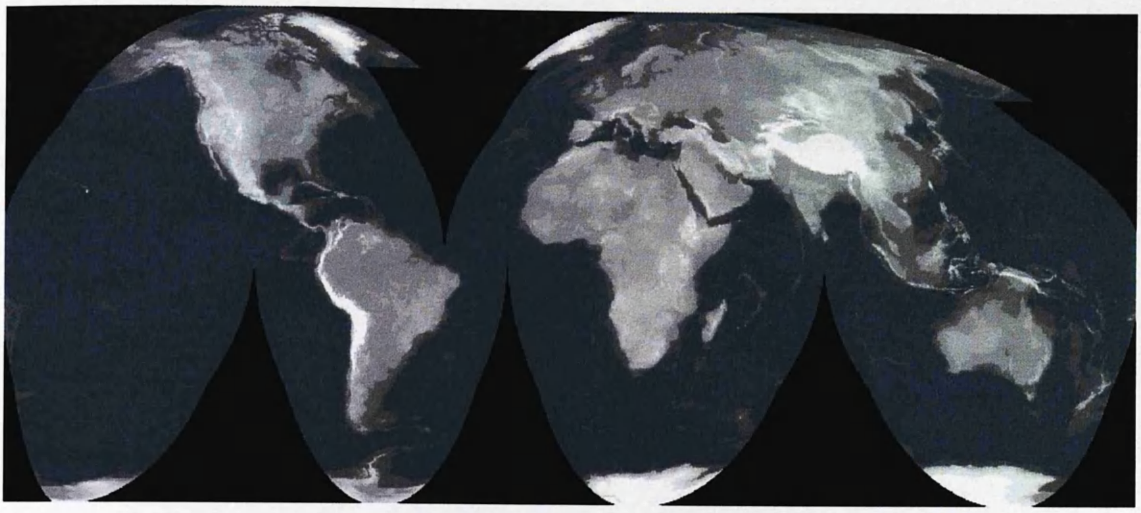


Figure 3.2 Interrupted Goode Homolosine Projection of the Globe (Source: (Steinwand, 1994)

At 1-km resolution, a raster image of Global extent in Goode's map projection consists of 17,347 lines (rows) of imagery with each line containing 40,031 pixels (columns). A software limitation of both IDRISI 32 and IDRISI Kilimanjaro is that it handles a maximum number of 32,000 rows and columns, which effectively renders it unsuitable for processing raster images of Global extent at 1-km resolution. The LandScan 2001 and 2002 versions of the worldwide population database were in raster binary format only downloadable in its Global extent. Its 0.5° x 0.5° (30 arc-second or approximately 1-km) resolution exceeded the IDRISI raster import capacity, thus a binary version for the Asian subcontinent had to be requested separately.

3.5.2 Image processing and re-projection in IDRISI

This study employed geographic, LAZEA and UTM map projections in parallel, in order to incorporate the various projections employed in the source datasets as well as to avoid data degradation through re-projection. The majority of global data used in this study are available on a per-continent basis. The Lambert Azimuthal Equal Area projection is commonly used for maps of hemispheres and continents (Steinwand, Hutchinson, & Snyder, 1995). This projection, further referred to as "LAZEA", preserves areas and sizes and is therefore generally preferable if area calculations have to be made.

IDRISI modules that calculate quantities based on distance automatically accommodate a latitude-longitude reference system by making adjustments for the changing length on the ground of a degree of longitude as the latitude changes (Eastman, 1999). The Global Land AVHRR 1-km Project used Goode's map projection. IDRISI has an import module which re-projects Global AVHRR products from Goode's map projection into geographic (latitude/longitude) coordinates. This module was used to process the AVHRR 10-day composite data, which can be downloaded in user-defined subsets.

GLCC raster datasets on a per-continent basis are available in either LAZEA, or in Goode's projection. The global dataset is available in either Goode's projection or in geographic (latitude/longitude) coordinates (i.e. a Plate Carrée projection). The data dimensions of the LAZEA projection for the Eurasia land cover characteristics data set optimized for Asia are 12,000 lines (rows) and 13,000 samples (columns) resulting in a data set size of approximately 156 megabytes for 8-bit images. The Landsat TM and ETM+ imagery employed in this study is available in the Universal Transverse Mercator (UTM) reference system.

3.5.3 Data degradation

Re-projection of raster data sets results in data degradation, especially for large study areas studied at small scales. Re-projection involves calculation of a geometric transformation model, which warps images in the original projection space to the selected projection space. Image pixels are discrete units arranged in a rectangular grid and all pixels in the image have the same size. If this regularity is disrupted because of projection change, data loss results from dropping or changing image pixels during the re-projection process. Area enlargement results in the replication of image pixels, so that more pixels represent a given area, but detail does not improve. Area compression results in a loss of image resolution. Fewer pixels represent a given area and there is no way of recovering the original values from the reduced data (Steinwand *et al.*, 1995). Re-projecting a raster image in IDRISI requires the user to select the type of interpolation to be used. Bilinear interpolation produces a smoother result than nearest neighbour interpolation, but results in output values that are modified from the original because a linear distance weighted average of the four cells closest to the output cell is used. In a nearest neighbour interpolation, the value of the input cell closest to the position of the output cell is transferred, thus the output contains only values that were present in the original (Eastman, 1999). The re-projection of vector files involves direct transformation without an interpretive interpolation step and was therefore the preferred method in this study. Figure 3.3a represents the world map in a geographic (Plate Carrée) projection. Re-projection to an equal area projection optimised for Asia, accomplished in IDRISI, results in Figure 3.3b.

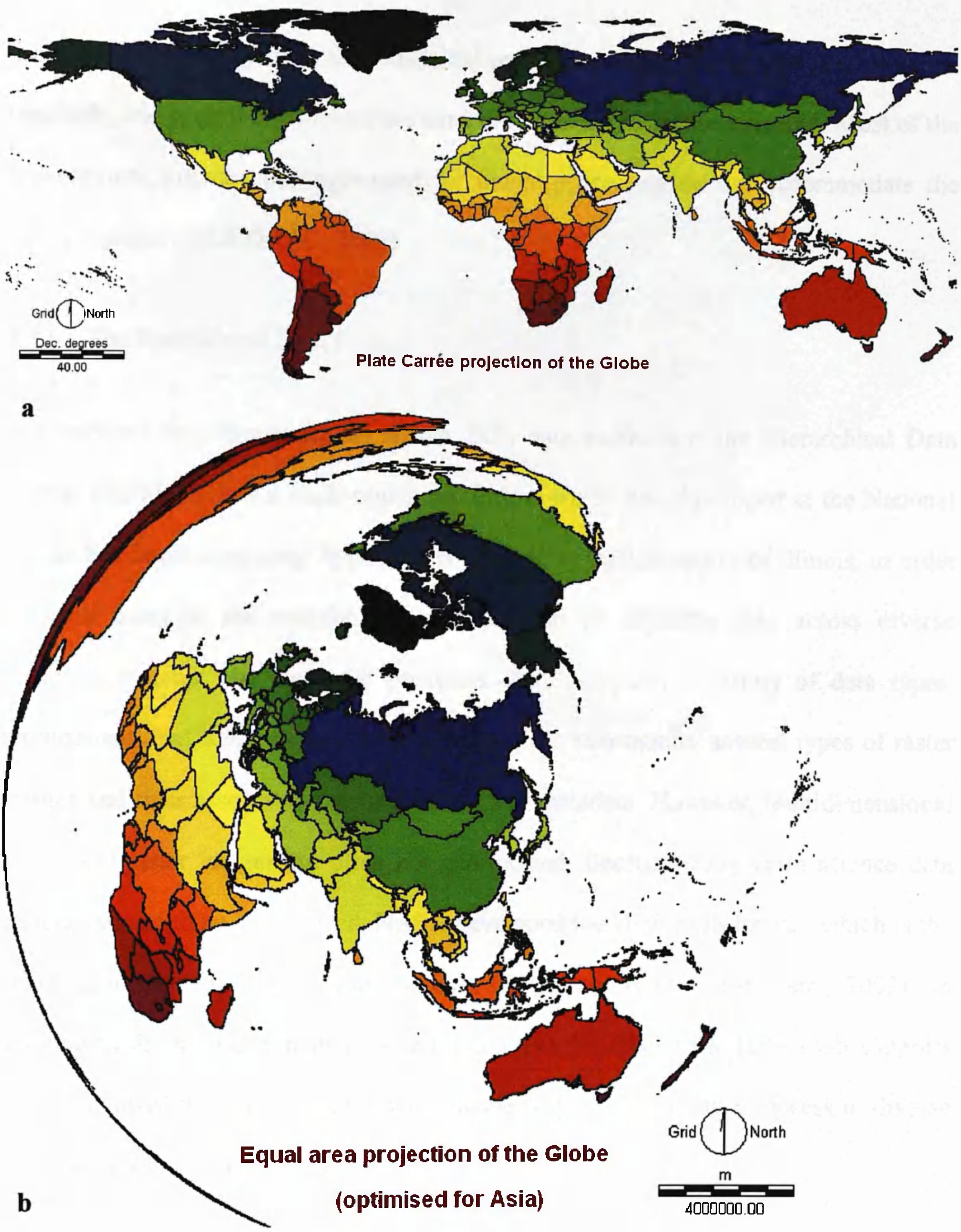


Figure 3.3 The world in a) geographic projection (Plate Carrée) and b) Lambert Azimuthal Equal-Area projection optimised for Asia

An extra processing step was required for the correct projection of MODIS VI products. MODIS land products are generated as gridded output in the Sinusoidal and Integerized Sinusoidal (ISIN) projection. The ISIN projection is unique to the MODIS land products and is analogous to the Sinusoidal projection except that it is centred about 0° longitude, and special coefficients are used to flatten the reference ellipsoid. Most of the conventional software packages used for image processing do not accommodate the ISIN projection (EDCDAAC, 2005).

3.5.4 The Hierarchical Data Format

The standard data format for all NASA EOS data products is the Hierarchical Data Format (HDF). HDF is a multi-object file format which was developed at the National Center For Supercomputing Applications (NCSA) at the University of Illinois, in order to assist users in the transfer and manipulation of scientific data across diverse operating systems and computer platforms. HDF supports a variety of data types: multidimensional scientific data arrays, tables, text annotations, several types of raster images and their associated colour palettes, and metadata. However, multidimensional arrays and raster images are often not geo-located. Because many earth science data structures need to be geo-located, NASA developed the HDF-EOS format, which is the standard format for EOS instrument data (Raytheon Systems Company, 2003). In addition to the normal conventions and data types for HDF files, HDF-EOS supports three geospatial data types, grid, point and swath, providing uniform access to diverse types of data in a geospatial context (NSIDC, n.d.).

IDRISI Kilimanjaro supports HDF-EOS and was used in this study to access gridded MODIS VI products via the EOS Data Gateway. The IDRISI HDF-EOS import routine is generic. It creates a plane, non-georeferenced raster image and copies the HDF metadata to the image documentation. The reference system has to be specified by the user. The Sinusoidal projection presents shapes more accurately in the equatorial regions. Nevertheless the output image of the target area displays significant distortion (Figure 3.4 a). A HDF-EOS Format Conversion Tool (HEG Version 1.0) was downloaded and applied for re-projection of the image to geographic coordinates (Figure 3.4 b).

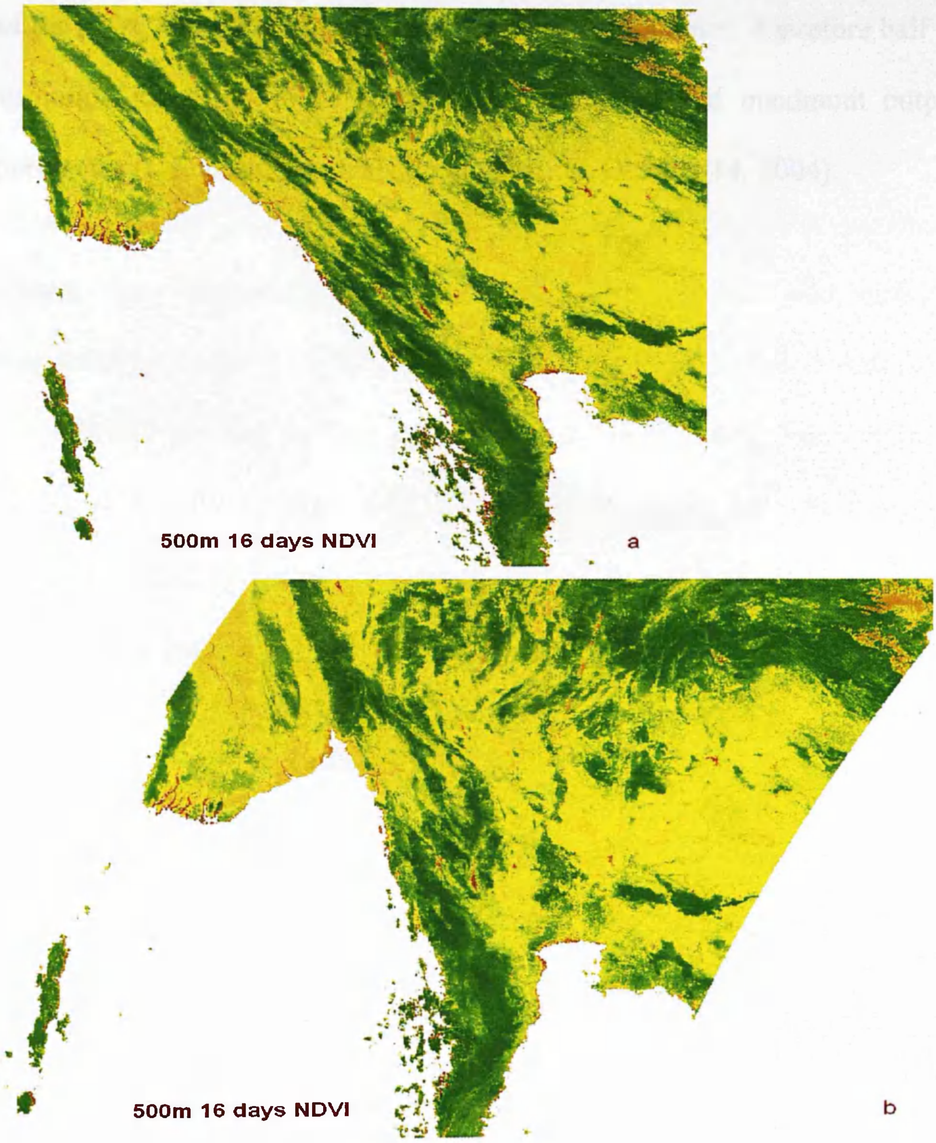


Figure 3.4 MODIS VI product (a) before and (b) after re-projection

HEG allows a user to reformat, re-project and perform operations such as sub-setting and stitching on HDF-EOS objects (Raytheon Systems Company, 2003). The output reference system was set to geographic and the minimum and maximum image coordinates, read from the HEG output status window, were specified in the IDRISI image documentation file. In the original MODIS product the grid point reference location is in the centre of the pixel, but in IDRISI the minimum location is in the upper left corner of the pixel, and the maximum is in the lower right corner. Therefore half of the pixel resolution value has to be added to the minimum and maximum output reference coordinates (I. Lucena, personal communication, October 14, 2004).

4 The river basin framework

4.1 Introduction

Land and water resources, their interactions and their natural boundaries, are to a large extent shaped by a set of inextricably linked topographic and climatologic variables which dictate the primary conditions for societal development. Natural resources are the assets necessary for the development of productive activities, and water resources in particular are mobilized for domestic use and food production (Molle, 2003). As human societies develop, their infrastructure to tap and use water resources also expands. Anthropogenic activities affect the flow and quality of water from source to sink (Kite & Droogers, 2000) and growing demand for water resources frequently leads to water shortages. Societies usually respond with adjustment strategies such as adopting conservation measures and by reallocating water towards more beneficial uses. These responses are normally devised at various levels, ranging from the national level to implementations at local community- and household level, and are partly interdependent. Collective adjustments such as allocation require intervention of public entities, and can be described as a political process, which includes legal changes (Molle, n.d.).

The concept of river basins as hydrological and ecological entities only recently became a focus of societal concern for improved water management. Several frameworks have been proposed to conceptualise the anthropogenic development of river basins. A river basin can be considered as a fundamental landscape unit alongside eco-regions, property boundaries, census tracts, political divisions, and protected areas. A basin perspective allows for the management of water resources through an integrated approach of upstream and downstream issues. It includes human interventions and management of other natural resources and thus covers the interrelatedness of uses and competing users (Verdin, 1997).

The overall impact of public interventions, especially in water resources development and irrigation, remains a point of much controversy. Agriculture is typically the largest user of basin water resources, and contributes significantly to their degradation and depletion. On the other hand it plays a crucial role in ensuring food production and in raising rural incomes. The adoption of intervention methodologies that fully recognise the multiple benefits of such interventions justifies a focus on relationships between water, agriculture and environment. Irrigation for example, can also provide water for reservoir fisheries and aquaculture, non-process beneficial uses for backyard orchards and domestic use, but a quantitative assessment of its unintended impacts on the environment is not easy (Molle, n.d.).

The growing awareness of the interrelated nature of anthropogenic water uses and of the natural water cycle within a basin has led to the emergence of widely popular concepts such as Integrated Water Resources Management (IWRM) or Integrated River Basin Management (IRBM), and the establishment of new organisational levels such as Water Policy Boards or River Basin Organisations (Molle, n.d.). Such organisations often have to operate at transboundary levels as administrative boundaries rarely correspond to basins. IRBM is a complex task in a multi-jurisdictional river basin where management responsibility has to be shared between several nations (Chenoweth *et al.*, 2001)

4.2 River basin delineation

4.2.1 Introduction

A river system naturally receives its drainage water from a catchment area, or basin. This area may encompass a series of tributary rivers and their sub-basins (World Commission on Dams, 2000). At appropriate resolution, the sub-basin can be considered as a natural boundary unit which can be used to delimit eco-regions with their natural resource endowments as well as agro-ecological zones and land use. This study bases its assessment of natural resource endowments, and their importance for aquaculture and aquatic resources development that targets poverty and food insecurity, upon this fundamental ecological unit. The availability of water and related resources within each unit largely determines its potential development pathways.

4.2.2 Data sources for Mekong basin delineation and geography

The procedure adopted to extract and delineate the Mekong Basin in this study follows a methodology based upon a geographic database that provides comprehensive and consistent global coverage of topographically derived datasets at a resolution of 1 km. The database was developed at the EROS Data Center (EDC) in cooperation with the United Nations Environment Programme's Global Resource Information Database (UNEP/GRID) at Sioux Falls. The goal of the project was the development of a globally consistent hydrologic derivative dataset that can be of value to the entire user community requiring common derivative products for hydrologic and land form studies (USGS, n.d.).

The HYDRO1k database is developed from the USGS' GTOPO30, a consistent set of Digital Elevation Models (DEM) with 30-arcsecond (approximately 1-km) postings for the land masses of the Earth (Verdin & Jenson, 1996). For each continent the HYDRO1k package provides a suite of six raster and two vector data sets. The basis of all data layers available in HYDRO1k is the hydrologically correct DEM. The derivative raster data sets are the flow directions, flow accumulations, slope, aspect and a compound topographic (wetness) index. The derived basins and streamlines are distributed as vector data sets. The data sets relevant to this study are downloadable from the USGS' Land Processes Distributed Active Archive Center (LPDAAC) and are located in the HYDRO1k main file for the Asian subcontinent (As.tar). The datasets are in LAZEA projection. The default parameters for this projection are optimised for North America in IDRISI, i.e. the latitude and longitude of the origin are set to 45°N, 100°W. These parameters were changed to 45°N, 100°E as is recommended for Asia (Steinwand *et al.*, 1995).

4.2.3 Procedure

The procedure for river basin delineation and codification was adopted from the methodology developed by Otto Pfafstetter, a Brazilian engineer. Implementation of the system uses a continental DEM which is refined prior to basin analysis, and transformed to a cartographic projection which supports area calculations, such as the LAZEA coordinate system. The system for delineation and codification of basins is based upon topography and the topology of a vectorised drainage network derived from the DEM, and the size of the surface area drained. The basin numbering scheme is selfreplicating, thus offering the possibility to provide identification numbers down to the level of the smallest sub-basins extractable from a DEM (Verdin, 1997).

At the continental level (level 1), the vectorised drainage network is subdivided into ten polygons, numbered 0 through 9. Definition of the appropriate basins and coastal interbasins requires examination of the four river systems with the largest drainage areas at the continental scale, draining directly to the sea. The four are numbered in a clockwise order as 2, 4, 6, and 8. Basin 0 (zero) is defined as the largest closed basin (i.e. not draining to the sea) at the continental level. The remaining continental area corresponds to coastal interbasins 1, 3, 5, 7 and 9. Further subdivision of coastal interbasins 1, 3, 5, 7 and 9 is carried out to obtain a level 2 set of basins and interbasins according to the criterion of area drained. Again this requires examination of the four largest river systems flowing to the coast and definition of their appropriate basins, numbered 2, 4, 6 and 8 in a clockwise order (Verdin, 1997). The Mekong Basin, coded 96, is delineated at the level 2 subdivision of coastal interbasin 9, covering Southeast Asia (Figure 4.1). Four principal river basins are identified clockwise; Hwang He (92), Yangtze (94), Mekong (96) and Irrawaddy (98).

At the main river basin level, the process is repeated by subdividing the area drained by the system. The main stem and tributaries are identified and sorted by size of area drained. The main stem of a river is always taken as the watercourse which drains the greater area; the tributary drains the lesser of the two areas. At this level, the interbasin is the area directly drained by the reach of the main stem (Verdin, 1997). The area drained by a tributary is further referred to as a sub-basin.

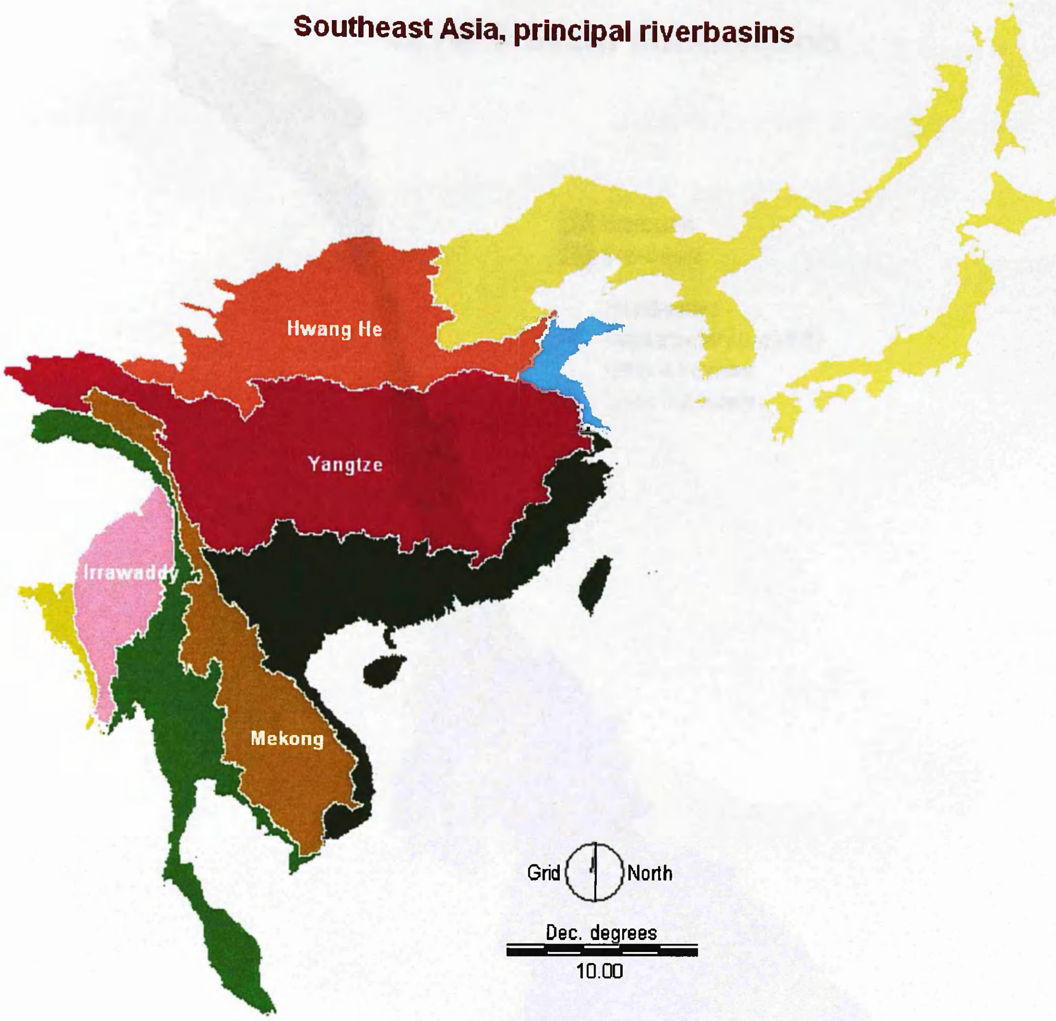


Figure 4.1 Southeast Asia, level 2 subdivision of coastal interbasin 9

In Figure 4.2 this methodology is applied to the Mekong Basin. Tributaries are assigned the numbers 2, 4, 6, and 8, in the order in which they are encountered passing upstream along the main stem. Next, the interbasins are numbered 1, 3, 5, 7, and 9, again working upstream from the mouth of the main stem. Interbasin 1 is the area drained by the main stem between the mouth of sub-basin 2 and the mouth of the main stem. Interbasin 3 is the area drained by the main stem between the mouths of sub-basins 2 and 4. Interbasin 5 is the area drained by the main stem between sub-basins 4 and 6, and interbasin 7 lies between sub-basins 6 and 8. Interbasin 9 always consists of the headwaters area of the main stem, and always drains more area than sub-basin 8, by definition (Verdin, 1997).

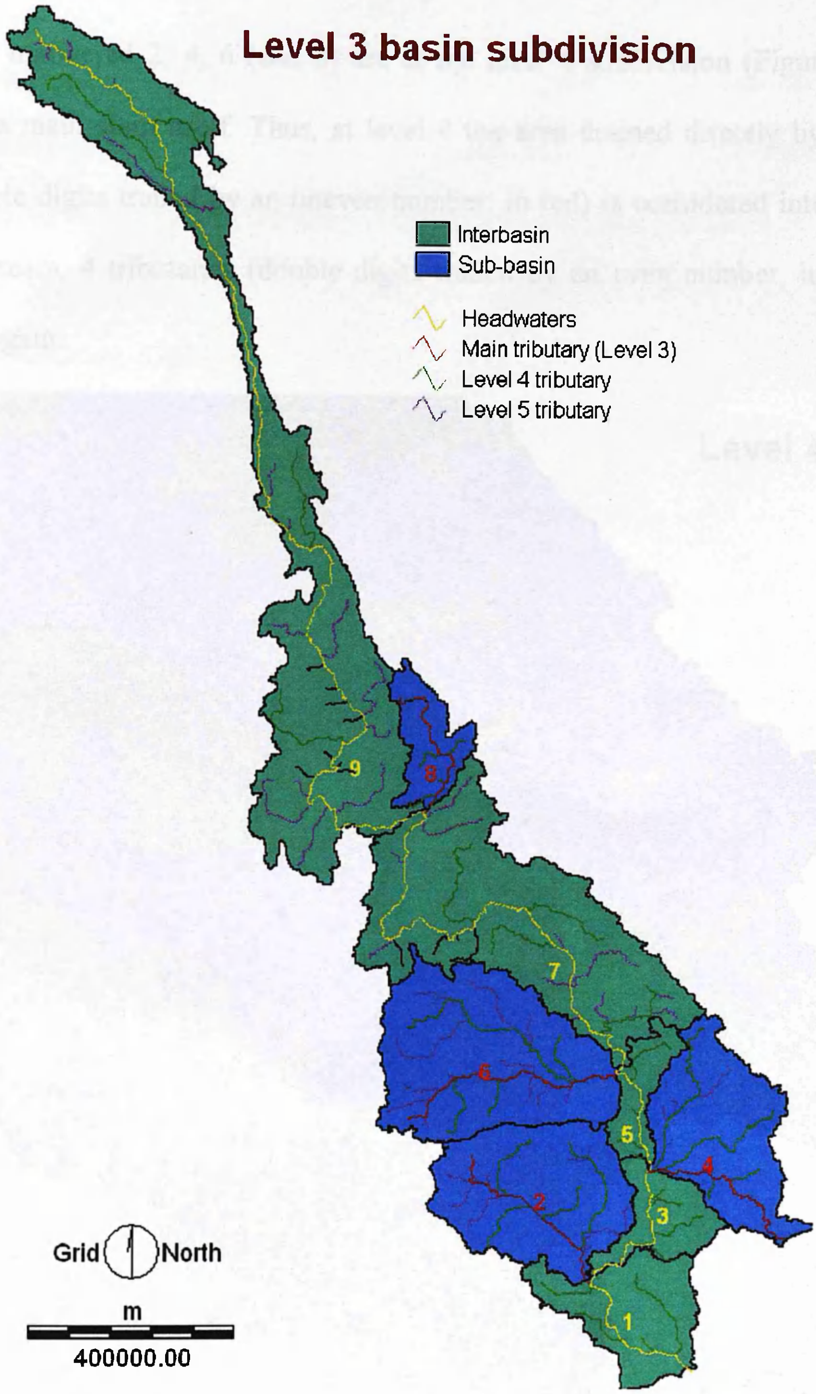


Figure 4.2 Pfaffstetter level 3 subdivision of the Mekong Basin; even numbers (red) indicate level 3 sub-basins (blue), uneven numbers (yellow) indicate interbasins (green)

Each sub-basin may be further subdivided by repeating the application of the same rules to the area within it (Figure 4.3). Level 3 tributaries to the Mekong, in Figure 4.2 shown in red and numbered 2, 4, 6 (and 8) are at the level 4 subdivision (Figure 4.3) each regarded as main stem itself. Thus, at level 4 the area drained directly by each main stem (double digits trailed by an uneven number, in red) is considered interbasin, and going upstream, 4 tributaries (double digits trailed by an even number, in green) are identified again.

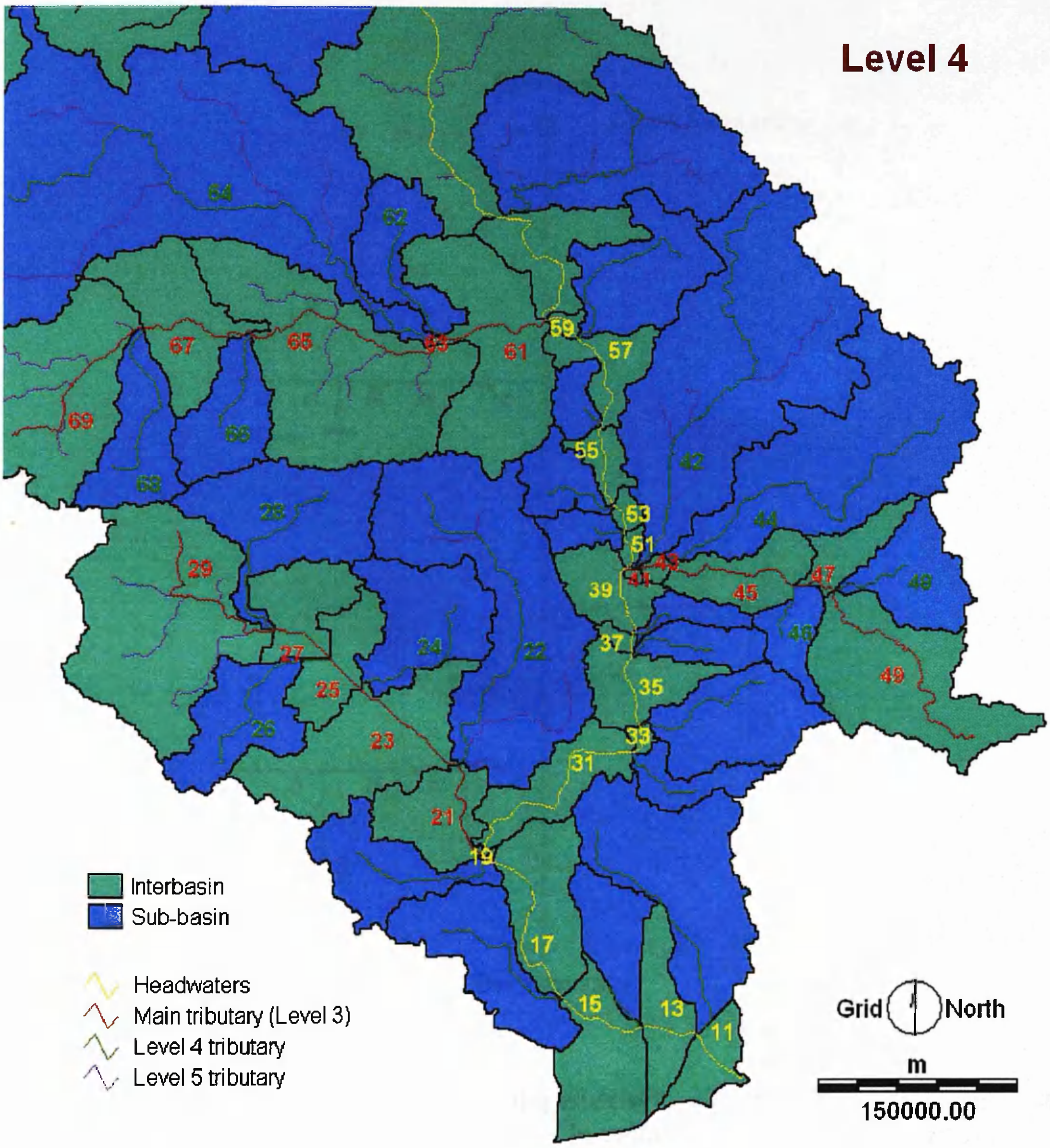


Figure 4.3 Level 4 subdivision of the lower part of the basin; double digits trailed by an even number (green) indicate level 4 sub-basins (blue), double digits trailed by an uneven number (red) indicate interbasins (green). Headwaters in yellow.

The Pfaffstetter numbering scheme has considerable potential for application as a comprehensive decision support tool which assists basin-wide water management policy. The scheme allows for inferring upstream-downstream dependency between locations by examining and comparing the topological information carried by the identification numbers (Figure 4.4).

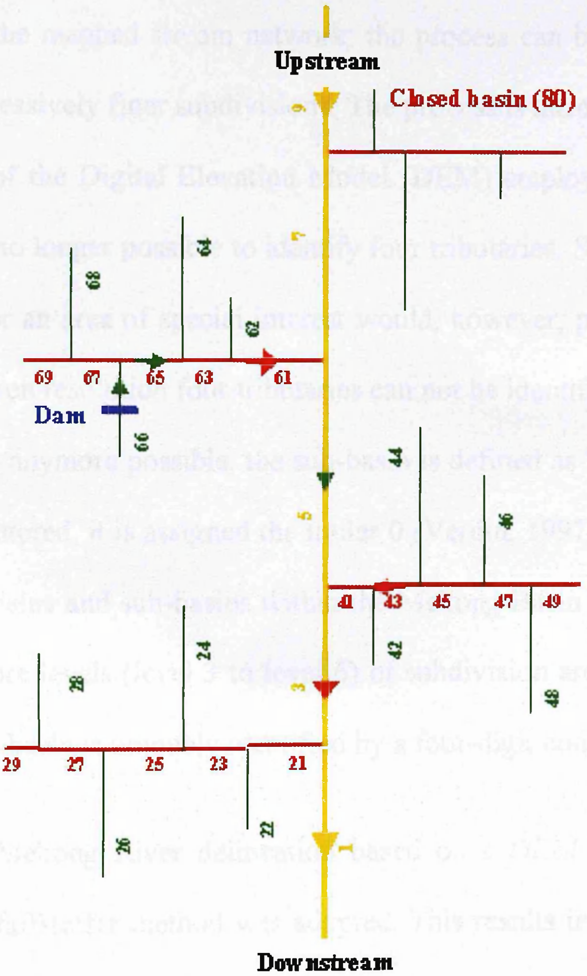


Figure 4.4 Upstream-downstream dependency inference according to Pfaffstetter numbering scheme: headwaters in yellow, main tributaries in red

For example, construction of a dam on tributary no. 66, will affect flows (indicated by arrows) to river reaches having a match of leading digit 6, and trailing odd digits less than 7. These are: 65, 63 and 61. At the main stem (yellow) all reaches downstream from 6 are affected (adapted from (Verdin, 1997). Any tributary discharging into the main stem downstream from 6 remains unaffected by events upstream.

This basin delineation method allows one to uniquely identify sub-basins smaller than 4,000 km^2 in mean surface area if based on a DEM at a resolution of 1 km. Depending on the density of the mapped stream network; the process can be repeated over and over to obtain successively finer subdivisions. The process is ultimately limited by the spatial resolution of the Digital Elevation Model (DEM) employed, which becomes evident when it is no longer possible to identify four tributaries. Switching to a higher resolution DEM for an area of special interest would, however, permit the process to continue. If at a given resolution four tributaries can not be identified, and further sub-division is thus not anymore possible, the sub-basin is defined as "closed". If a closed sub-basin is encountered, it is assigned the trailer 0 (Verdin, 1997). In order to extract the smallest interbasins and sub-basins within the Mekong Basin from a DEM at this resolution, four more levels (level 3 to level 6) of subdivision are possible. After the 96 prefix, each sub-basin is uniquely identified by a four-digit code (Figure 4.5).

In this study the Mekong River delineation based on a DEM at 1 km resolution according to the Pfaffsteffer method was adopted. This results in a basin delineation that differs slightly from the Mekong River basin area as defined by the Mekong River Commission (MRC). Some inland areas in Cambodia are included when applying this delineation method whereas the coastal peninsula of Ca Mau, Southwest Vietnam, is largely excluded. The inland area of Southeast Cambodia, notably Svay Rieng province, is located outside the MRC delineation of the Mekong Basin, but falls within the delineation adopted in this study, which is appropriate to its focus on inland water resources.

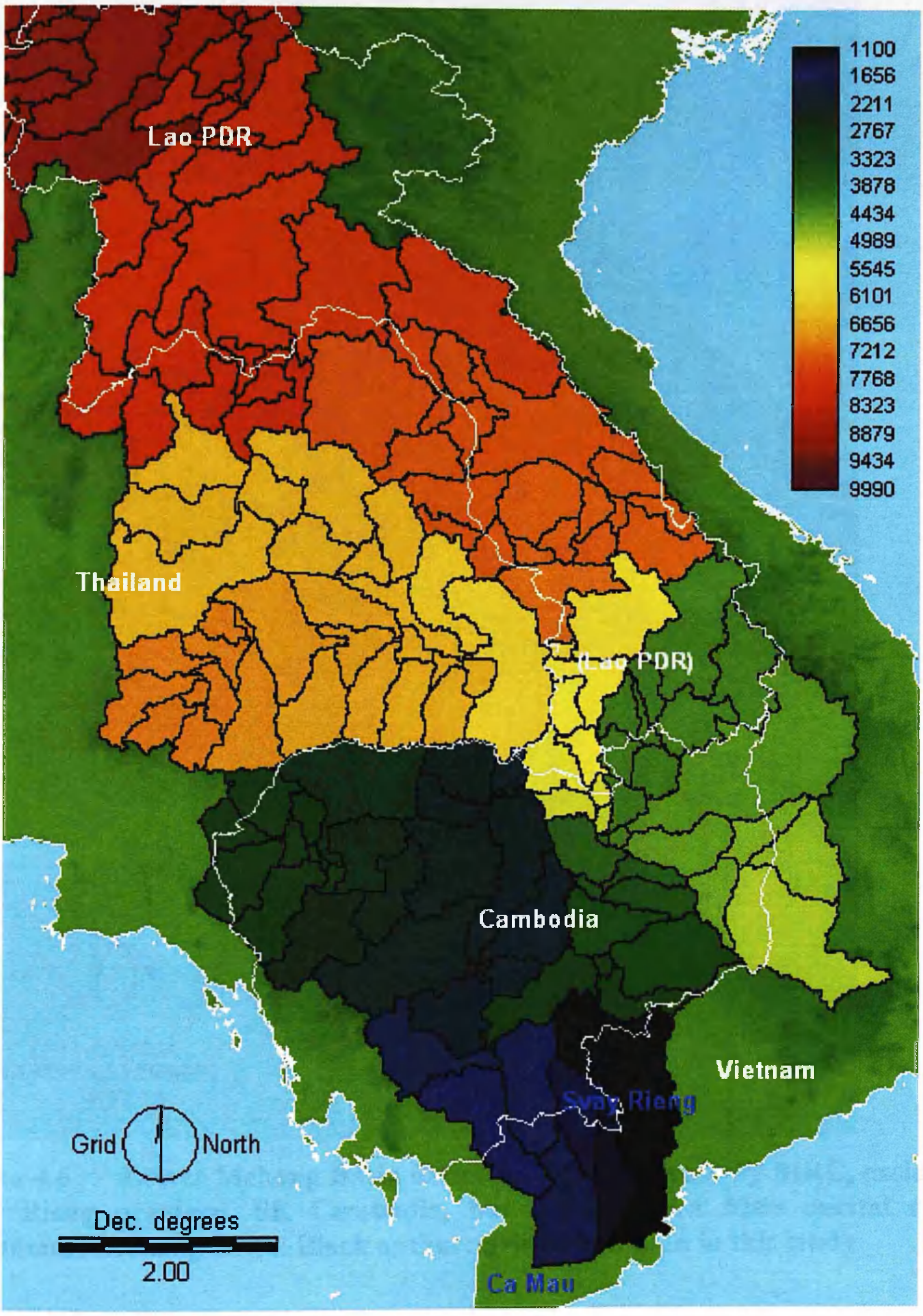


Figure 4.5 Lower Mekong Basin delineation in this study, including Svay Rieng province, SE Cambodia, but excluding Ca Mau coastal areas, Vietnamese Mekong Delta. Basin subdivision according to Pfaffstetter numbering scheme (four trailing digits)

Figure 4.6 Lower Mekong Basin delineation (light green) by MRC, excluding Svay Rieng province, SE Cambodia, but including Ca Mau coastal areas, Vietnamese Mekong Delta. Black outline: delineation used in this study

4.3 A spatial model for aquaculture development

4.3.1 A basin-scale assessment of aquaculture suitability

Within the geographical context of a river basin approach a simple preliminary model for aquaculture suitability was developed, based on the assumption that a tropical rainy climate and level to gently undulating terrain provide optimal circumstances. This general model helps to target areas which are potentially of interest for aquaculture development on the basis of geographical and climatologic feasibility, and the natural capital available under such conditions. The model was based upon three principal anthropogenic and natural factors and its interdependencies that in the basin-wide context were assumed to dictate overall development potential (Figure 4.7). Climate and geography underlie the natural resource base for societal development whereas a population's collective strategy towards natural resource exploitation will affect the availability of land and water resources and its allocation.

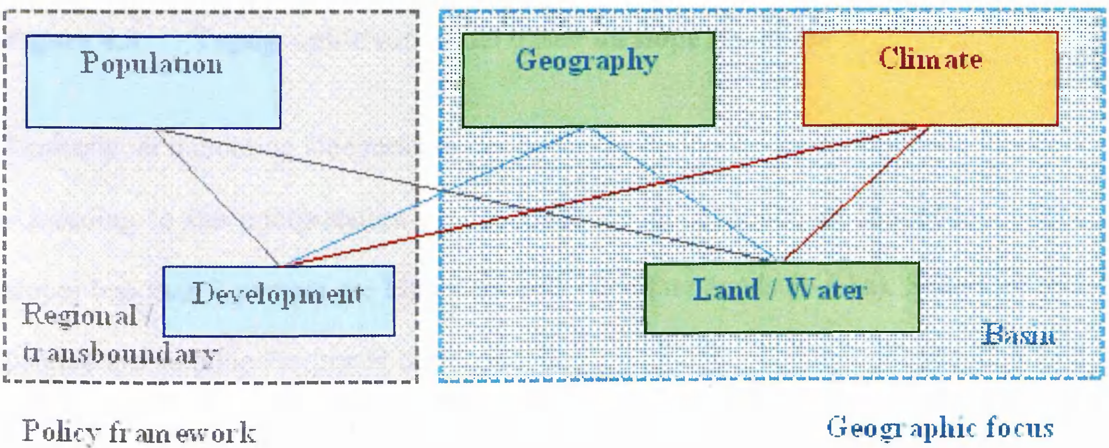


Figure 4.7 A basin-wide framework for development

4.3.2 Topographic suitability for aquaculture

A sub-model for topographic suitability (Figure 4.8) for aquaculture was developed from the HYDRO1k DEM and the derivative slope raster data set. Slope was considered more important than elevation as a predictive factor for human settlement and, as a consequence, land use and natural resource exploitation. With increasing steepness, slopes become a limiting factor for settlement whereas moderate slopes, plateaus and floodplains at higher elevations still may support considerable human population.

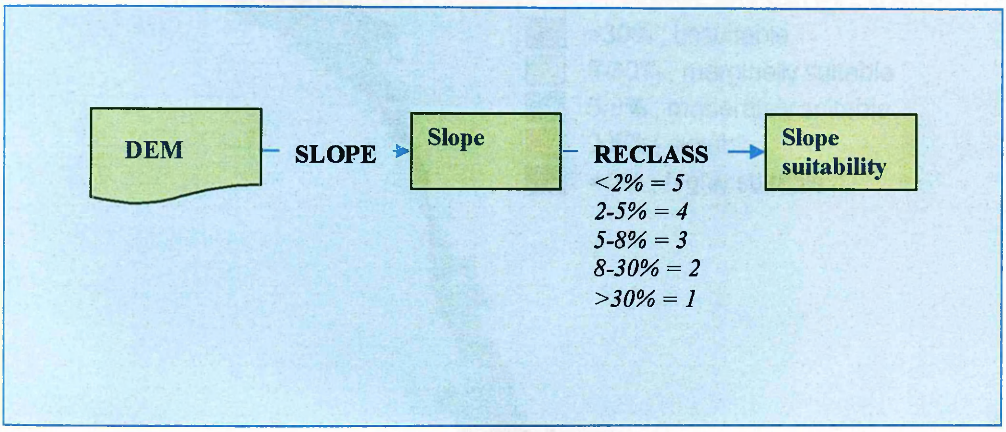


Figure 4.8 Topographic submodel based on slope steepness

Similarly, at increasing steepness slopes become limiting for aquaculture site location. According to the interpretation of ICLARM and GTZ (1991, *in* (Kapetsky, 1993), slopes less than 2 percent are highly suitable for estate ponds (1-5 ha). Slopes up to 5 percent are suitable for ponds between 1 to 5 ares (100 – 500 m^2). Slopes of 5 to 8 percent are moderately suitable for paddy ponds. Slopes greater than 8 percent but less than 30 percent are marginally suitable, with some potential for contour ponds, but slopes exceeding 30 percent are too steep even for contour ponds and thus unsuitable for aquaculture. The slope percentages are averages, which are derived from a DEM at approximately 1 km resolution. Therefore, at higher resolution some opportunities for ponds not captured at the 1 km resolution may still become apparent. For example in steeply dissected to mountainous areas, covering the northern reaches of the Mekong Basin, opportunities may still exist locally in valley floors although the topography of the region is generally unsuitable for aquaculture. Topographic conditions for aquaculture improve considerably towards the south of the basin (Figure 4.9).

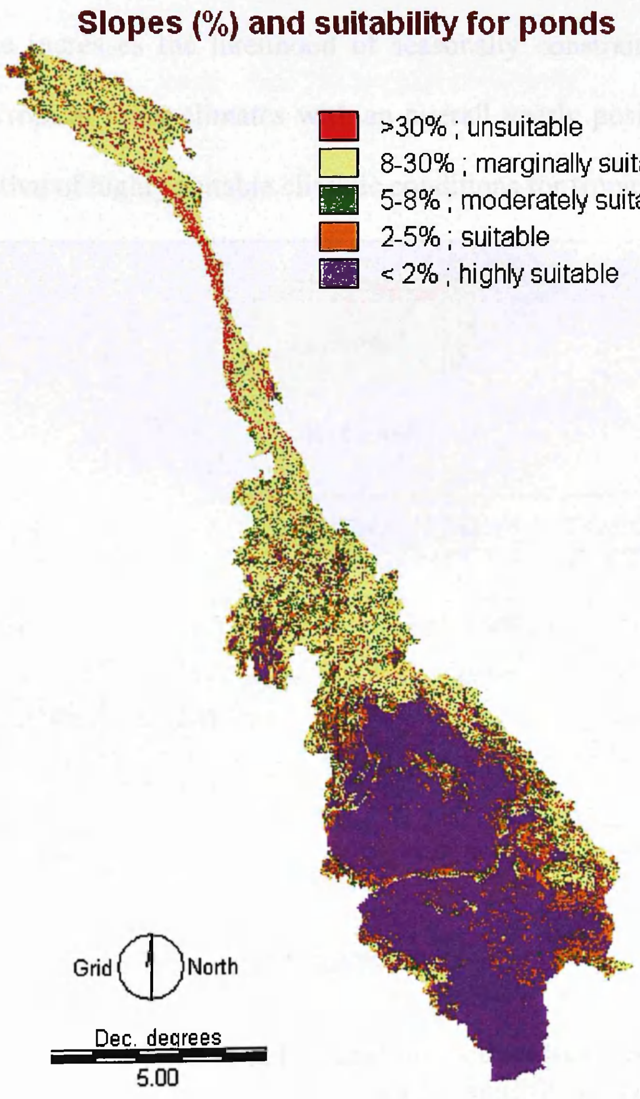


Figure 4.9 Slope suitability for pond construction

4.3.3 Climate suitability for aquaculture

A second sub-model was developed as an indicator of climate suitability for inland aquaculture (Figure 4.10). A tropical climate, defined as the coolest month having an air temperature (T_{avg}) on average greater than 18°C, allows tropical fish to grow year-round. The overall yearly water balance was considered as a proxy indicator for the likelihood of occurrence of seasonal droughts under rain-fed conditions. A positive water balance thus improves overall climate suitability for aquaculture whereas a negative balance increases the likelihood of seasonally constrained water supplies (Figure 4.10). Tropical rainy climates with an overall yearly positive water balance (WB) are indicative of highly suitable climatic conditions for tropical aquaculture.

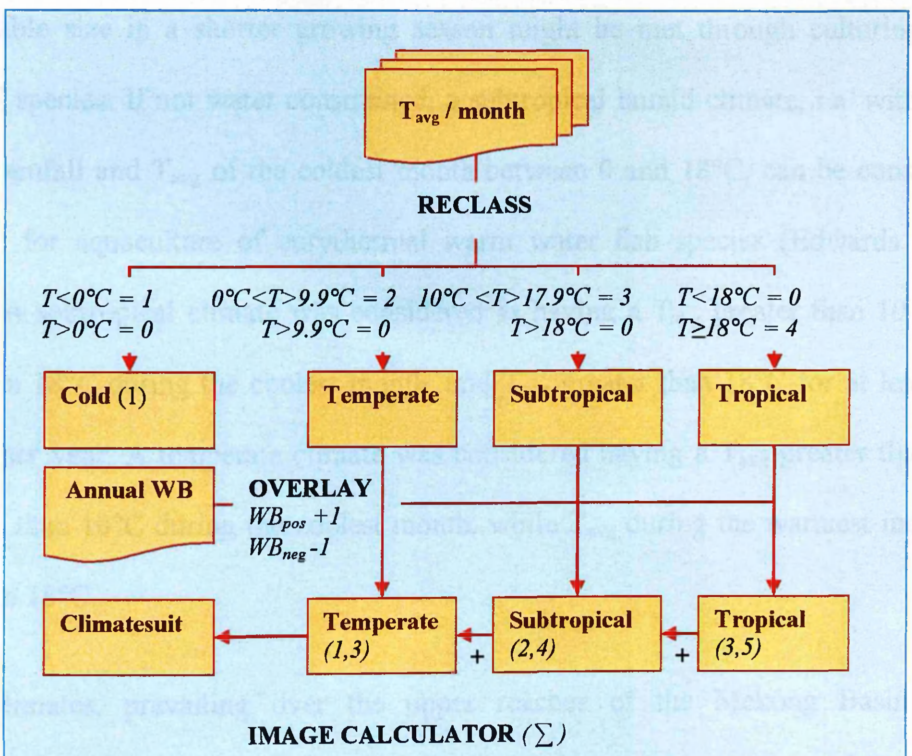


Figure 4.10 Climate suitability sub-model for aquaculture. Suitability T_{avg} ± 1 WB = overall climate suitability (T_{avg} - average monthly air temperature, WB - water balance)

The lower Mekong Basin is characterised by a tropical monsoon climate with distinct wet and dry seasons. In the dry season water shortages could constrain not only fish culture but also the availability of inputs from forage and by-products of crop and livestock systems. This is particularly relevant for integrated farming systems which are operated under rain-fed conditions (Edwards *et al.*, 1988). If proper water conservation measures are taken such systems may still be moderately suitable. A semi-arid climate with a long dry season and a short rainy season is generally unsuitable for inland aquaculture (Edwards *et al.*, 1988), and water availability is likely to become seasonally constrained under such conditions.

In the subtropical climate prevailing over the central Mekong Basin, the need to attain marketable size in a shorter growing season might be met through culturing non-tropical species. If not water constrained, a subtropical humid climate, i.e. with year-round rainfall and T_{avg} of the coldest month between 0 and 18°C, can be considered suitable for aquaculture of eurythermal warm water fish species (Edwards *et al.*, 1988). A subtropical climate was considered as having a T_{avg} greater than 10°C but less than 18°C during the coolest month, and T_{avg} greater than 18°C for at least one month per year. A temperate climate was considered having a T_{avg} greater than 0°C but less than 10°C during the coolest month, while T_{avg} during the warmest month is less than 18°C.

Cold climates, prevailing over the upper reaches of the Mekong Basin were considered unsuitable for warm water aquaculture, irrespective of water balance. A climate was considered cold if T_{avg} is less than 0°C for at least one month, while not exceeding 18°C in the warmest month. According to the chosen criteria, climate conditions for warm water aquaculture are generally very good across the lower Mekong Basin, except for possible drought constraints in the western part (Figure 4.11). Good conditions prevail over the central parts of the basin. The upper Mekong Basin is broadly unsuitable for warm water aquaculture

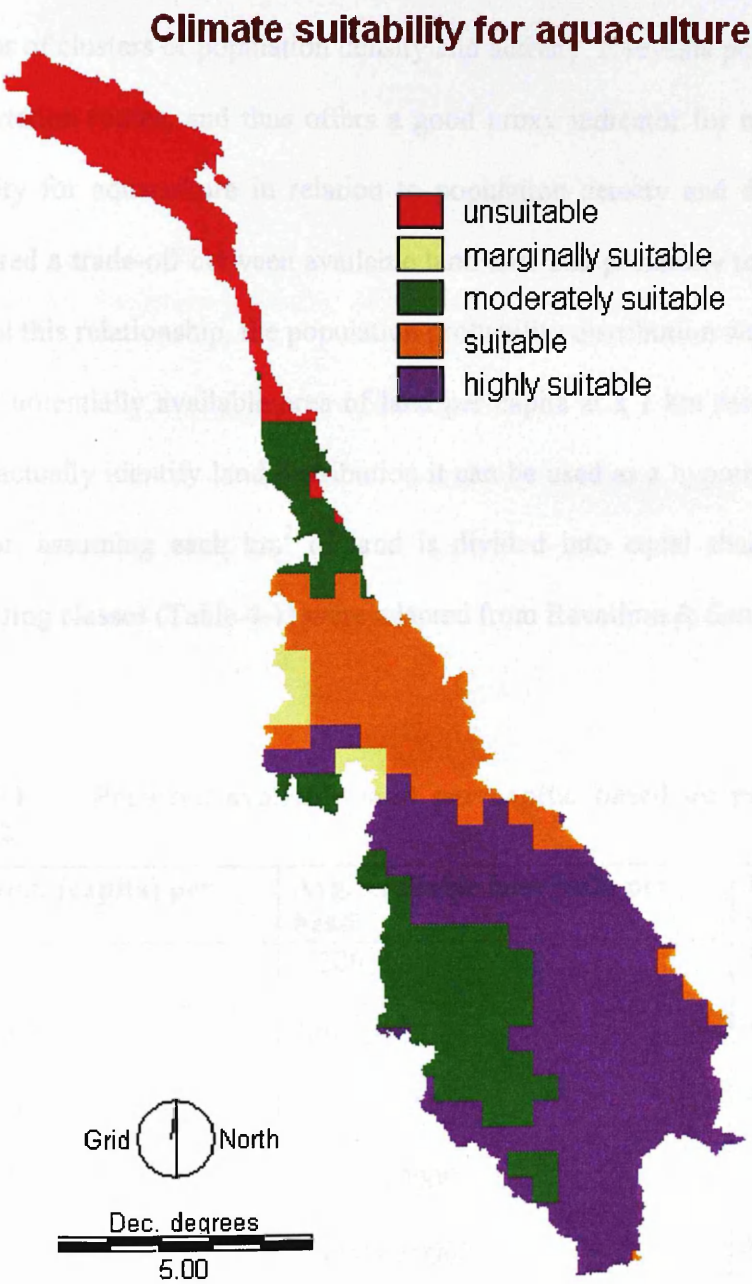


Figure 4.11 Suitability for aquaculture based on climate and yearly water balance

4.3.4 Population density related suitability for aquaculture

The third submodel, based on mean population density per km^2, was derived from the LandScan dataset. This dataset is a population probability distribution rather than an estimate of the actual number of inhabitants per km^2. It is nevertheless a good spatial indicator of clusters of population density and activity. It reveals populated places and transportation routes, and thus offers a good proxy indicator for market access. The suitability for aquaculture in relation to population density and distribution can be considered a trade-off between available land area and proximity to markets. In order to model this relationship, the population probability distribution was expressed as the average potentially available area of land per capita at a 1 km resolution. Though it cannot actually identify land distribution it can be used as a hypothetical landholding indicator, assuming each km^2 of land is divided into equal shares per head. The landholding classes (Table 4-1) were adapted from Ravallion & Sen (1994).

Table 4-1 Potential available land per capita, based on population density per km2

Population (capita) per km2	Avg. available land (m2) per head	Landholding class
> 5000	< 200	Landless
500 - 5000	200 - 2000	Near landless
167 - 500	2000 - 6000	Marginal
100 - 167	6000 - 10000	Small
33 - 100	10000 - 30000	Medium
< 33	30000 >	Large

A population related suitability sub-model (Figure 4.12) for aquaculture was developed according to these landholding criteria.

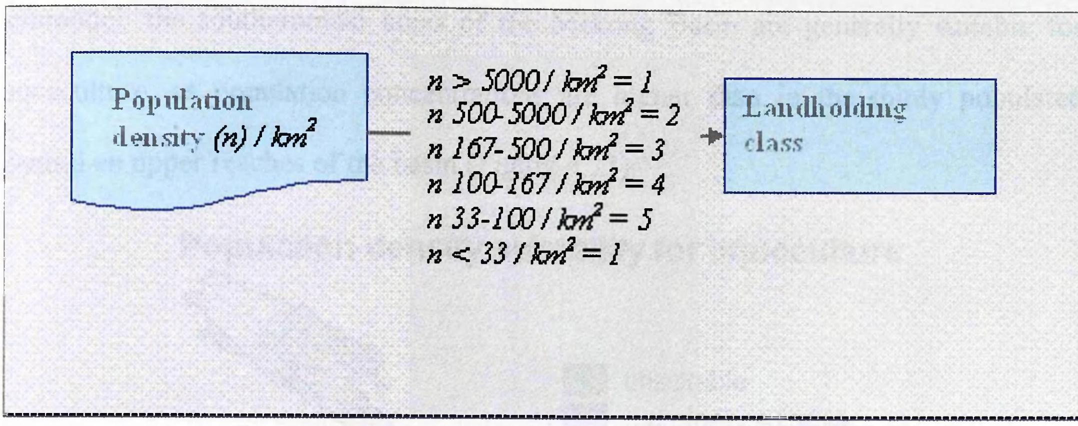


Figure 4.12 Population density distribution sub-model

Population centres counting over 5000 heads per km^2 indicate high population density and activity with accompanying infrastructure, such as roads. Economic activity tends to cluster around these centres, thus the market potential of such areas is high. This was expressed as a proxy for "landlessness" and "no area available for aquaculture". Areas offering easy access to these centres are also highly populated as settlements emerge along roads and in peripheral areas of cities, and can be interpreted as a proxy for near-landlessness (< 0.2 ha.), indicating marginal suitability for aquaculture. Some small backyard ponds and ditches for domestic use can be expected. Population densities approximating marginal landholdings (0.2-0.6 ha) are considered moderately suitable for aquaculture. Smaller ponds between 100 – 500 m^2 can be part of the household production system, for example in a backyard orchard. Smallholder systems (0.6-1 ha.) are suitable for small-scale commercial aquaculture production. Medium sized systems (1-3 ha.) where one or more large ponds can be part of the production system are considered highly suitable, especially when these are within easy reach of markets. Low population densities of less than 33 heads per km^2 are an indicator of remote areas with difficult access, and can be assumed inappropriate for market oriented aquaculture. According to the population density derived suitability submodel, the southernmost areas of the Mekong Basin are generally suitable for aquaculture, as population concentrations are higher than in the thinly populated central en upper reaches of the basin (Figure 4.13).

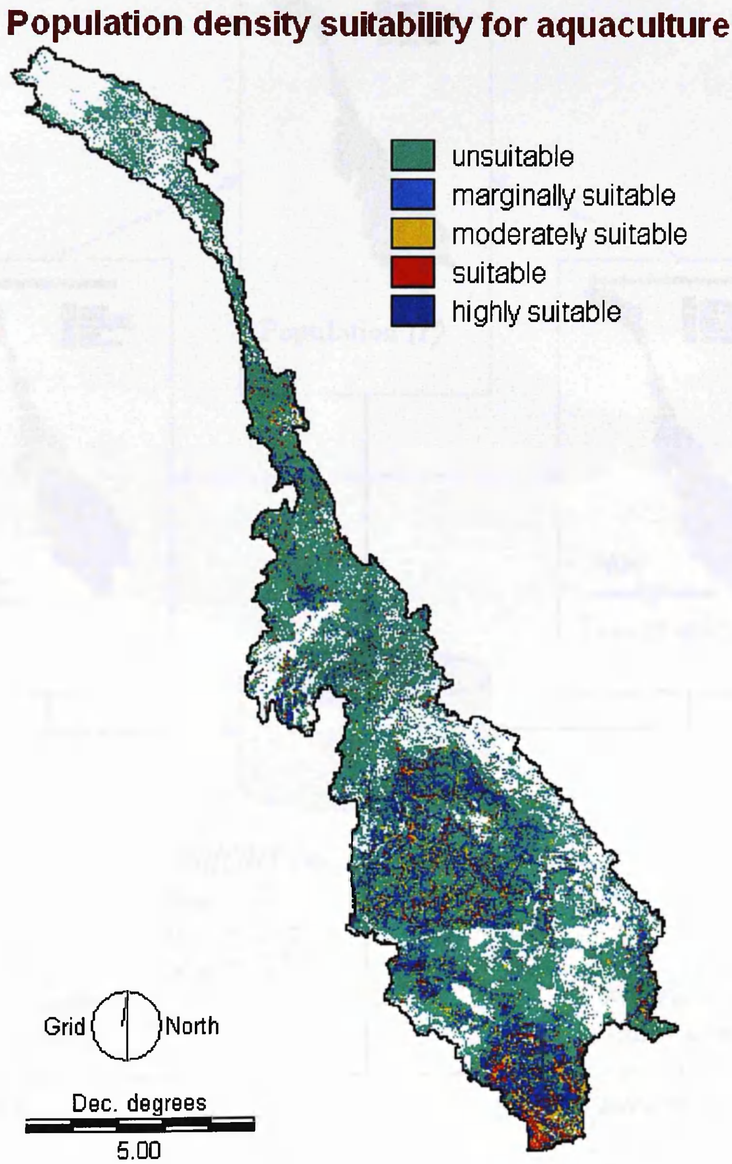


Figure 4.13 Suitability for aquaculture based on population density distribution (white areas: no population / no data)

4.3.5 Multiple criteria evaluation

A multiple criteria evaluation (MCE) was performed in order to model the aggregated aquaculture suitability at the basin scale according to the three submodels (Figure 4.14).

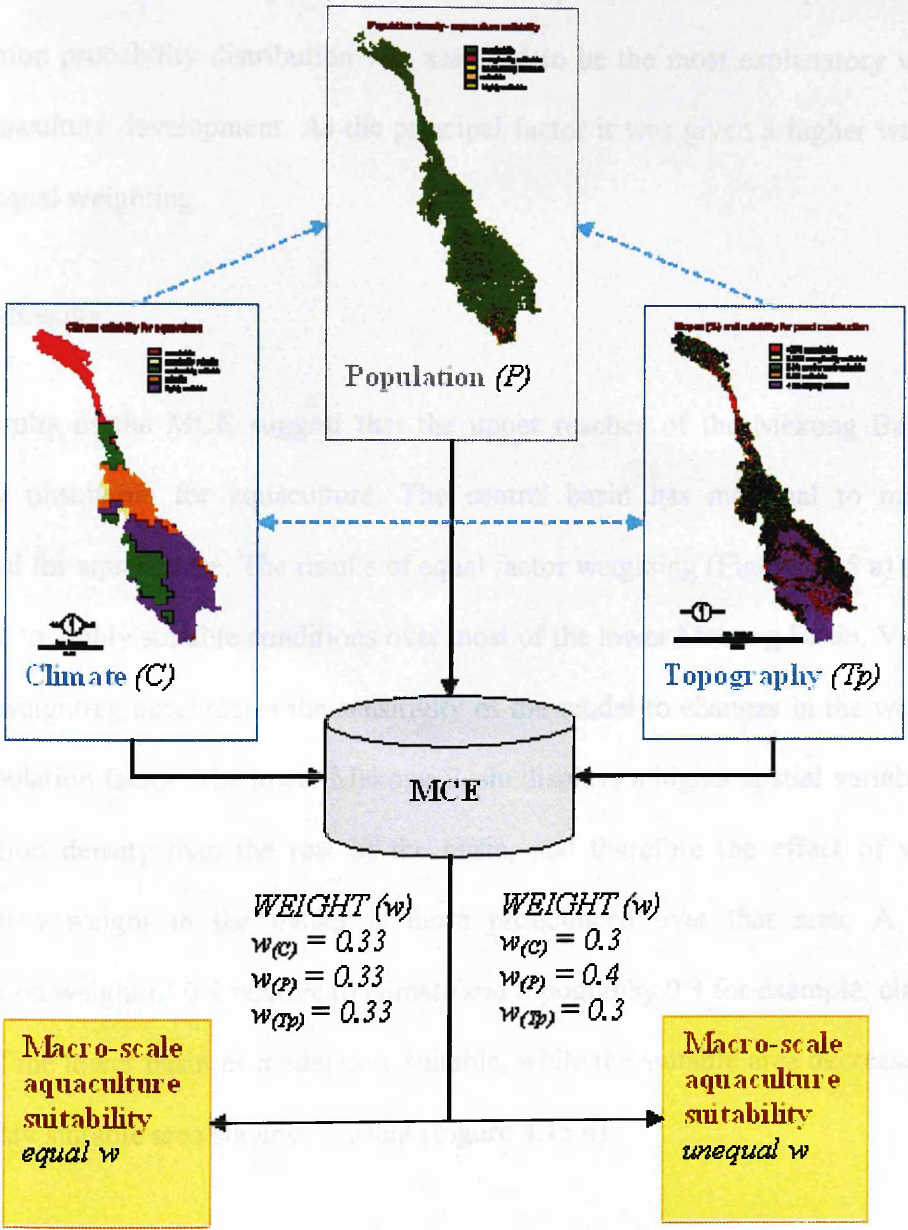


Figure 4.14 Decision support model for aquaculture suitability at basin level

A MCE is an example of the use of GIS as a decision support system (Eastman, 1999). The technique chosen was that of Weighted Linear Combination (WLC). Non-populated areas were used as a constraint factor, and applied as a Boolean mask. Different weightings (w) were used to assign different levels of importance, to reflect different scenarios affecting the overall suitability of an area for aquaculture. The population probability distribution was assumed to be the most explanatory variable for aquaculture development. As the principal factor it was given a higher weight in the unequal weighting.

4.3.6 Results

The results of the MCE suggest that the upper reaches of the Mekong Basin are broadly unsuitable for aquaculture. The central basin has marginal to moderate potential for aquaculture. The results of equal factor weighting (Figure 4.15 a) suggest suitable to highly suitable conditions over most of the lower Mekong Basin. Variation of the weighting accentuates the sensitivity of the model to changes in the weight of the population factor. The lower Mekong Basin displays a higher spatial variability in population density than the rest of the basin, and therefore the effect of varying population weight in the model is more pronounced over that area. A higher population weight of 0.4 relative to climate and topography 0.3 for example, classifies most of the lower basin as moderately suitable, while the suitable area decreases with the highly suitable area staying constant (Figure 4.15 b).

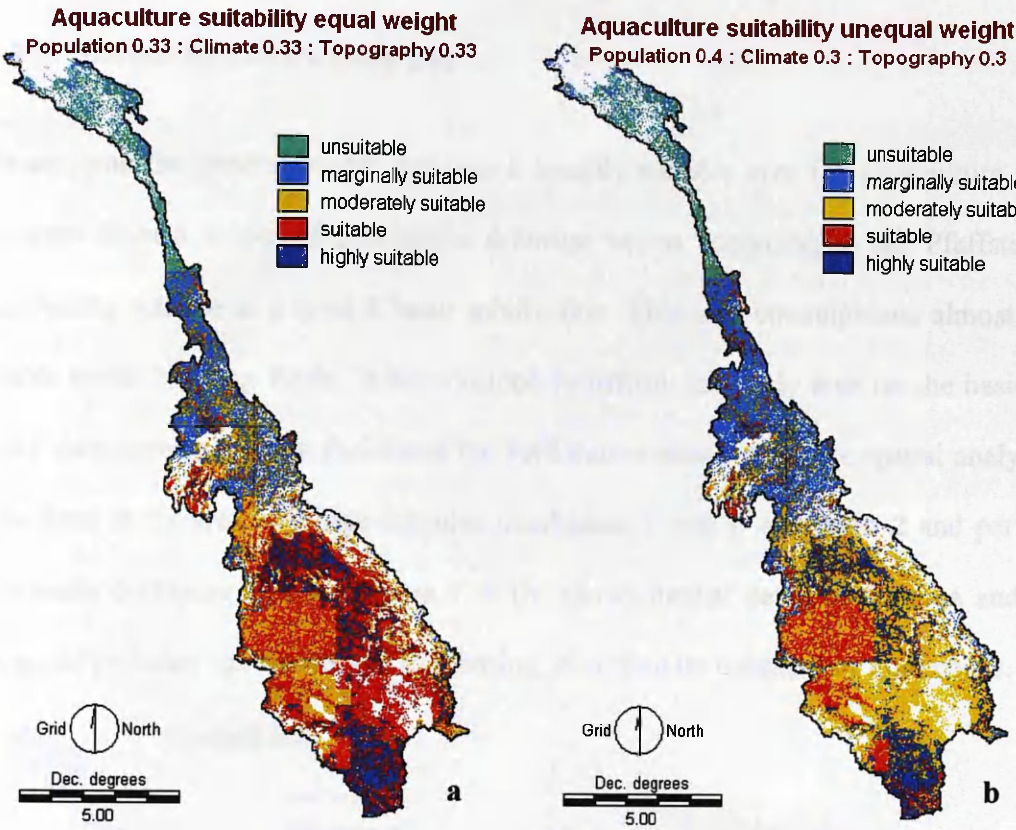


Figure 4.15 Aquaculture suitability based on population, climate and slope; a) outcome for equal factor weights and b) outcome for higher population weight of 0.4 relative to climate and topography 0.3

Shortcomings of the general model are that it fails to take a number of considerations into account, such as the implications of population density on water use and quality, and the assumption of stability in the climate variables, which does not account for known climate variability and change. Scale effects are also an inherent limiting factor resulting from the combination of different levels of data aggregation. Climate data are aggregated at 55 km resolution whereas population and topographic data are at 1 kilometer resolution. Nevertheless the model can be considered sufficiently robust to provide a basis for the selection of a suitable target area. The lower Mekong Basin is characterised broadly as suitable to highly suitable for aquaculture, the central basin as moderately suitable and the upper basin as marginally suitable.

4.3.7 Demarcation of the study area

Based upon the general model outcome a broadly suitable area for aquaculture was selected from a subset of contiguous drainage basins according to the Pfaffstetter numbering scheme at a level 3 basin subdivision. This area encompassed almost the whole lower Mekong Basin. It was decided to narrow the study area on the basis of field visit coverage which facilitated the verification exercise for the spatial analysis. The final study area coverage includes interbasins 1 and 3, sub-basin 2 and part of sub-basin 6 (Figure 4.16 a). Figure 4.16 (b) shows further detail of the area and its range of included sub-basins and interbasins, identified by unique four digit codes.

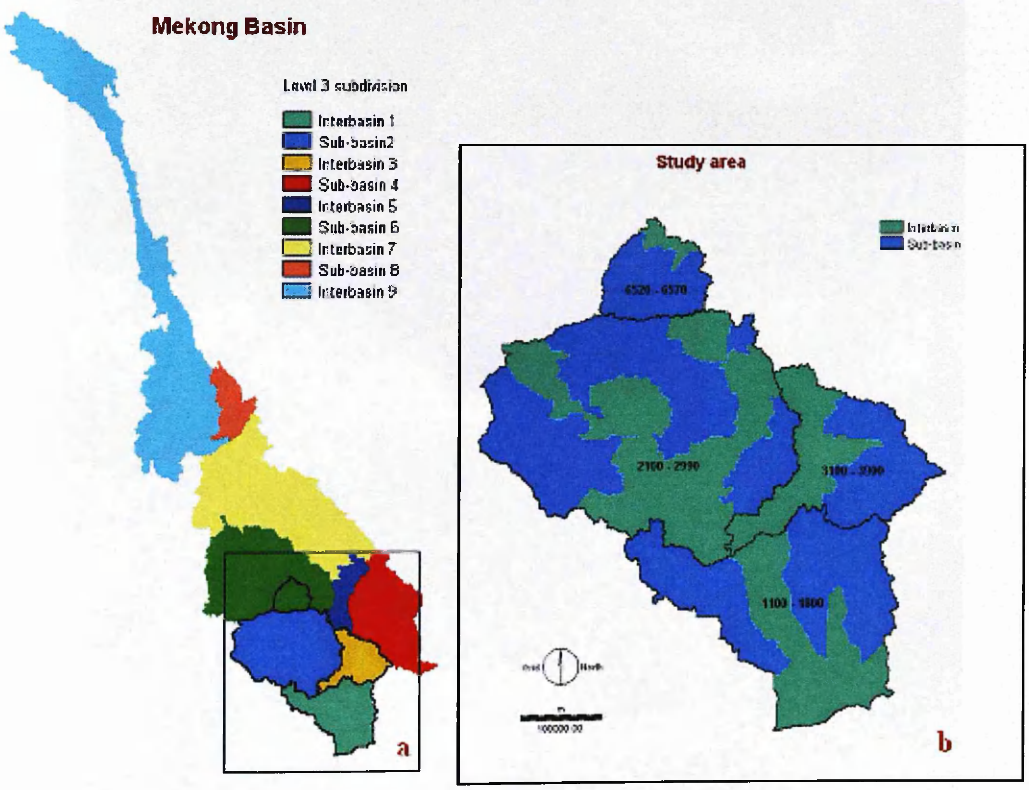


Figure 4.16 Coverage of the study area based on Pfaffstetter scheme

Administratively, the coverage (Figure 4.17) includes a northwest – southeast diagonal of Cambodia, excluding the coastal area and north-eastern parts of the country bordering Lao PDR and Vietnam. Outside Cambodia the study area includes the southern part of Northeast Thailand. In southern Vietnam it covers the Mekong Delta provinces. The area reflects a range of moderately to highly suitable conditions for aquaculture according to the preliminary model (Figure 4.18) and is heterogeneous in terms of population density. After removal of the largely uninhabited areas, the area accounts for approximately 29 percent of the total 612,000 km^2 inhabitable area of the Mekong Basin and covers approximately 46 percent of the total 70,000 km^2 area estimated by the preliminary model as highly suitable for aquaculture. It accounts for another 36 percent of the total area estimated as suitable for aquaculture.

Figure 4.17 Administrative coverage of the study area

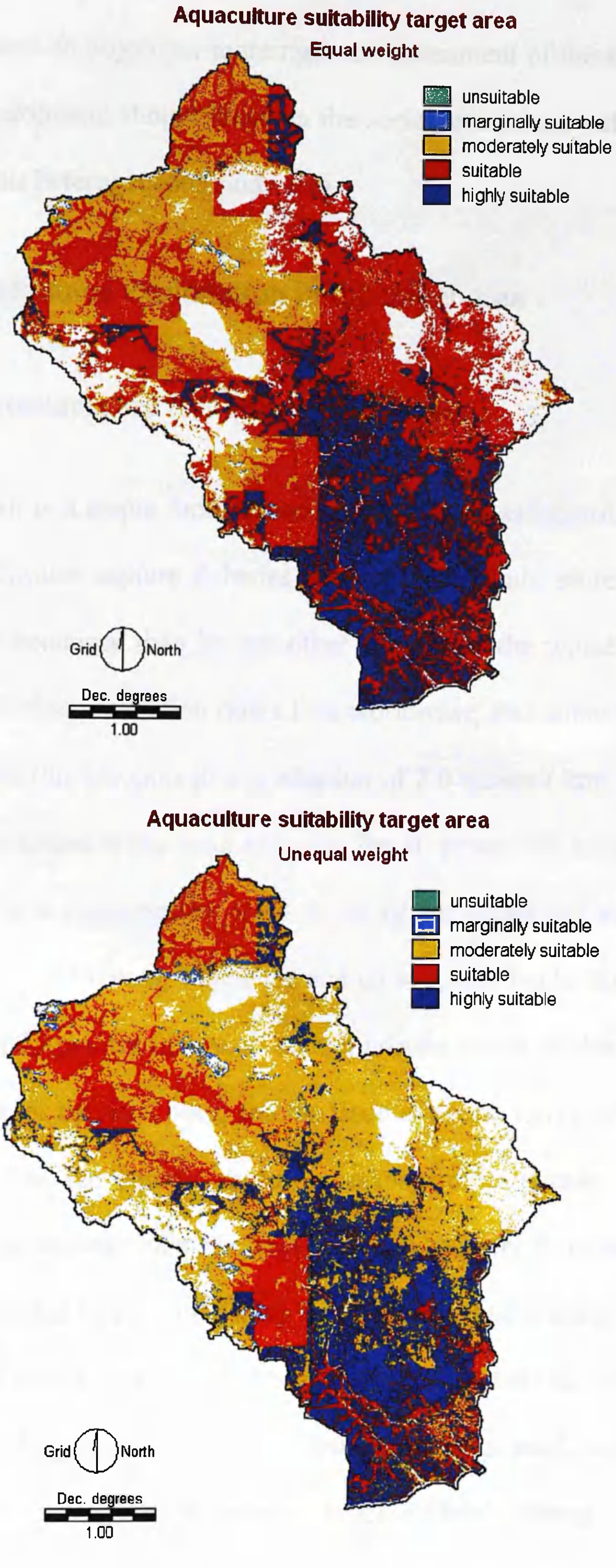


Figure 4.18 Aquaculture suitability over the study area

It was decided that an objective, more rigorous assessment of the actual potential for aquaculture development should focus on the social, economic, cultural and political context across this heterogeneous study area.

4.4 Aquatic resource exploitation in the target area

4.4.1 Aquatic resources and food security in Cambodia

In Cambodia, fish is a staple food second only to rice in safeguarding food security. Cambodian freshwater capture fisheries probably contribute more to national food security and the economy than in any other country in the world. Cambodia's per capita inland fisheries production ranks first worldwide, and amounts to 28.2 kg per year. Per unit area this amounts to a production of 2.0 tonnes / km^2 (FAO, 2003). On average, fish consumption per head accounts for 30 percent of animal protein in the diet, amounting to a consumption of 30 to 40 kg per capita per year. In floodplain areas within the main Mekong watershed and close to the Tonle Sap Great Lake fish amounts to about 75 percent of overall animal protein intake. Fishery is an important livelihood source for the rural poor, and the issue of access rights to fishing areas is a dominant theme on the aquatic resources management agenda. The Cambodian system of fisheries management has been changed recently from state-monopolistic regulation that granted large scale fishing operations exclusive access to sites through purchase of government licences, to a co-management strategy in which 56 percent of the commercial fishing lot areas has been devolved to local small-scale family fishing communities. Under the co-management scheme, local fishing communities are encouraged to participate in management and conservation in order to ensure sustainable exploitation of aquatic resources (Ministry of Planning, United Nations World Food Programme, & United Nations Development Program, 2001).

The attention to poor aquatic resource users in Cambodia (DFID-SEA Aquatic Resources Management Programme, 2000) tends to focus on subsistence fishers who indeed constitute a large percentage of the rural poor. Collection of aquatic resources however is an important part of diverse livelihood portfolios of the majority of the rural poor. Livelihoods of poor rice farmers and the landless depend heavily on foraging for aquatic resources in paddy fields. Landless people commonly collect and trade aquatic organisms for rice, and fish paste, 'prahoc', is a key component of seasonal food security for poor rice farmers. A typical rural livelihood strategy is therefore a balance between the access to private property such as agricultural land and common property such as fishery- and forest resources. In the context of rural Cambodia, rational use of common pool resources in combination with agriculture production probably is a more sustainable strategy for food security rather than relying on fisheries or agriculture alone (DFID-SEA ARMP, 2000). Understanding this livelihood context and the relationship poor people have with the resources is a central issue in addressing their needs. Therefore, it is important to target resource users, both current and potential, in such a way that the largest group of entry-level users possible is included, and to focus on removing any barriers that might exclude poor groups from applying and benefiting from aquatic resources development interventions (Meusch, 2002).

4.4.2 Fish supply and demand in Cambodia

Official figures from the Cambodian Department of Fisheries (DoF) estimate total fish supply in Cambodia at 122,000 metric tons in 1998, of which 62 percent was from inland capture fisheries, 26 percent from marine capture fisheries and 12 percent from freshwater aquaculture (DFID-SEA ARMP, 2000). Overall real freshwater fish production in Cambodia is likely to be closer to 300,000 to 450,000 tons annually, with a value at the landing port of USD 100 - 225 million, increasing to USD 250 – 500 million along the market chain (Van Zalinge, 1997, as cited in DFID-SEA ARMP, 2000). Fish consumption has traditionally been high in Cambodia, but has drastically fallen according to a Fisheries Sector Review by the Mekong Secretariat (1992, as cited in DFID-SEA ARMP, 2000) which estimates that supply falls 77,000 tons short of demand annually. Cambodian people prefer wild freshwater fish over captured marine fish and cultured freshwater fish. From late November, when major migrations of fish out of the floodplains begin, till late March - early April, wild fish is abundant and the fresh fish price is low. From May onward fish become scarce and prices at urban markets increase steeply (Naret *et al.*, 2003). The growing demand for fish can possibly not be met through capture fisheries supplies in the near future, and the RGC is increasing its attention to small-scale aquaculture development through pond-based and rice-fish aquaculture, as its potentially important role in providing food security and rural income generation is being realised (Ministry of Planning *et al.*, 2001).

4.4.3 Inland aquaculture in Cambodia

Annual inland aquaculture production was estimated at 14,100 tonnes in 1998, with an estimated theoretical cash value of 17.2 million USD (DoF, Cambodia, as cited in DFID-SEA ARMP, 2000). Cage culture is the principal system of inland aquaculture in Cambodia. It accounted for 70 to 80 percent of total Cambodian aquaculture production during the period 1992 – 1998. Over 80 percent of reported aquaculture production comes from cages and pens in the Tonle Sap Great Lake and the Tonle Sap, Mekong and Bassac river systems. Cambodian aquaculture is closely interrelated with capture fisheries, especially in Tonle Sap Great Lake. It has evolved from the activity of stocking surplus catch from the highly seasonal inland fishery in floating cages and bamboo fish-pens, in order to keep the fish alive for sale in the off-season. Fishermen subsequently started to capture and stock juveniles from the wild, in order to grow the fish in the cages to market size (DFID-SEA ARMP, 2000). The two major species cultured in cages are river catfish (*Pangasianodon hypophthalmus*) and giant snakehead (*Channa micropeltes*). Cage culture of such high value species is usually beyond the reach of poor and marginal farmers as high investment levels are required. This type of culture is highly dependent on feed fish from the wild, and concerns have been raised over the impacts of expanding feed fish demand on the availability of fish for poorer consumers and on the environment (Phillips, 2002; Sverdrup-Jensen, 2002).

Fish culture in ponds and rice fields is less developed than cage culture in Cambodia, and accounted for 15 to 20 percent of total aquaculture production during the period 1992 – 1998 (DFID-SEA ARMP, 2000). Pond based intensive *Pangasius* culture is common in Phnom Penh and Kandal provinces, near urban markets (Phillips, 2002;

Sverdrup-Jensen, 2002). Depending on the management strategy adopted, production can be as high as 30 – 100 tons/ha/year (DFID-SEA ARMP, 2000).

Sufficient supply of fish from capture fisheries initially was perceived to be an indicator that aquaculture was probably at best a niche technology in Cambodia (Demaine, 2002). Official statistics on aquaculture still underestimate small scale aquaculture (Phillips, 2002) and the use of data from case study material as guidance for estimates of aquaculture production is problematic. The development of small scale aquaculture is not static and is the result of decisions made by a vast range of small producers in response to a variety of factors, both in the physical and in the economic environment. Relative costs and returns of alternative farm enterprises vary with changing climatic and price conditions (Demaine, 2002) and the apparent success or failure of aquaculture uptake must be assessed in the light of wider household livelihood strategies that adapt to changing conditions (Friend & Funge-Smith , 2002). Aquatic resources are one component of such livelihood strategies and small scale aquaculture can often be a temporary or irregular coping strategy in response to scarcity of aquatic resources from the wild, for example during the dry season. A pond in such cases is an important natural asset for small-scale farm households, not only for fish production but also as a water storage that can be used for livestock, supplementary irrigation and as a domestic water supply. Gregory & Guttman (2002) consider the distinction between small scale aquaculture and floodplain and ricefield fisheries irrelevant for most lowland rice farmers in rural Cambodia, and in order to improve food security through fish they propose a broader fisheries development approach including aquaculture as one component.

The recent increases in the development of pond based aquaculture are mainly a response to declining supplies of wild fish. Most small scale pond culture systems concentrate on exotic fish species which feed low in the food chain, such as Chinese carps, Indian carps and tilapia. The increase in importance of low-input pond culture, as well as rice-fish and integrated fish/livestock/vegetable culture systems involving both exotic and indigenous fish species was also a result of its promotion through donor assisted projects. In Cambodia, large numbers of multi purpose household ponds have been dug by NGO's and donor agencies (Ministry of Planning *et al.*, 2001; Demaine, 2002; Phillips, 2002; Sverdrup-Jensen, 2002). Although many of these ponds are tiny, in many cases just 80 m^2 as this was the standard size of ponds dug by UNICEF's Family Food Production Program (Tuy, 1996, as cited in Demaine, 2002), such ponds potentially can be utilised for aquaculture in areas experiencing a shortage of fish. In areas further from the Tonle Sap and other major rivers, small scale aquaculture can provide an important opportunity for poor households to improve nutrition and generate cash income. Poor households engaged in aquaculture often consume the fish in order to spare other livestock for income generation, but also tend to sell their aquatic produce in order to buy cheaper locally available wild fish for their own consumption.

Experience of the AIT Aqua Outreach Program (AOP) in Takeo and Svay Rieng provinces, South and Southeast Cambodia respectively, suggests that the demand for aquaculture is strongest in areas with poorer water resources. In field trials under resource poor conditions a production of 2 – 5 tons per ha in 8 months has been obtained. Despite the small total amounts of fish obtained, the AOP experience recorded clear farmer appreciation of the extra degree of food security offered by such small-scale systems. The initial interest toward small-scale aquaculture in Svay Rieng however was followed by a trend of contraction, which was probably mainly induced by climatologic factors. Since 1998 a series of years with high rainfall at the beginning of the rainy season encouraged the expansion of wild fish stocks and many farmers returned to fish capture in paddy fields and ponds. Wild fish entering the aquaculture system early in the culture cycle moreover caused significant losses through predation (Demaine, 2002). Farmers in Svay Rieng province reportedly have stopped culturing most fish species except tilapia which breeds in the pond, and *Pangasius* as large seed is readily available from Vietnam.

4.4.4 Aquaculture market demand

The development of aquaculture is strongly influenced by market demand. Market demand will depend on the availability of consumers who can pay the price, especially in local markets. A cautious development of small scale aquaculture, based on understanding of local markets, can contribute to meeting local demand in areas where wild fish supply is limited and can contribute to food security in such areas. In Cambodia and Northeast Thailand, fish farmers were observed to obtain higher farm gate prices for fish sold locally in relatively small amounts, rather than for fish being destined in bulk for urban markets. This might be indicative for a degree of urban market saturation in some areas. *Pangasius* in rural areas in Cambodia fetches R3000 per kg (3800 Riel is approximately 1 USD) compared to only 1600 per kg in bulk. *Pangasius* fish from Svay Rieng, transported live by pick-up truck to Phnom Penh, fetches only low prices of R1500-2000 per kg. The price of pond raised *Clarias* varies seasonally from a low of R2000-2100 / kg in the rainy season when wild fish is abundant to R2800 / kg in the dry season. Indigenous carps, being promoted for culture, fetch high prices. Even exotic species can be sold for R3500-4000 per kg at village level, but exotic fish are not popular in urban markets, except large tilapia. Farm gate prices of exotic carps have fallen recently with the demise of the wedding trade for exotic species (P. Edwards, personal communication, 23 August 2002).

4.5 Spatial data and ground verification for the study area

Field visits were undertaken in Cambodia, Thailand and Vietnam in order to verify satellite derived information on agro-ecosystems use and spatial socio-economic data on livelihood characteristics for selected administrative units over the target area.

In Cambodia, target areas of a project which ran from April 2001 till November 2004 within DFID's Aquaculture and Fisheries Genetics Research Programme (AFGRP) were visited. The purpose of the project, self-recruiting species in aquaculture – their role in rural livelihoods (SRS) was to characterise the importance of fish and other aquatic animals that can be harvested from farmer managed systems without regular stocking, to the livelihoods of the rural poor. The SRS project sites in Cambodia were located in Svay Rieng province and Takeo province respectively (Figure 4.19). Svay Rieng province is situated in the southeast part of Cambodia, and is bounded by Kampong Cham province to the north and Prey Veng province to the west. The southern and eastern boundaries are with Long Anh and Tha Ninh provinces respectively, of Vietnam. Svay Rieng province covers a land area of 2966 km^2 and had an estimated population of 442,000 people in 1998, averaging 149 persons per km^2. The province is subdivided in 7 districts, with 80 communes and 690 villages (DFID/AFGRP, 2002c). Takeo province is located in the southern part of Cambodia.

The province is subdivided in 10 districts, with 100 communes and 1122 villages (DFID/AFGRP, 2002b). In Prey Veng province, sustainable community agriculture systems incorporating fish ponds on-farm, as promoted by the Cambodian development NGO Partnership for Development in Kampuchea (PADEK), were visited. Prey Veng is one of the poorest and most densely populated provinces in Cambodia with an average population density of 210 inhabitants per km^2 (CARE International, 2002).

Sisaket province is located in the southern part of Northeast Thailand, bordering Cambodia to the south (Figure 4.19). The province was visited in June 2003. The objective of the survey was to characterise agro-ecosystems and aquatic resource use through ground verification of sub-district (Tambon) level data derived from a national rural development database (NRD-2C). The survey focused on the use of SRS in farmer managed systems and on the impact of pond dike integrated farming on the livelihoods of farming households. The latter was one of the main research objectives of an EC funded project on improved resource use efficiency in Asian integrated pond-dike systems (POND LIVE). The survey was conducted in connection with a situation appraisal of pond-dike systems in the area by POND LIVE and longitudinal surveys of rice field fish production by AFGRP's SRS project.

In the Vietnamese Mekong Delta, some areas in Can Tho, Vinh Long and Tien Giang provinces (Figure 4.19), which were also targeted by the POND LIVE project, were visited for the purpose of comparative analysis. Poverty data for these areas were not available at sub-district or commune level, and were considered not sufficiently disaggregated to be useful in the context of this study. Because of the problem of using different administrative scales, comparison across countries with target areas in Cambodia was not possible, and an accessible source of socio-economic data necessary for spatial analysis could not be identified for the Vietnamese context.

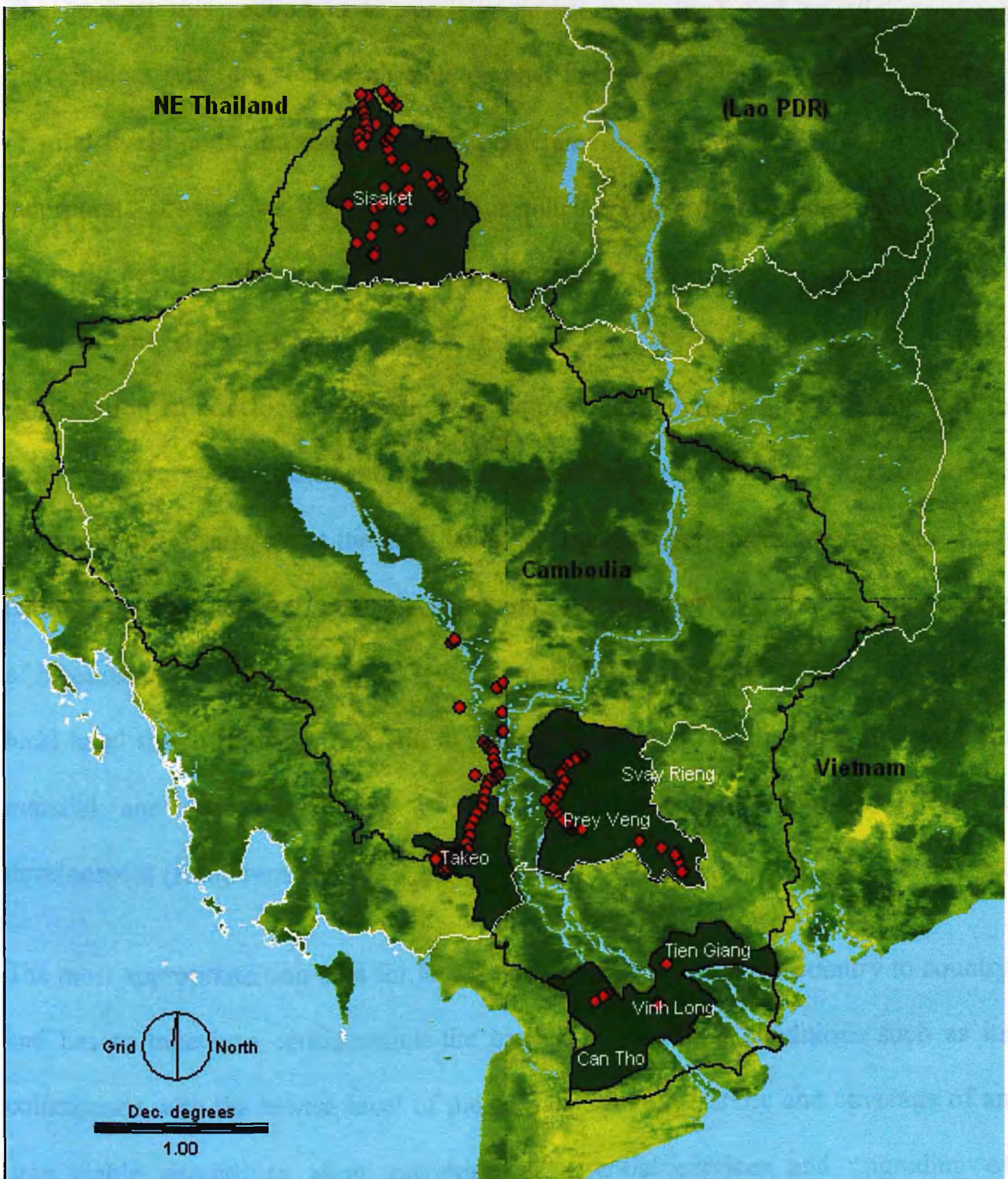


Figure 4.19 Provinces visited for field verification in the target area. Red dots represent GPS locations for ground truthing

5 Poverty targeted aquatic resource development

5.1 Introduction

The goal of this section is to spatially target aquaculture and aquatic resources development within a socio-economic context focusing on poverty and vulnerability of rural livelihoods and their assets to participate in the rural economy. In order to incorporate aquaculture development in a policy framework that takes into account the basic needs of the poor and the participation of the local population in planned development, it has to be targeted at the local level. Local level planning and the participation of the local population in planned development play a major role in reducing poverty and fulfilment of the basic needs of the poor. Direct participation of the rural poor is possible at the local level, but the rural poor cannot participate at the national or regional level, other than through representatives. The nature and volume of resources available at the local level are not reflected in national plans. It is at the local level that it becomes possible to identify these, and mobilise and allocate both material and human resources in order to achieve the desired objective of development (Kaojarern, 1986).

The most appropriate unit area for local level planning varies from country to country and has to take into consideration the particular prevailing conditions such as its coincidence with the lowest level of the administrative hierarchy and coverage of an area viable enough to allow provision of essential services and upgrading of managerial and productive skills of the rural poor through group action in order to achieve a particular desired development outcome (Kaojarern, 1986). In the context of poverty targeted aquaculture and aquatic resources development such prevailing conditions include the existing dependence of the rural poor on aquatic resources and its scope of poverty alleviation through exploiting its growth potential at local level.

5.2 Poverty in Cambodia

5.2.1 Spatial distribution of poverty

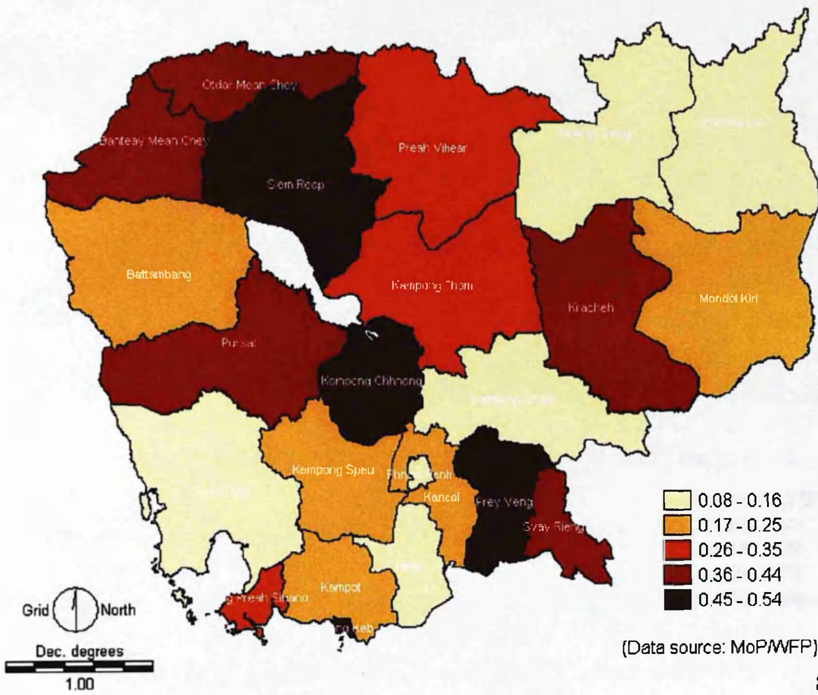
The benchmark national poverty rate of Cambodia was 36.1 percent in 1998. Rates of poverty vary widely across the country. This reflects a high level of income inequality in general, but also reveals important differences between rural and urban areas, and various regions in the country. Most poverty reduction occurred in the capital Phnom Penh and provincial towns, reflecting important differences between urban and rural areas. 90 percent of the poor live in rural areas and the highest incidence of poverty is found among households where agriculture is the primary source of income (World Bank, n.d.). Poverty rates range from a low of 12 percent in Phnom Penh to a high of over 50 percent in Siem Reap and Prey Veng provinces. Phnom Penh and surrounding provinces on the Mekong-Bassac floodplain enjoy the best social conditions and higher levels of wellbeing, whereas the remote north-eastern provinces of Ratanakiri and Mondulkiri generally exhibit poor social conditions in terms of health and education. The provinces in the Tonle Sap plain area are characterised by high levels of poverty and related poor social conditions (Hook *et al.*, 2003).

A nation-wide socio-economic survey (CSES) was undertaken in 1997 by Cambodia's Ministry of Planning (MoP) and World Food Programme (WFP). The survey was divided into three strata; Phnom Penh, Other Urban and Rural. Poverty rates found at this stratum level are quite similar to an earlier assessment, described in

WFP (2001). The poverty rate in Phnom Penh was around 10-12 percent, Other Urban was 25-30 percent, and Rural was 40-50 percent, reflecting the important differences between rural and urban areas. The poverty lines in terms of per capita per day consumption for these strata translated into 2.30, 1.72 and 1.46 USD respectively, in terms of purchasing power parity (PPP). The average official exchange rate in 1998 was USD 1 = 3807.8 Riel. Based on the World Development Indicators, the PPP conversion factor to official exchange rate ratio in 1998 was 0.189 (Ministry of Planning, R. G. o. C. & United Nations World Food Programme, 2002).

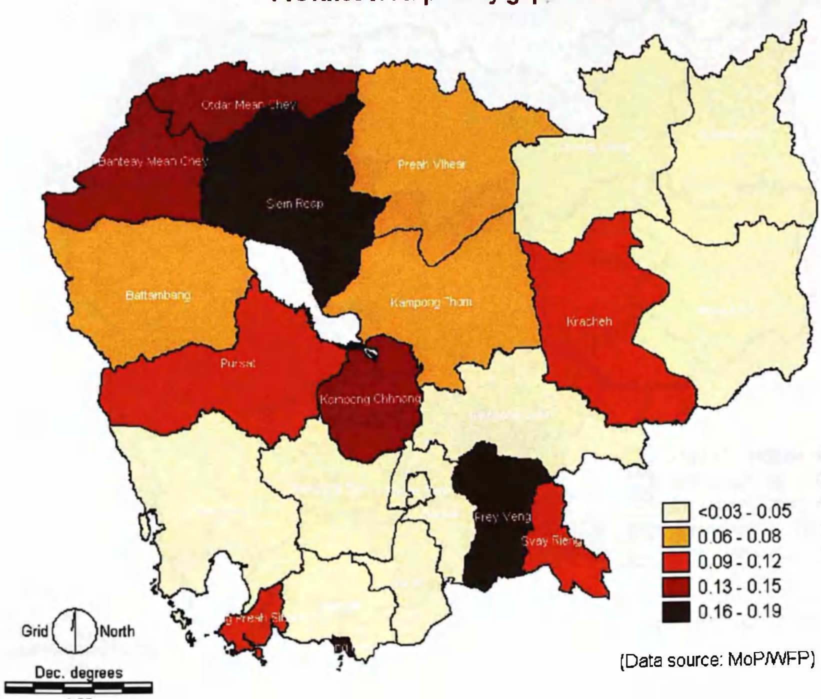
The results of the national poverty assessment indicated that at province level the 1998 poverty rate in terms of headcount index (Figure 5.1 a) was highest for Siem Reap province, at 0.54 (53.73 percent), closely followed by that of Prey Veng province at 0.53 (53.14 percent). Poverty depth and severity (Figure 5.1 b and Figure 5.2 a respectively) were also highest for Siem Reap province and second highest for Prey Veng province. Poverty in terms of absolute numbers of poor people (Figure 5.2 b) was highest in Prey Veng, with an estimated number of 493.6 thousand poor people, followed by an estimated number of 356.8 thousand poor people in Siem Reap province (MoP & WFP, 2002).

Province level poverty rate (Head Count Index), 1998



a

Province level poverty gap, 1998



b

Figure 5.1 Province level poverty measures, Cambodia; a) poverty rate (incidence) and b) poverty depth (poverty gap) (Data: courtesy of World Food Programme Cambodia)

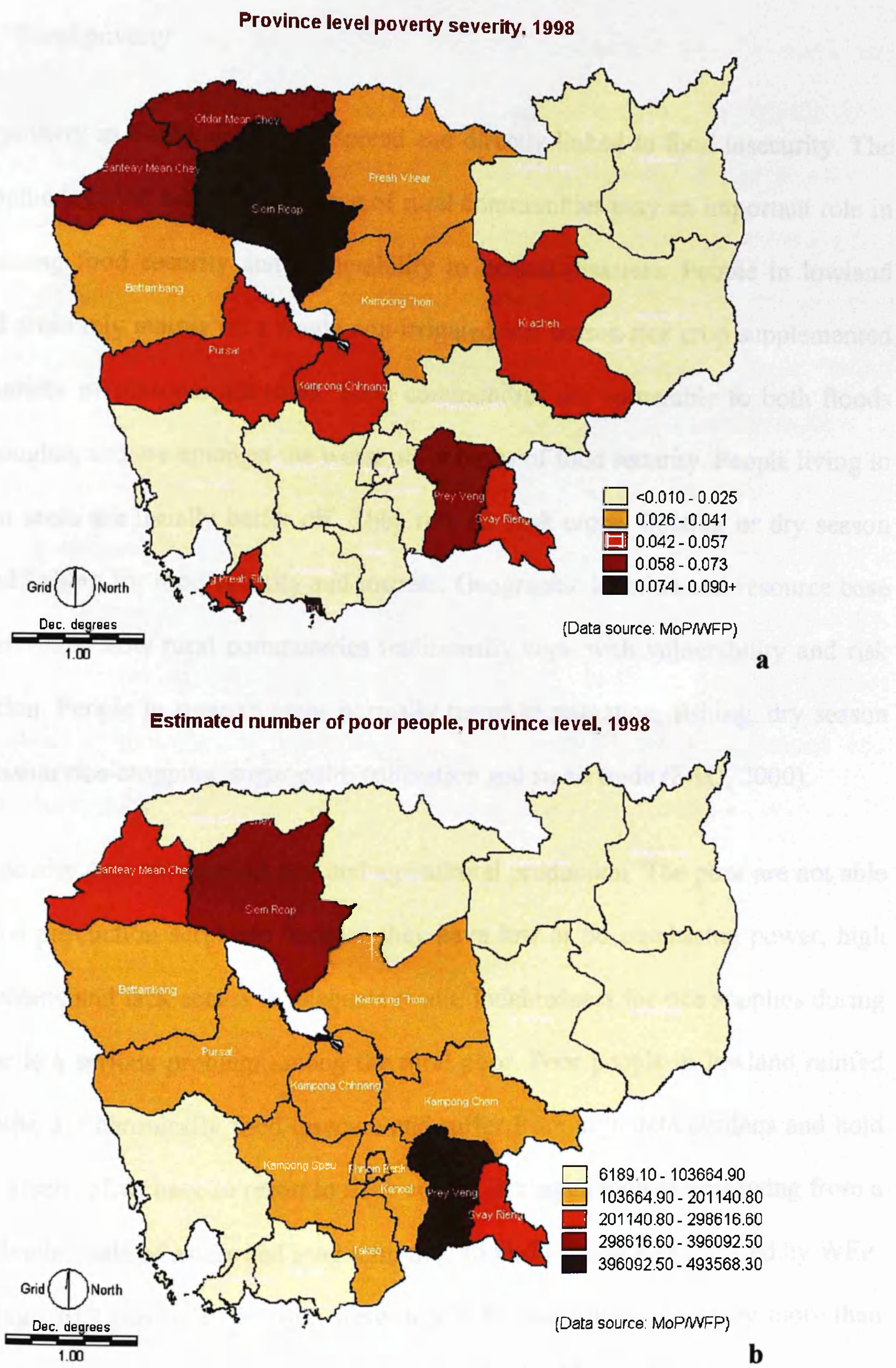


Figure 5.2 a) Province level poverty severity and b) no. of poor people

5.2.2 Rural poverty

Rural poverty in Cambodia is widespread and directly linked to food insecurity. The geographic location and resource base of rural communities play an important role in determining food security and vulnerability to natural disasters. People in lowland rainfed areas rely mainly on a single non-irrigated wet season rice crop supplemented by a variety of seasonal activities. Such communities are vulnerable to both floods and droughts, and are amongst the worst off in terms of food security. People living in riparian areas are usually better off. They rely on cash crops, floating or dry season rice and fishing for food security and income. Geographic location and resource base also determine how rural communities traditionally cope with vulnerability and risk mitigation. People in riparian areas normally resort to migration, fishing, dry season or recession rice cropping, sugar-palm cultivation and small trade (FAO, 2000).

Food security goes far beyond rice and agricultural production. The poor are not able to access production surpluses because they have low or no purchasing power, high debt burdens and lack access to adequate credit. Indebtedness for rice supplies during the year is a serious problem among the rural poor. Poor people in lowland rainfed areas, who are chronically food insecure and suffer from high debt burdens and hold limited assets, often have to resort to risky coping strategies such as borrowing from a money lender, sale of assets and long term migration. In communes targeted by WFP, on average 30.2 percent of families were in debt for daily needs spanning more than three months of the previous year. Access to food is also hindered by poor marketing- and distribution systems, price variations, poor transportation and communication infrastructure, limited off-farm employment opportunities and low investment in agriculture. A crop and food supply assessment conducted by the Food and Agriculture Organization (FAO) and World Food Programme (WFP) in 1999 identified a number of factors causing food insecurity among certain population groups in Cambodia, despite a small national rice production surplus forecasted in that year. Commune level data revealed that less than 25 percent of rice growing communes, representing approximately 15 percent of the population, was producing 75 percent of the national surplus. On average 17 percent of communes suffered from rice consumption deficits greater than 3 months. Poor nutritional outcomes demonstrated that the need for improved consumption at the household level was widespread. National stunting rates, low height-for-age, stood at 56 percent, underweight levels at 52 percent and the rate of wasting or short duration malnutrition, as indicated by low weight-for-height, was 13 percent. Seasonal sub-national wasting rates for children under five years of age reached as high as 20 percent and levels of anaemia in children reached 80 percent in rural areas (FAO & WFP, 1999).

5.2.3 Small area poverty estimation

A detailed spatial assessment of poverty at commune level was conducted in 1998 by the United Nations World Food Programme (WFP), the Ministry of Planning (MoP, Cambodia) and the World Bank. The methodology involved a rigorous statistical analysis of the 1998 census data set and the 1997 socio-economic survey (CSES), using a small area estimation technique developed by Elbers, Lanjouw, & Lanjouw (2003), to identify poor areas. The methodology uses household consumption expenditure instead of income as a monetary measure for welfare. Income is often subject to under-reporting and seasonal variation, and is less likely to estimate welfare very well in situations where a large informal sector exists or a large fraction of production is for self-consumption. Consumption is defined as goods and services bought on the market, received in kind or produced by the household. The basic idea of the small area estimation is to use consumption for each household in the census to estimate poverty rates. As the target population becomes smaller, this imposes a practical limit to the degree of disaggregation possible. Reliable estimates cannot be derived without aggregating up to a certain level. As the level goes up, the estimate becomes less subject to random errors. Commune level aggregation was chosen as a useful level of aggregation at which the estimate is still acceptable (MoP & WFP, 2002).

The accuracy of poverty estimates was found to vary from commune to commune. Explicit treatment of standard errors associated with the poverty estimates helps to reduce the errors associated with targeting and therefore increases the efficiency of targeting. If standard errors associated with the poverty estimate are very large, the estimate contains almost no information on actual poverty rates. When a commune cannot be classified, the communes can be aggregated to district or even province levels to reduce standard errors. Poverty rates with small standard errors allow for a sharp comparison between communes. The standard errors associated with commune level estimates ranged between 0.1 percent and 22.6 percent, with the urban areas having lower standard errors than rural areas. If the point estimates for poverty are high enough, a relatively high level of standard error may not matter. Poor communes and non-poor communes can be defined by the ratio of the difference between the poverty estimate and a reference level to the standard error. For example a commune can be defined as significantly poorer than the benchmark national poverty rate of 36.1 percent, when its point estimate is higher by at least two times the standard error (MoP & WFP, 2002); Figure 5.3).

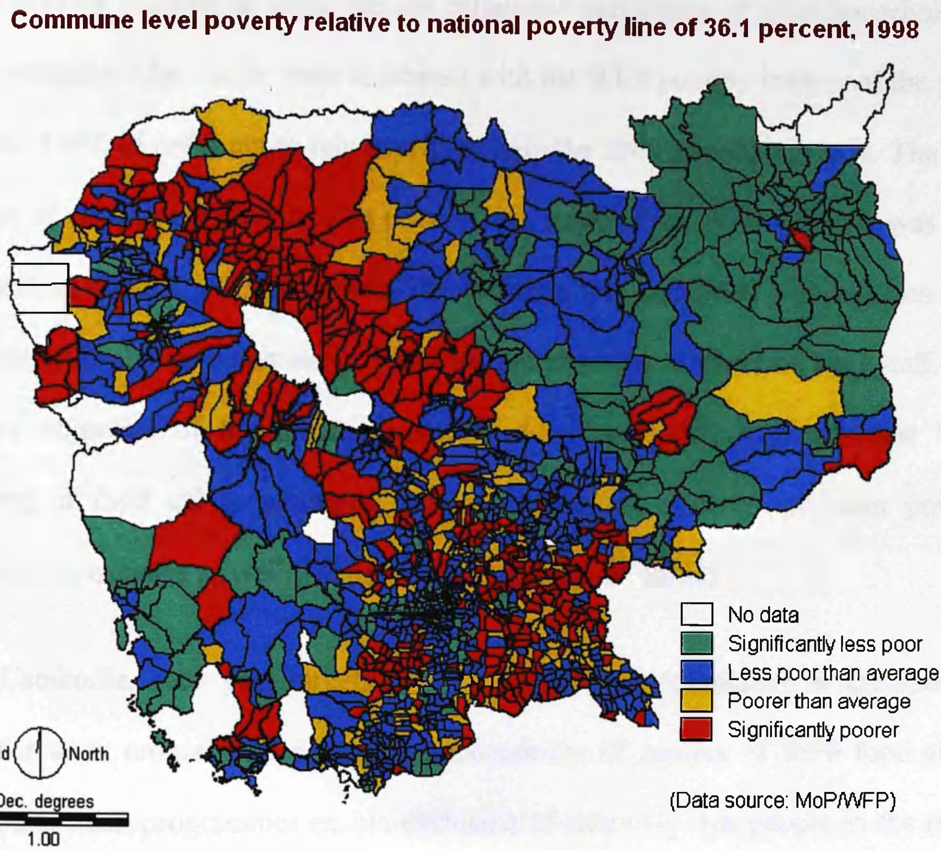


Figure 5.3 Commune level poverty rates relative to 1998 poverty line (36.1 percent)

5.3 Poverty map applications

5.3.1 Targeting of food aid

WFP has applied GIS to create poverty maps based upon the result of the small area estimation. The maps serve as a basis to formulate targeting plans for various social interventions carried out by WFP, and they are provided to other organisations as a planning tool for the development of poverty reduction strategies (MoP & WFP, 2002). The first comprehensive poverty maps for Cambodia have been used to prepare targeting plans for the WFP food aid programme between 2001 and 2003. The output of the poverty analysis in 2000 was the calculated percentage of poor households in each commune. The results were combined with the WFP poverty indices of the years 1997 till 1999, in order not to rely overly on only the 2000 poverty analysis. The total number of communes classified as poor in this stage of the WFP analysis was 358, representing about 2,431,000 people. The outcome was combined with relevant field information on "poor communes", based on the recommendations of field staff. The primary objective of the targeting process described above was to assist WFP targeting of food aid programmes, but the results can be used for other poverty targeted programmes as well (Ministry of Planning *et al.*, 2001).

WFP Cambodia, each year targets food to the neediest communes in the country. Food for work programmes on average account for 85 percent of WFP food aid in Cambodia. Such programmes enable exclusion of relatively rich people in the target area, as the opportunity cost from work is relatively high for richer people. Such targeting schemes, called self-targeting, can therefore be more efficient than administratively targeted interventions, where the targeted people are determined by project staff. The food for work targeting process was reviewed on a yearly basis from 1997 through 2000 (Ministry of Planning *et al.*, 2001).

In 1997, 550 poor communes were selected and half the villages in each of them, totalling 2751 villages, were covered for detailed socio-economic analysis. A poverty score was compiled from 27 socio-economic indicators. Village results were averaged by commune and communes falling in the lowest 25 percentile were mapped. Geographic clusters of communes were identified for first priority food for work targets. In addition, emergency targets were included as first priority areas (Ministry of Planning *et al.*, 2001).

In 1998, five food economy zones were derived at district level, based on a series of indicators, such as satellite data, crop production, wage income prevalence and urban locations. The five predominant food economy zones were urban, riverine, forest, lowland rain fed and scrub. Food access strategies differed between food economy zones, but were broadly homogeneous within each zone. Rice crop statistics were found to be a powerful determinant to outcomes in lowland rice areas, but not in other areas. Cash income sources and reliance on high risk coping strategies were closely linked to scrub zones, while distance from markets and major roads were more closely related to outcomes in riverine areas. Adjacency to a national highway was one of the single most important factors to both better nutritional and expenditure outcomes. A set of criteria was adopted to update commune information on the basis of significant changes in reliance on high risk coping strategies, changes in production and sudden changes in sources of income (Ministry of Planning *et al.*, 2001).

5.3.2 Targeting of national poverty reduction strategies

The development of poverty maps will be instrumental in the formulation of poverty reduction strategies by the Cambodian government (RGC). The RGC policy on poverty reduction and medium- and long term strategy of economic development through agricultural growth targets those areas with higher incidence of poverty and food insecurity. Rice production alone will not realise the objective of poverty reduction. Improved water control and irrigation is necessary in order to minimise the agriculture dependency on natural conditions and mitigate the risks of agricultural losses due to floods and drought. The importance of improved water control is underlined by the fact that the irrigated area comprises only about 19.5 percent of the total cultivated area in Cambodia, but accounts for approximately 31.4 percent of total Cambodian rice production. 12.4 percent of 2.06 million hectares of wet season rice, and little more than 55 percent of 259,919 hectares of dry season rice receive irrigation water. Current irrigation can be classified into three types; 1) wet season supplementary irrigation for rainfed lowland rice, 2) supplementary irrigation for dry season flood recession rice and 3) irrigation of dry season lowland rice. The importance of supplementary irrigation for crop security resides in the fact that it allows timely planting of crops, while during the growing season it enables the plants to survive prolonged drought spells. Farmers also need facilities for improved drainage of flood flows and access to their fields. Emphasis is given to the rehabilitation of existing irrigation schemes and small-scale schemes capable to irrigate up to 10 ha (Ministry of Planning *et al.*, 2001).

The Cambodian lowland area has the highest potential to respond to the RGC policy on poverty reduction and medium- and long term strategy of economic development through agricultural growth. Lowland rain-fed and scrub- and degraded forest zones have been primarily targeted by WFP to assist communities with severe problems of chronic or recurrent food insecurity (FAO & WFP, 1999). In lowland rainfed areas, livelihoods depend on a single non-irrigated wet season rice crop as a major source of food and income. Land is divided into small independent landholdings, and agricultural production is below average. Lowland communes are constrained by poorly developed water resources and a lack of improved tertiary roads to markets and basic services. Most of the rural roads are impassable during the rainy season. Income is supplemented by a variety of seasonal activities and high-risk coping strategies prevail, including long-term indebtedness for food. Smallholder agriculture needs to be strengthened through crop diversification and intensification. The production of vegetables in order to meet local food requirements needs to be promoted, while the development of local agro-industry through investment in agro-processing and post harvest technologies should generate income and employment opportunities (Ministry of Planning *et al.*, 2001).

5.4 Targeting aquaculture development on poor areas

5.4.1 Selection of target areas for aquatic resource development

The selection of target areas in past aquaculture related development projects such as the project on self-recruiting species (SRS) in aquaculture was not explicitly directed towards poverty. In the SRS project selection criteria rather focused on the status of aquatic resources in relation to the different topographies across the target provinces. A line transecting the provinces was drawn, and communes situated along or close to the transect line were randomly selected. The selected communes were visited in order to collect secondary information about aquatic resource use, population and economic conditions at village level. The subsequent village selection was done on the basis of this information (DFID/AFGRP, 2002c). As rural poverty is widespread in Cambodia, such a targeting strategy is likely to reach rural poor that are dependent on aquatic resources even though it does not maximise the number of poor people ultimately reached.

A framework for targeting the rural poor for aquatic resources development can be based on the results of the poverty mapping exercise undertaken by WFP in 2000. In order to reach a large number of poor individuals allocation of resources can be targeted at communes which are both poor and densely populated (Figure 5.4), or through targeting on the basis of high poverty incidence (Figure 5.5 a). The latter is also likely to include people deeper in poverty (Figure 5.5 b).

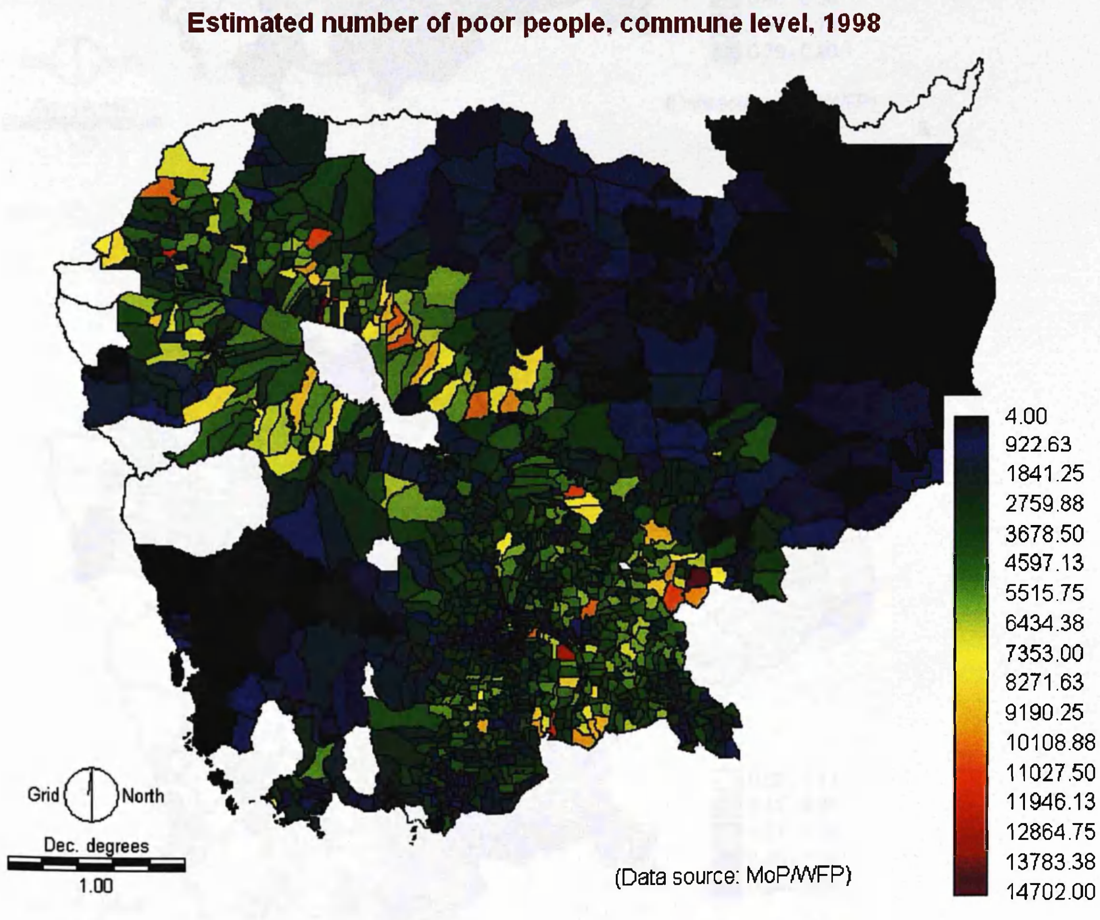


Figure 5.4 **Estimated number of poor people per commune, 1998 (Data source: WFP Cambodia)**

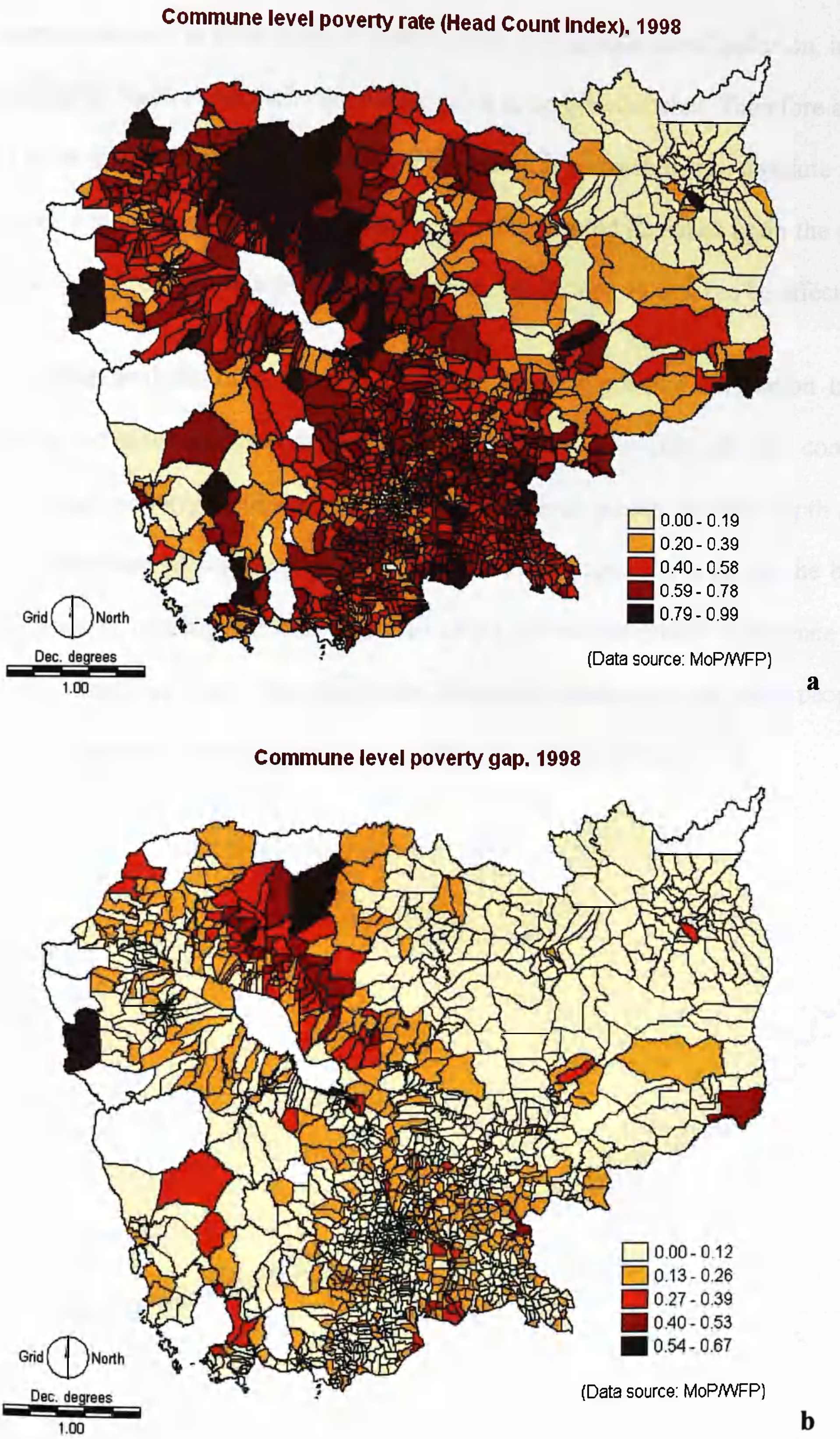


Figure 5.5 Commune level poverty; a) poverty incidence, b) poverty gap

Targeting densely populated areas is more likely to lead to error of inclusion, in which the benefits reach people who are not intended to be beneficiaries. Therefore a choice has to be made whether the aim of an intervention is to reach a high absolute number of poor people as intended beneficiaries, or rather should be based upon the poverty incidence, i.e. the proportion of the population that is poor, in order to be effective.

On further analysis of poverty at commune level, a positive correlation between poverty incidence and poverty gap becomes apparent. This suggests that communes with a high poverty incidence are likely to experience greater poverty depth (Figure 5.6). Allocation of resources to alleviate poverty at commune level on the basis of high poverty incidence is thus likely to target communes which experience a high poverty depth as well. The correlation between total number of poor people per commune and the poverty gap is also positive, but weaker (Figure 5.7).

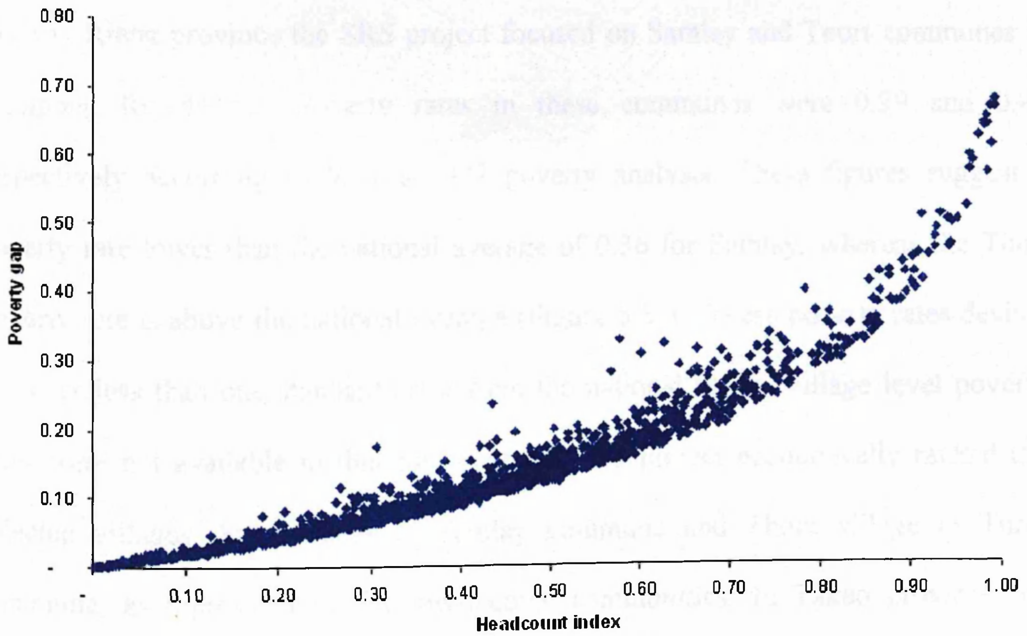


Figure 5.6 Correlation of poverty incidence (headcount index) with poverty depth (poverty gap)

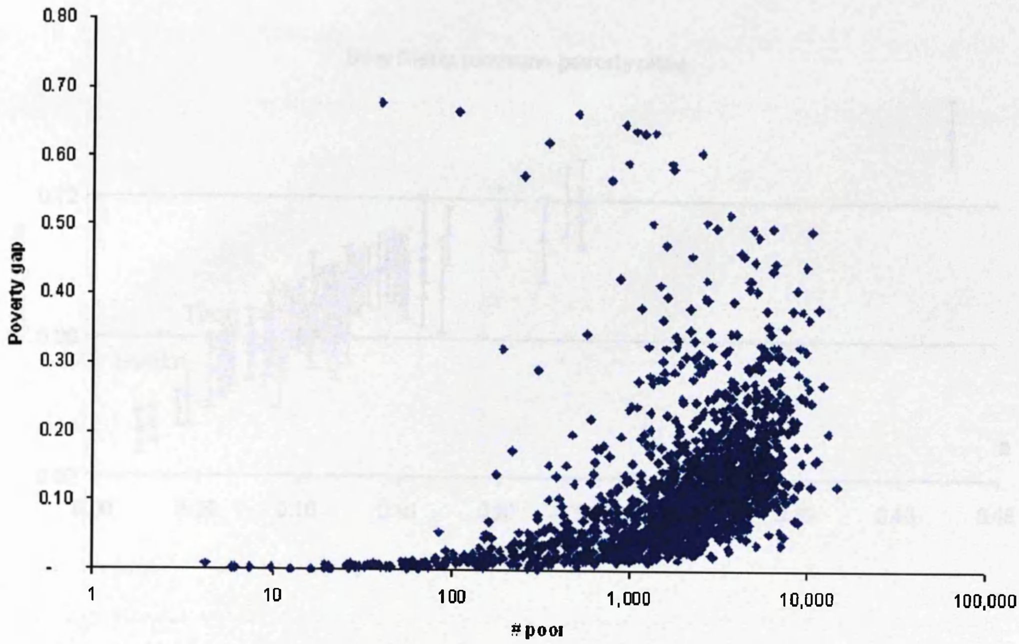
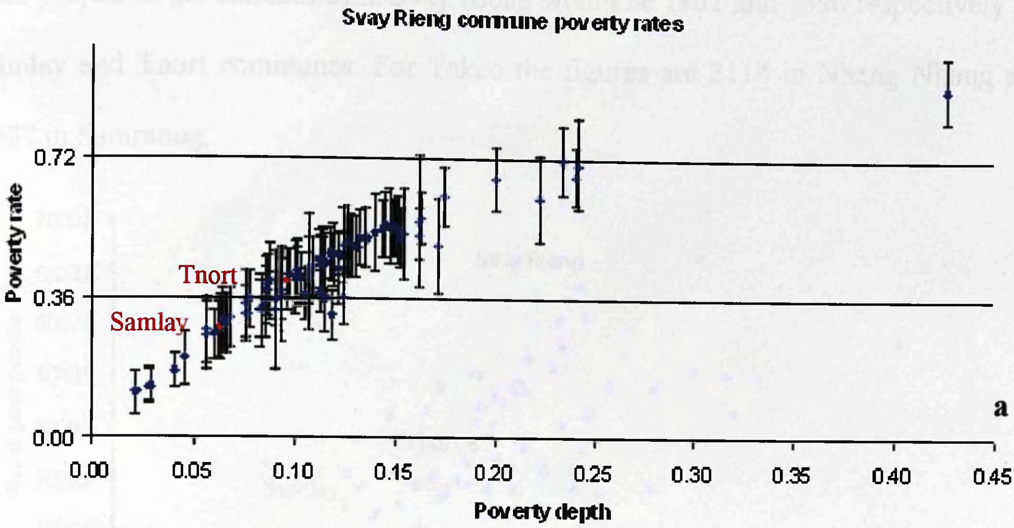


Figure 5.7 Correlation of number of poor persons per commune with poverty depth (poverty gap)

5.4.2 Poverty levels in the target communes

In Svay Rieng province the SRS project focused on Samlay and Tnort communes in Kampong Ro district. Poverty rates in these communes were 0.29 and 0.41 respectively according to WFP's 1998 poverty analysis. These figures suggest a poverty rate lower than the national average of 0.36 for Samlay, whereas the Tnort poverty rate is above the national average (Figure 5.8 a). These poverty rates deviate however less than one standard error from the national mean. Village level poverty rates were not available in this study but the SRS project economically ranked the selected villages, Svay Cheak in Samlay commune and Thom village in Tnort commune, as representative for low-income communities. In Takeo province the poverty rates in communes targeted by the SRS project in Tramkok district, Samraong and Nheng Nhang, are 0.48 and 0.39 respectively (Figure 5.8 b).



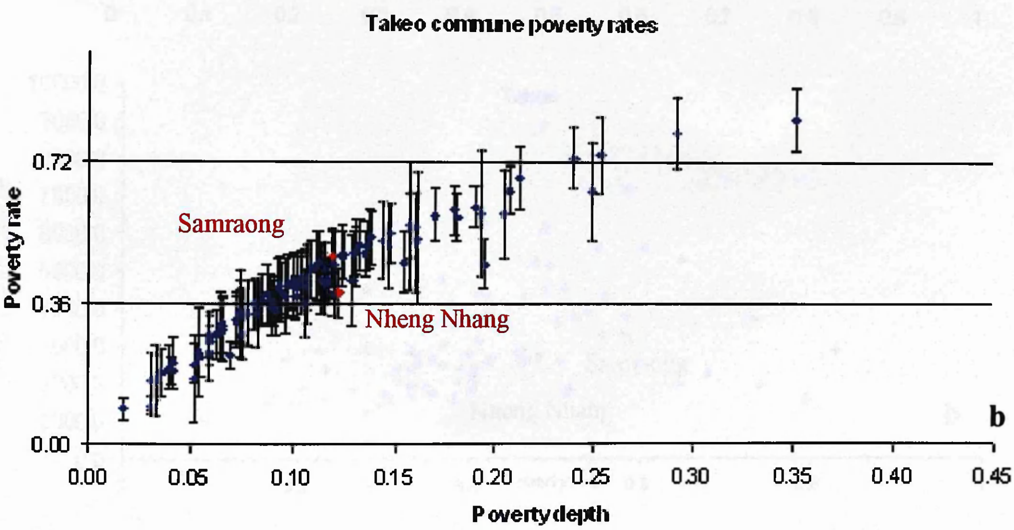


Figure 5.8 Poverty rate (± standard error) vs. poverty depth in SRS target communes (red dots) relative to all commune level poverty rates in a) Svay Rieng province and b) Takeo province

Figure 5.9 shows a positive correlation between poverty rates and the absolute number of poor people in Svay Rieng province (a) whereas the correlation is weaker in the case of Takeo province (b). Targeting at commune level on the basis of high poverty rates is therefore likely to reach a high number of poor people in Svay Rieng, but not necessarily in Takeo. According to the WFP estimate, the number of poor people in

SRS project target communes in Svay Rieng would be 1901 and 2590 respectively for Samlay and Tnort communes. For Takeo the figures are 2114 in Nheng Nhang and 2687 in Samraong.

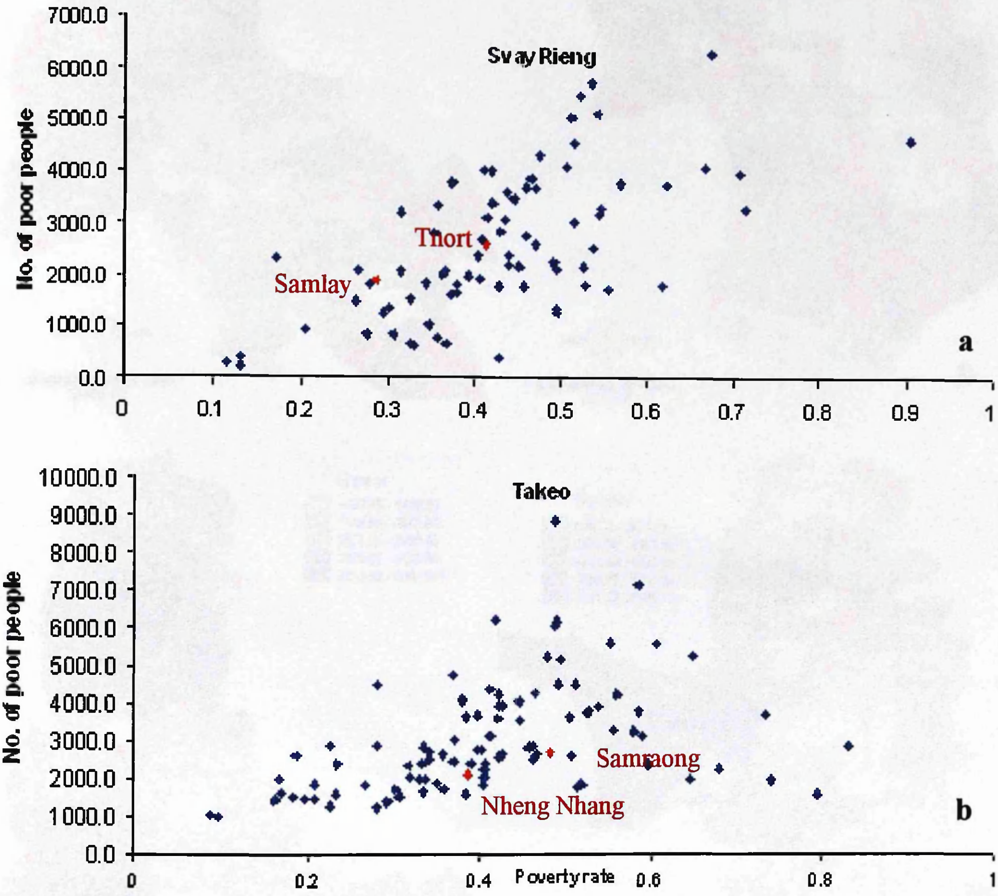


Figure 5.9 No. of poor people per commune as a function of poverty rate in a) Svay Rieng province and b) Takeo province

Poverty in Svay Rieng is concentrated in Romeas Haek district in the north of the province (Figure 5.10 a, c). In Takeo, poverty rates are higher in the more densely populated northern and north-eastern part of the province and in the relatively thinly populated southwest (Figure 5.10 b, d). As a consequence poverty in terms of numbers is concentrated in the north and northeast of the province, especially in Tramkok district (Figure 5.10 b, d).

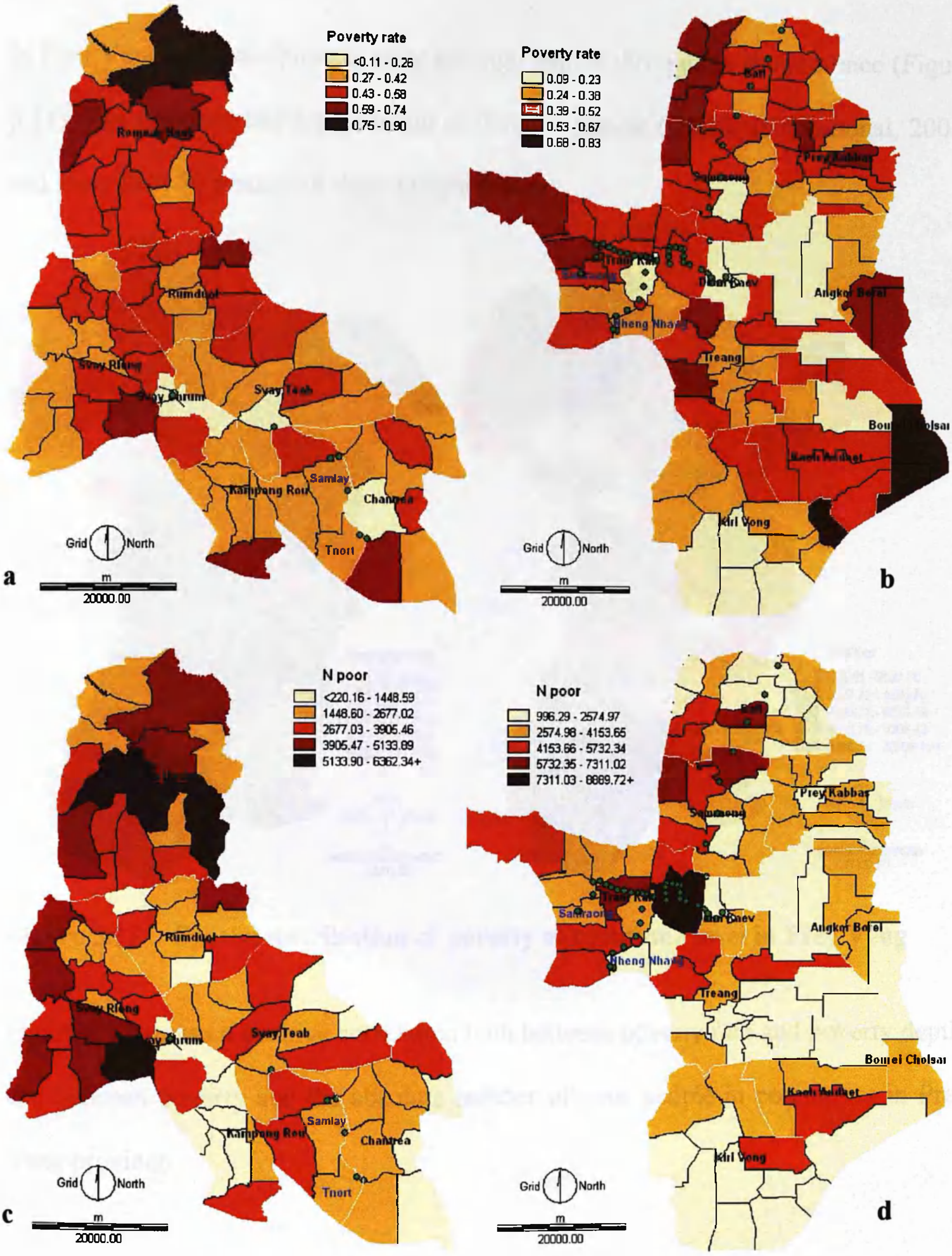


Figure 5.10 Spatial distribution of poverty at commune level; a) and b) poverty rate in Svay Rieng and Takeo respectively, and c) and d) number of poor per commune for both provinces respectively (SRS project communes in blue, green dots are GPS waypoints)

In Prey Veng province poverty rates are high almost throughout the province (Figure 5.11). The province has a population of 946,042 people (CARE International, 2001) and more than 50 percent of these people is poor.

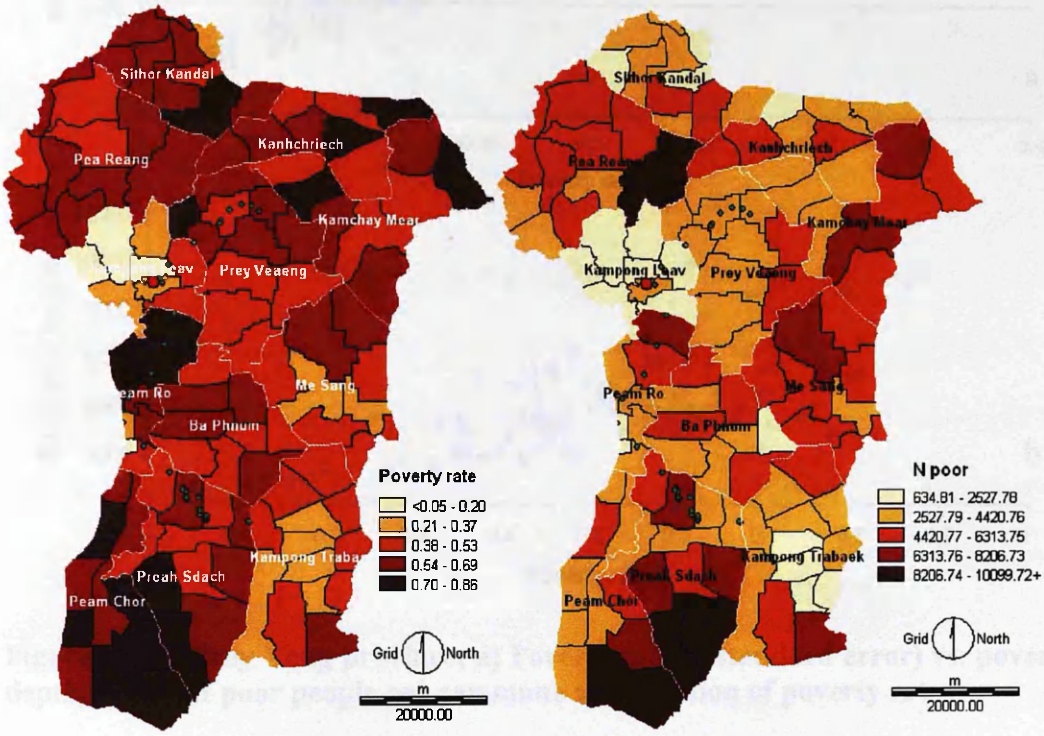


Figure 5.11 Spatial distribution of poverty at commune level in Prey Veng

Figure 5.12 shows a positive correlation both between poverty rate and poverty depth, and between poverty and the absolute number of poor people in communes in Prey Veng province.

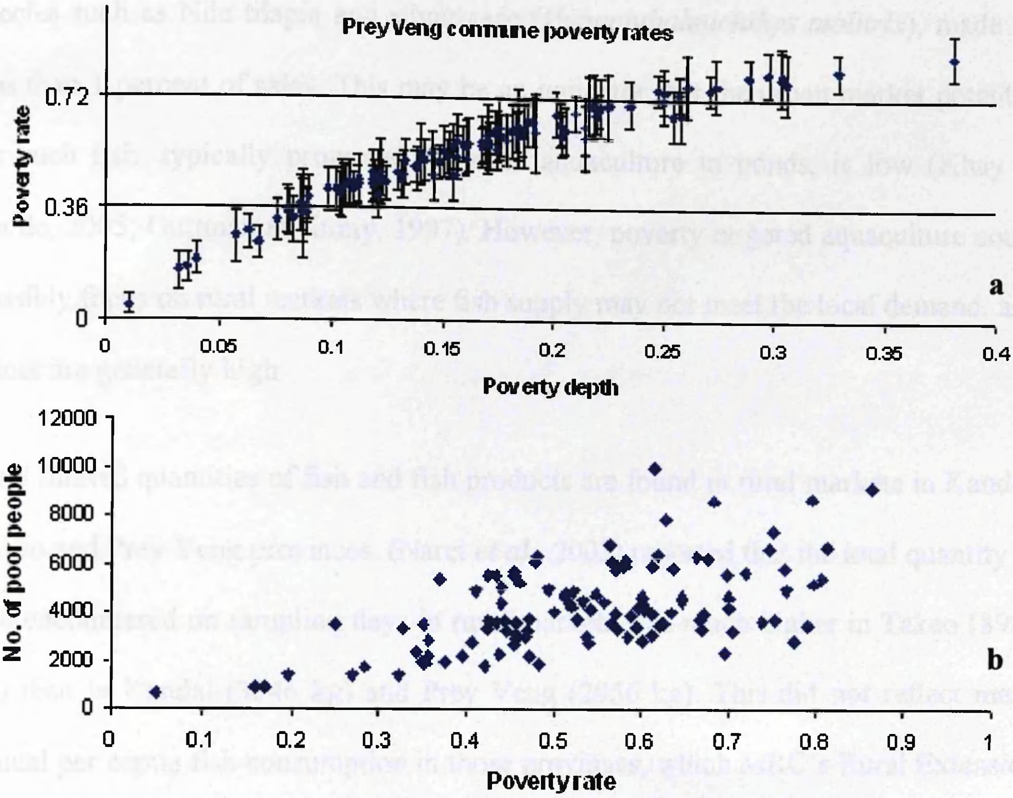


Figure 5.12 Prey Veng province; a) Poverty rate (± standard error) vs. poverty depth, b) No. of poor people per commune as a function of poverty rate

5.5 Socio-economic sub-model for targeting aquaculture

Poverty targeted aquaculture development has to consider socio-economic factors such as market demand and access. Fish marketing in Cambodia traditionally has targeted larger urban markets and export supply, because fish destined for these markets have a higher market value. Inland fish still dominates fish supply in Phnom Penh. A monitoring survey carried out in early 2003 (Khay & Hortle, 2005) confirmed that indigenous inland fish, dominated by snakehead, comprised about 85 percent of fresh fish weight sold at urban markets. The lack of refrigeration in traditional urban markets favours retailing of high quality air breathing fish, as it is able to survive with little water and can be transported and marketed alive. Introduced species such as Nile tilapia and silver carp (*Hypophthalmichthys molitrix*), made up less than 1 percent of sales. This may be an indicator that the urban market potential for such fish, typically promoted for rural aquaculture in ponds, is low (Khay & Hortle, 2005; Guttman & Kunty, 1997). However, poverty targeted aquaculture could possibly focus on rural markets where fish supply may not meet the local demand, and prices are generally high.

Only limited quantities of fish and fish products are found in rural markets in Kandal, Takeo and Prey Veng provinces. (Naret *et al.*, 2003) reported that the total quantity of fish encountered on sampling days in rural markets was much higher in Takeo (8901 kg) than in Kandal (3346 kg) and Prey Veng (2956 kg). This did not reflect mean annual per capita fish consumption in those provinces, which MRC's Rural Extension for Aquaculture Development (READ) found to be 17.1, 21.5 and 15.2 kg respectively, in its 1998 baseline survey of 150 households. The quantities of fish available in these markets do not reflect fish capture and consumption patterns of rural households. Wild fish species found in the markets came primarily from rivers and lakes, with only small quantities coming from rice fields. It is likely that a higher proportion of wild fish caught in rice fields are consumed within rural households instead of being sold.

The major cultured fish species traded in these rural markets were river catfish (*Pangasianodon hypophthalmus*), snakehead (*Channa* spp.) and walking catfish (*Clarias* spp). These species were available throughout the year in Kandal province, less so in Takeo and much less in Prey Veng markets, where they were available in small quantities only, for a limited part of the year. Cultured fish represented 38, 13 and 8 percent of traded fish in those provinces respectively (Naret *et al.*, 2003). Prey Veng province is located close to urban markets in Phnom Penh, which possibly diverts away most of the marketable fish from local rural markets, reducing local availability. The high population density in the province itself, in combination with the limited availability of fish in its rural markets indicates towards a considerable unfulfilled fish demand which could offer opportunities for poverty targeted aquaculture development.

The rural market perspective for fish products in Svay Rieng province appears to be quite different from that in Kandal, Takeo and Prey Veng provinces. Although not enough data are available to estimate net import and export of fish it is clear that the market for fish products in the province is well developed, with the trading network stretching out to the villages. Small scale fisheries are substantial in certain districts of Svay Rieng province, Svay Theap in particular. Guttman & Kunty (1997) reported an active trade of fish, primarily from trap ponds, which generates the main cash income for poor farmers in three villages studied in that district. The amount of fish handled at district markets in the province is substantial. An estimated 1.7 to 3.5 tonnes of fish was traded daily during March 1997. Most fish in these markets can be classified as larger and relatively high value, the bulk consisting of snakehead (*Channa striata*) and catfish (*Clarias macrocephalus*), and some climbing perch (*Anabas testudineus*). Most of this fish is destined for the capital, Phnom Penh, or for export directly to Vietnam, whereas the smaller markets sell a higher proportion locally. Smaller fish, caught in the rice fields, is traded in the villages.

5.5.1 A proxy indicator for market accessibility

The above supply- and demand trend analysis does suggest that the potential for poverty targeted aquaculture is highest in Cambodia's south-eastern provinces. In the absence of reliable marketing data, a socio-economic sub-model for aquaculture market potential was developed, in order to test this hypothesis. A proxy for market demand was developed as a function of population distribution and distance to potential markets. A population data layer containing single summary values of absolute population density for each commune was developed from the WFP Cambodia population counts. It is however unlikely that the true population is spread exactly evenly through each commune. Therefore the population counts were redistributed on the basis of the LandScan 2002 population density probability distribution model at 1-km resolution, developed by Oak Ridge National Laboratory. This resulting population layer (Figure 5.13) retains the sum of population for each commune. The assumption for market potential was that the probability of encountering more than 5000 people per km^2 at any given moment is an indicator of presence of urban markets, whereas a probability of 500 to 5000 people per km^2 equivalent to "near-landlessness" is an indicator of potential for rural markets.

The population density at any point of origin divided by its distance to these markets was considered a proxy for the accessibility of markets from that point. The method assumes a certain degree of concentration effects of rural population in the proximity of rural towns and major urban centres, implying that the population density is higher than in an area distant from urban centres. The basis of this approach is the concept of social gravitation. Urban centres are regarded as physical masses, where the magnitude of attraction or interaction is proportional to population size, and inversely proportional to some form of spatial friction, in this case geographic distance (Deichmann & Eklundh, 1991).

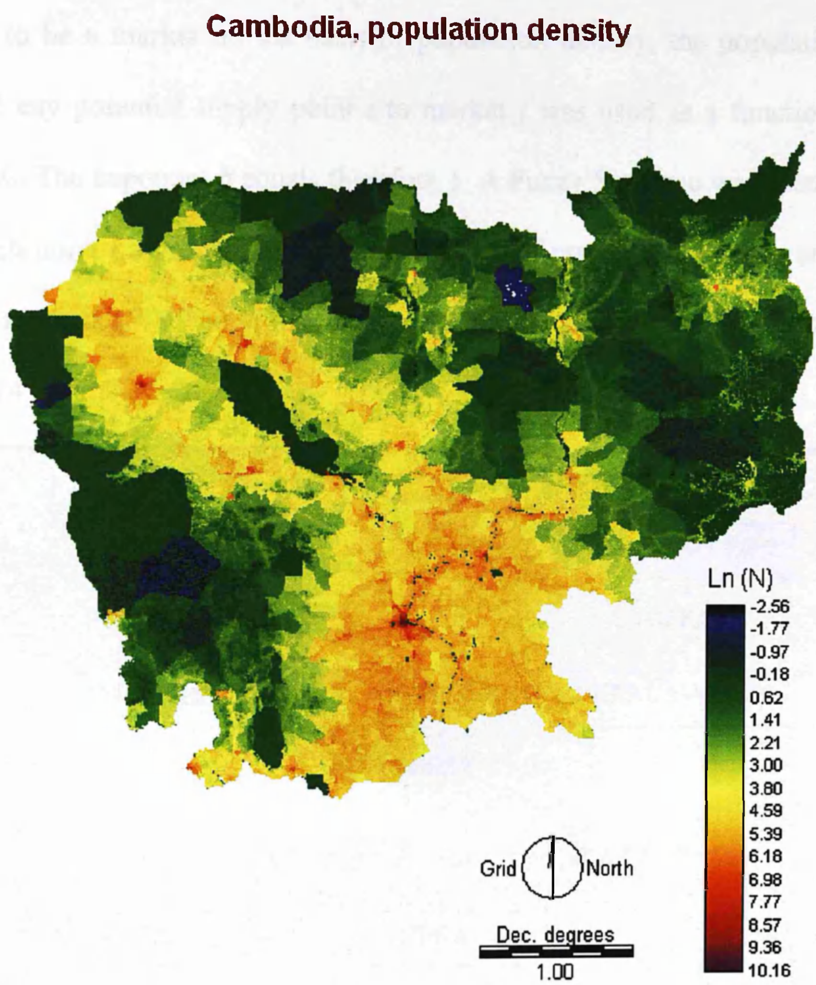


Figure 5.13 Log-linear distribution (Ln N) of population density (/km^2) in Cambodia. Ln(6.21) – Ln(8.51) = rural market (500 - 5000 people/km^2), >Ln(8.51) = urban market (> 5000 people/km^2)

For a given point i the interaction potential of population V_i with any urban centre in a given region, in this case Cambodia, is therefore:

$V_i = \sum_{j=1}^{n} POPD_j / (d_{ij})^b$ Where $POPD_j$ is the population density of town j, and d_{ij} is the distance between point i and j. The exponent b is a distance weight that determines the structure of the distance decay. In this study the population density at any point is assumed to be "known". Rather than being interested in $POPD_j$, which also is "known" to be a market on the basis of population density, the population density $POPD_i$ at any potential supply point i to market j was used as a function of linear distance d_{ij}. The exponent b equals therefore 1. A Fuzzy Set logic was then applied to assign each point i a probability between 0 and 1 of proximity to urban markets (P_u) and rural markets (P_r). The probability model for market proximity is summarised in Figure 5.14.

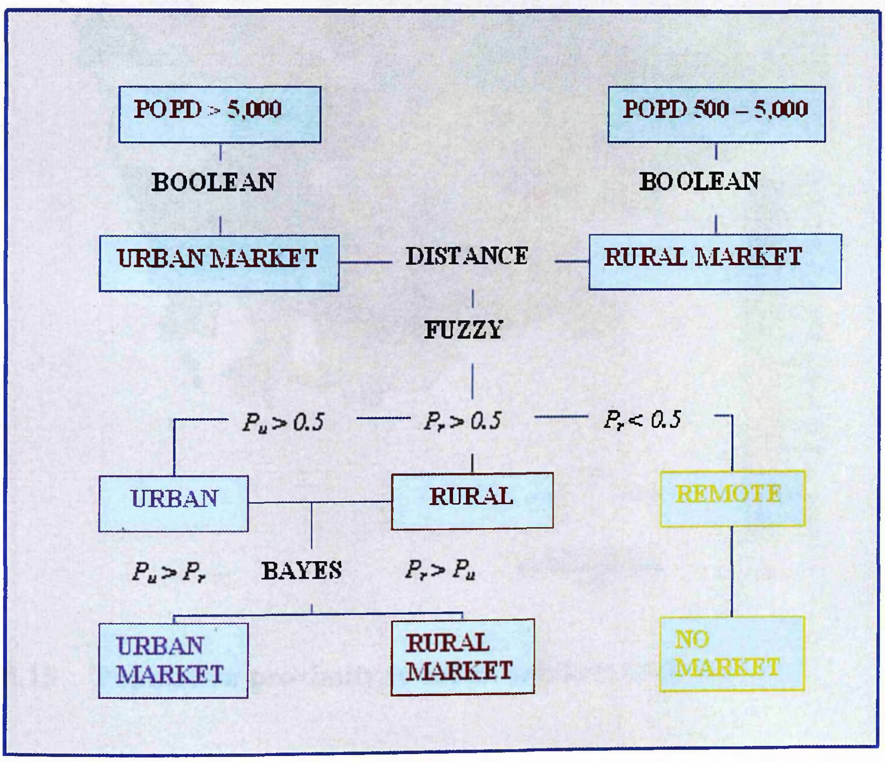


Figure 5.14 Market proximity model

A Bayesian probability model was applied to predict the likelihood of access to either urban or rural markets. Bayesian probability theory establishes the probability that an entity belongs to any of a number of different classes or states, in this case the two classes being 'urban market access' (P_u) and 'rural market access' (P_r). A relative proximity to urban markets is apparent in the Southeast of Cambodia, with some smaller urban concentrations in the Northwest (Figure 5.15).

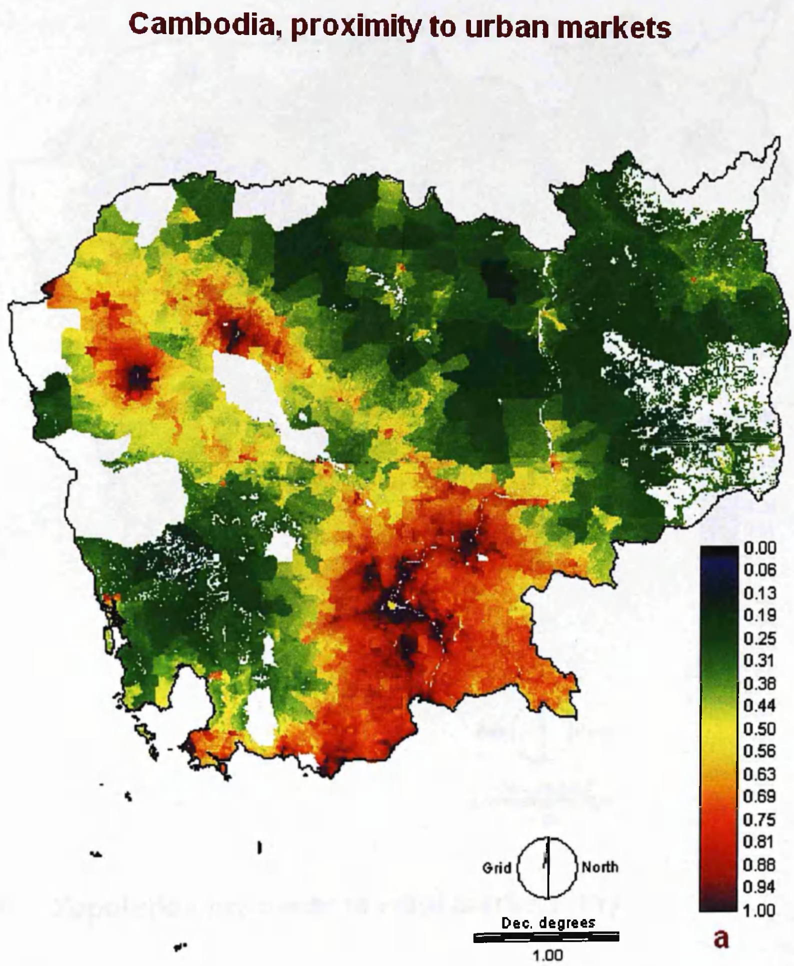


Figure 5.15 Population proximity to urban markets (Pu)

A larger spread of population densities associated with rural markets implies that the relative proximity of any point to these areas is higher, except where (P_u) > (P_r). In

Figure 5.16 provincial towns become apparent as dark spots, indicating rural markets. Values lower than 0.5 are indicative for relative market remoteness.

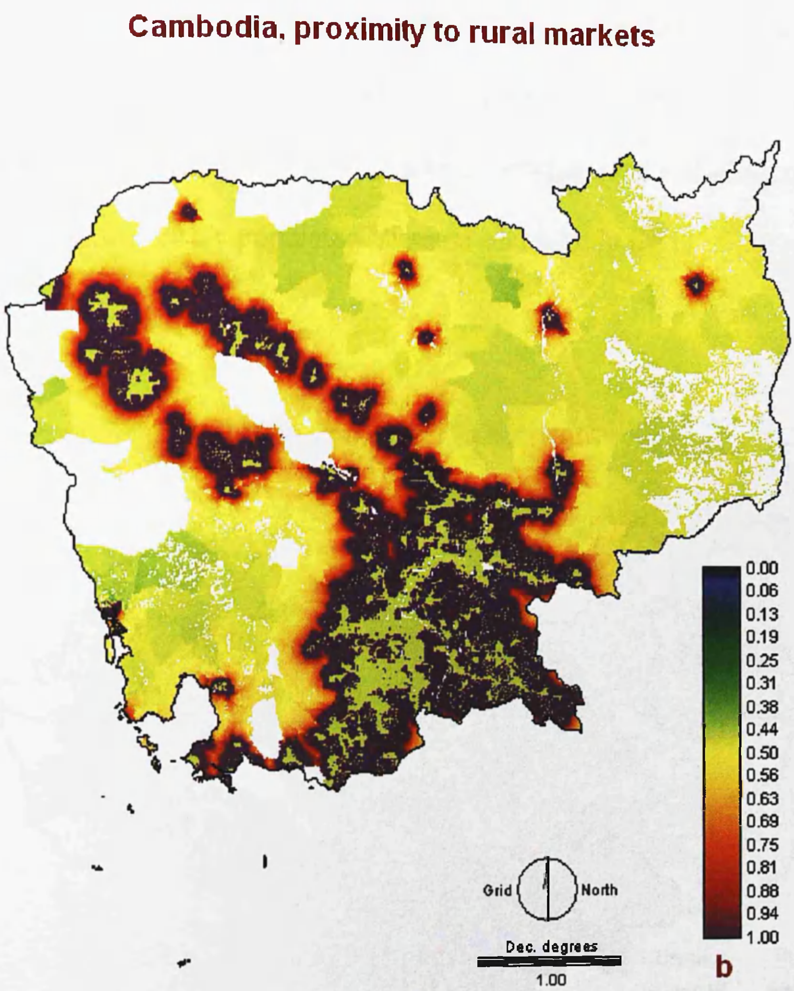


Figure 5.16 Population proximity to rural markets (Pr)

The relative proximities (P_u) and (P_r) are combined in Figure 5.17. Purple indicates the areas which are more likely to have access to urban markets than to rural markets (P_u) > (P_r), brown shades indicate areas which are most likely to have access to rural markets (P_r) > (P_u), where (P_r) > 0.5, and green shades indicate areas which are less likely to have proper market access (P_r) < 0.5. The latter are remote, thinly populated areas where aquaculture suitability, depending on agro-ecological circumstances, solely would satisfy household food security needs, with little prospects for additional cash income from aquaculture. The prospects for aquaculture to satisfy rural market demand are broadly good, especially in areas where higher farm gate prices can be obtained, as is the case in the south-eastern provinces. These provinces are also relatively better situated to serve urban markets, perhaps even including cross-border urban markets in the densely populated Vietnamese Mekong Delta.

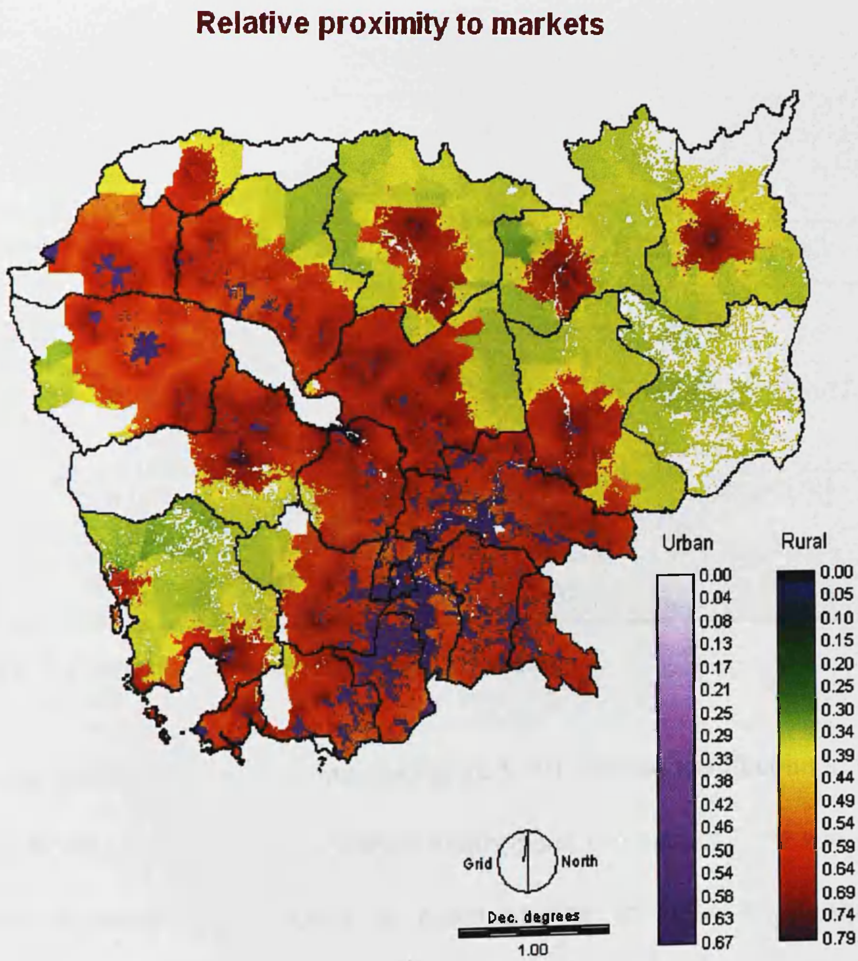


Figure 5.17 Likelihood of access to urban and rural markets (Province boundaries outlined in black)

5.5.2 Poverty and market access

A probability model for market access opportunities for poor people (Figure 5.18) was based on the distribution probability of poor population. The absolute population density per commune, disaggregated at 1-km level, was multiplied with the poverty headcount index per commune, using IDRISI's map overlay function.

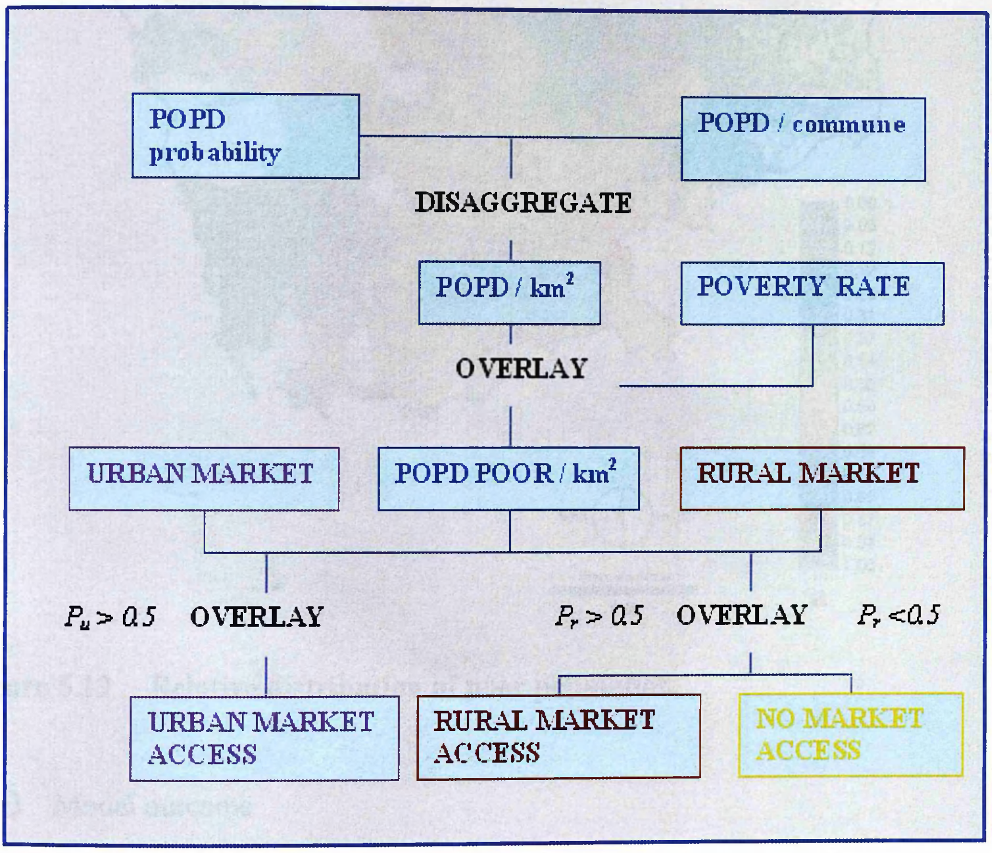


Figure 5.18 Poverty and market access sub-model

The resulting poverty distribution image (Figure 5.19) predicts the likelihood of poor population, *POPD* POOR, at any potential supply point *i* to market *j* and was used as the distance function. The distance d_{ij} exponent was set to 2, based upon the assumption that distance constrains access of poor people to markets more strongly.

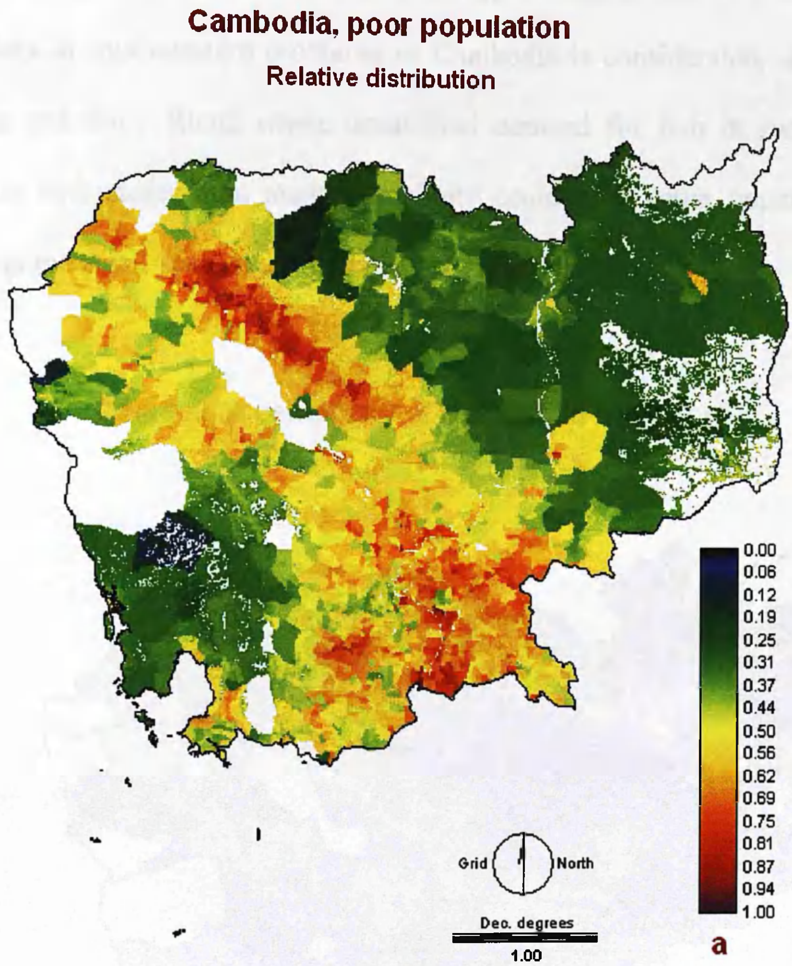


Figure 5.19 Relative distribution of poor population

5.5.3 Model outcome

The result demonstrates limited probability of access to urban markets for poor people (Figure 5.20), except in northern Takeo and south-western Kandal, where such markets can offer employment opportunities for considerable numbers of poor people living in close proximity of urban centres. The opportunity costs for poor people to access markets increase more rapidly with distance because their access to transport is limited. The access of poor aquatic producers to markets is therefore more constrained than for the better off. However, the output suggests that access of poor people to rural markets in south-eastern provinces of Cambodia is considerable, especially in Prey Veng and Svay Rieng where unsatisfied demand for fish in rural areas in combination with closer rural market proximity could offer better opportunities for poverty oriented small-scale aquaculture development.

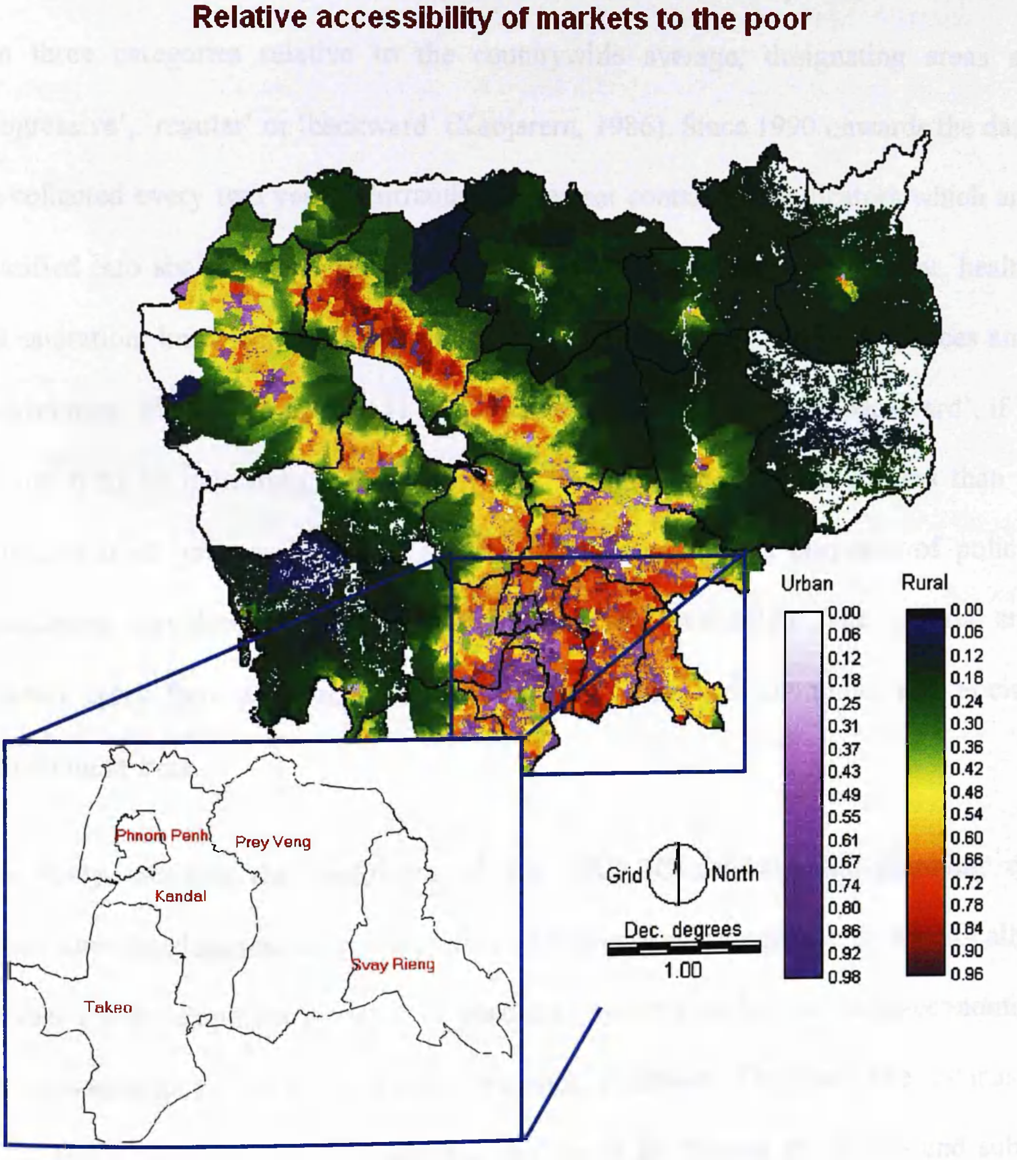


Figure 5.20 Relative proximity of poor population to markets

5.6 Targeting aquaculture in national rural development

Thailand's national rural development database at village level (NRD-2C) provides the basis for a more detailed identification of development needs and planning at the local level. The database provides a means to classify the relative levels of development and to identify poverty areas, for the purpose of local level planning from the tambon (sub-district) level upward. The levels of development are classified into three categories relative to the countrywide average, designating areas as 'progressive', 'regular' or 'backward' (Kaojarern, 1986). Since 1990 onwards the data are collected every two years. Currently the dataset contains 30 indicators which are classified into six basic problem groups covering infrastructure, employment, health and sanitation, knowledge and education, community strength, natural resources and environment. If a village lags on 11 to 30 indicators it is classified as 'backward', if it lags on 6 to 10 indicators it is classified as 'regular' and if it lags on less than 6 indicators it is 'progressive'. The information is used for the purposes of policy formulation, development planning, monitoring and evaluation. The criteria are adjusted every four years according to Thailand's National Economic and Social Development Plan.

This study assesses the usefulness of the NRD-2C database for planning of aquaculture development in a wider rural development framework. It specifically analyses the development potential of pond-dike systems within the socio-economic and agro-ecological context of Sisaket province, Northeast Thailand. The database was linked to administrative boundary vector layers for Sisaket at village- and sub-district level. The province was visited during a field survey in June 2003. The objective of the survey was to characterise agro-ecosystems and aquatic resource use, including the availability of wild fish resources, through field verification of village level socio-economic data from NRD-2C. The survey focused on the use of self-recruiting species (SRS) in farmer managed systems and on the impact of pond aquaculture on the livelihoods of farming households. The latter was one of the main research objectives of an EC funded project on improved resource use efficiency in Asian integrated pond-dike systems (POND LIVE). The survey was conducted in connection with a situation appraisal of pond-dike systems in the area by POND LIVE.

5.6.1 Aquatic resource exploitation in Sisaket

Sisaket province is located in the southern part of Northeast Thailand, bordering Cambodia to the south. The northern part of Sisaket is located in the lower plain of the Mun River, and is better endowed with water resources than most of the Northeast. Fishing is almost a universal activity in this area (Figure 5.21), and it is important that this is not overlooked when planning policy or programmes for rural development. 83 percent of respondents in a survey done by AIT's Aqua Outreach Program (AOP) in 1993-94 claimed to fish at some time of the year (AIT/AOP, 1998b). From surveys on wild fish catches there is evidence of major temporal and spatial variation in the availability of wild fish resources (AIT/AOP, 1998b; Demaine, 2002) and the potential of aquaculture development appears to depend on how far the natural stocks have declined in different situations. Fishing sites vary seasonally. During the wet season farmers tend to fish their own rice fields, while perennial water bodies are more commonly fished during the dry season.

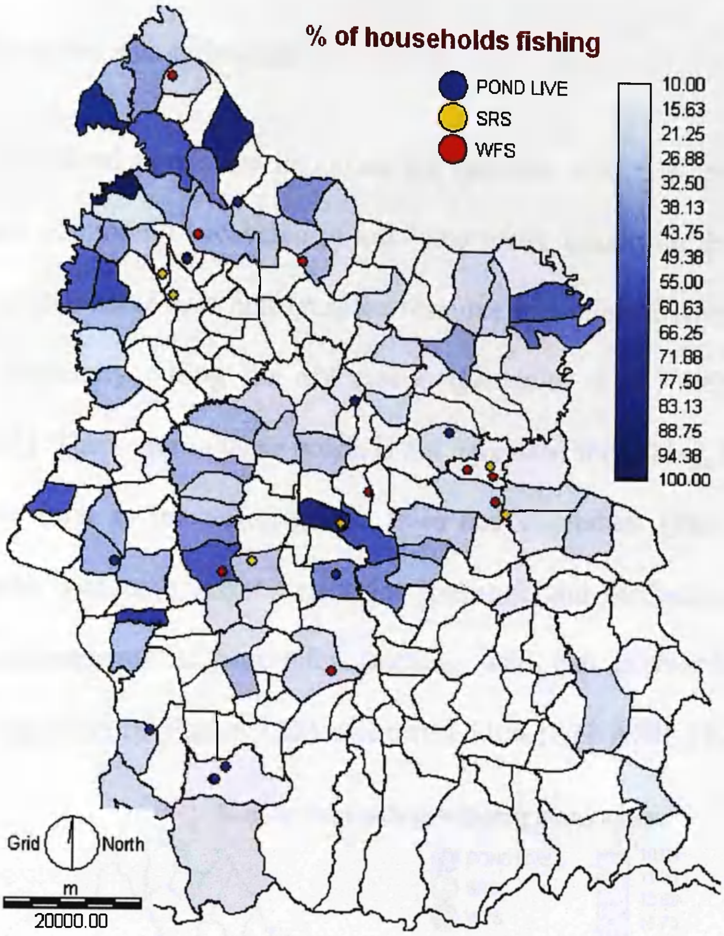


Figure 5.21 Fraction of households practicing fisheries as a source of income (Data source: NRD-2C)

The spatial distribution of water resources and their seasonal availability are also related to productivity from other agricultural activities such as rice farming, vegetables and fruits, which in Sisaket are the most important sources of agricultural income. NRD-2C provides criteria regarding the importance of such income sources on the basis of the percentage of households per village involved in these activities, as well as the criteria defining whether a village is to be considered 'backward', 'moderate' or 'progressive' in terms of production and income from each activity.

5.6.2 Pond systems and agriculture

In Northeast Thailand ponds are important for catching wild fish. Small and quite deep ponds are commonly excavated in low lying areas, usually in the farmers' rice fields. These ponds serve as a multipurpose resource in a context where water use is constrained, especially during the dry season (Demaine *et al.*, 1999, as cited in Demaine, 2002). The water in these ponds is not only used for fishing, but also serves other purposes such as for watering fruit trees and vegetables (Pant, Demaine, & Edwards, 2004), and to a lesser extent for livestock and for bathing (AIT/AOP, 1998b). The importance of ponds for catching wild fish in Northeast Thailand suggests that aquaculture (Figure 5.22) is prioritised less (AIT/AOP, 1998b).

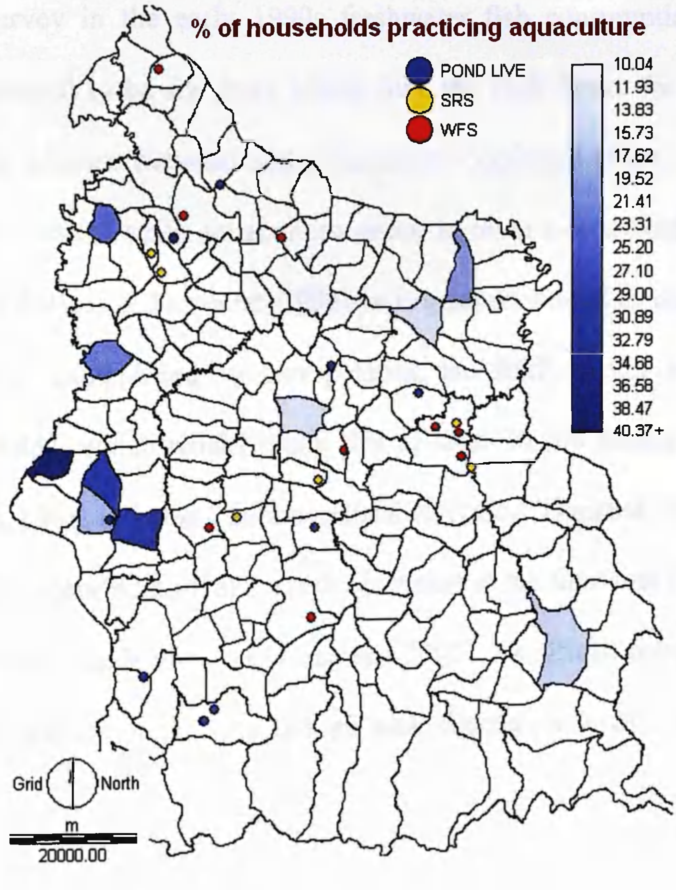


Figure 5.22 Fraction of households practicing aquaculture as a source of income (Data source: NRD-2C)

Also the length of time that water is sufficient for aquaculture is at issue (Demaine *et al.*, 1999, in Demaine, 2002). AOP found during its baseline survey in Northeast Thailand (1988) that in its project villages only 6 percent of farming families farmed fish, whereas the practice of trapping wild fish in rice fields was widespread (Edwards, Demaine, Innes-Taylor, & Turongruang, 1996). Nevertheless small-scale fish production through stocking in ponds is increasingly common in Northeast Thailand, both for home consumption and for income generation.

According to statistics of the Department of Fisheries (DoF, 2003), cited in ADB, (2004) aquaculture production in the Northeast has increased five-fold over a decade, from 9043 metric tons (mt) in 1990 to 47,929 mt in 2000. However, based on a food consumption survey in the early 1990s freshwater fish consumption in the same region was estimated to be six times higher than the DoF figure for freshwater fish production from capture fisheries and aquaculture combined (MRC, 1992, cited in ADB, 2004). The small-scale aquaculture sector is often overlooked in planning at national level (Edwards & Demaine, 1998) as it goes unnoticed in national statistics. This can also be exemplified by extrapolating the AOP survey estimate of fish farming households, which would imply that at least 30,000 farmers were farming fish at that time, 1988, in Udon Thani province, Northeast Thailand, alone. This is ten times the number reported by DoF, which estimated at the time that there were some 3,000 farmers in the whole province (Demaine, 2002). As official national statistics of fish production are unreliable, the use of such figures in local planning requires caution.

AOP was established in 1988 as an adaptive research project focusing on development of aquaculture technology for small-scale farmers. In its initial stages AOP followed an adapted farming systems research approach (Demaine, 2002). Since 1993 AOP has been engaged in studies of the capture of wild fish in paddy fields in Sisaket province. In Sisaket, the main water source for agriculture is rainfall. Most farmers get their main income from rice farming, but the average cash income from vegetables and fruits is substantial (AIT/AOP, 1998b). The province can broadly be divided into 3 agro-ecological zones parallel to the Mun river. The first zone coincides with the floodplain, the second is an intermediate zone of low terrace paddy in the central part of the province, and the third is an area of higher land to the south. A rather distinctive area of higher paddy land is found in Uthumporn Phisai and Muang Jan districts.

Each zone can be further subdivided according to the level of access to water resources (Figure 5.23). Within the lowland zone a low-lying zone of irrigated land is found close to the Mun river (Zone 1), whereas lowland zone 2 is located far from the Mun river but close to one of its tributaries, the Nam Khem. Lowland zone 3 is near the Mun river and Nam Siaw. Zone 4 is the distinct area of upland paddy. In the midland area an area close to a stream and with a high water table is found (Zone 5) as well as a zone subject to flooding (Zone 6). Another midland area, zone 7, is located far from the stream. The upland area can be divided into zone 8, near the river and subject to flooding, and zone 9 far from the river (H. Demaine, personal communication, May 19, 2003; D. Turongruang, personal communication, June 11, 2003).

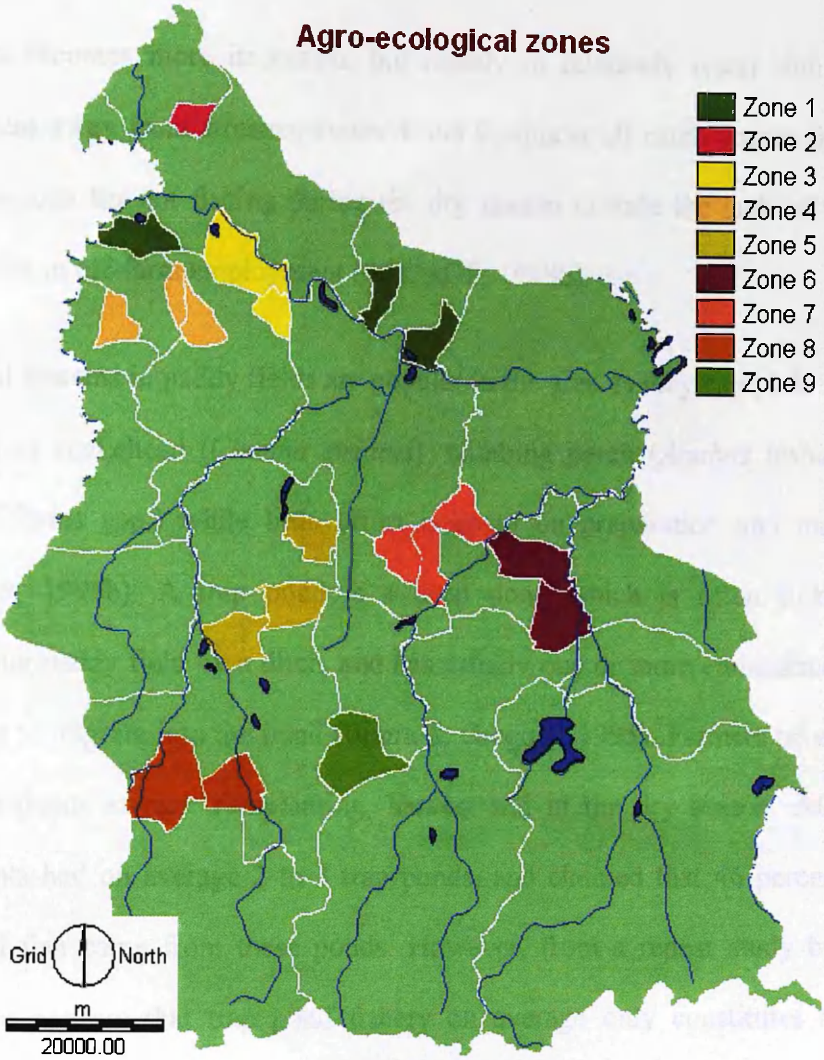


Figure 5.23 Agro-ecological zonation in relation to access to water resources

The proportion of households engaging in catching fish varies considerably between zones, as well as temporally. The temporal availability of wild fish can best be described by dividing the year into four main seasons according to the rice cultivation calendar. The bulk of wild fish catch in Sisaket comes from paddy fields and takes place during the period between rice transplanting and harvest, when the rice crop is inundated. The incidence of fishing appears to be lowest during the season of rice transplanting rather than during the dry season, mainly because of a lack of time for fishing during that period. In the dry season fishing in streams, swamps, oxbows and reservoirs becomes more important, but mainly in relatively water rich zones. In higher areas away from streams, zones 4 and 9, almost all catch comes from paddy fields. Reasons for not fishing during the dry season include the lack of water, and engagement in off-farm employment (AIT/AOP, 1998b).

Trap pond systems in paddy fields are popular in the area as they can yield high value fish such as snakehead (*Channa striatus*), climbing perch (*Anabas testudineus*) or catfish (*Clarias* spp.) while little effort is spent on preparation and management (AIT/AOP, 1998b). A trap pond is a deep pond which is often linked to the surrounding paddy field by a ditch, and has usually one or more embankments cut to allow fish to migrate into the pond (Bunra & Gregory, 1995). Farmers take fish from their trap ponds at rice transplanting, harvest and in the dry season. AOP survey respondents had on average 2 to 3 trap ponds, and claimed that 46 percent of their consumed fish came from these ponds. However, from a repeat study by AOP in 1994-95 it appears that trap pond fishery on average only constitutes around 30 percent of the total paddy field catch, and contributes most to overall yields in zones where the total catch is lowest. This suggests that trap pond fishery emerged as a response to declining catches. This hypothesis is supported by the fact that most trap ponds were less then ten years old at the time of AOP's survey, while over half of the respondents had increased the number of trap ponds recently, or had plans to do so in future (AIT/AOP, 1998b).

AIT/AOP (1998b) estimated the value of fish caught per household per year to be on average 3286 baht, ranging from 240 to 19,360 baht, representing around 11 percent of the annual cash income. NRD-2C data on income derived from fishery confirm that fishery is an additional income source rather than the main occupation for most households, with almost 40 percent of households involved earning between 1000 and 2000 baht per year from the activity (Figure 5.24 a). A similar picture becomes apparent for aquaculture, although aquaculture income ranges wider (Figure 5.24 b).

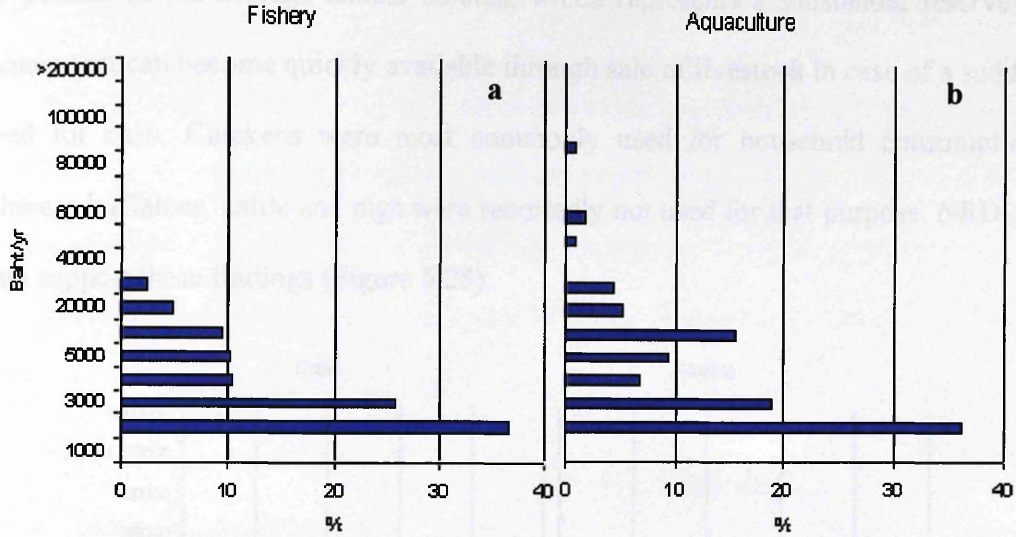


Figure 5.24 Distribution of annual income derived from a) fishery and b) aquaculture (Data source: NRD-2C)

The data suggest that almost 26 percent of rural households derive some income from fisheries, but this figure does not account for the catch contributing to household consumption and represents almost certainly a gross underestimation of the importance of wild fish production to farming households in the province. From AOP's survey on wild fish capture in 1995-95 it appears that only 38.6 percent of trap pond holding households are selling fish and that sale is most common in zones with the highest aggregate catch, while sale is absent in the upper paddy zone 4, which has the least fishing in the dry season and the highest dependence on the paddy field catch. The majority of respondents in AOP's 1994 survey, over 75 percent, derived their main income from rice farming, but off-farm employment appeared to provide also an important source of income. Other important sources of farm income are vegetables, dry season agriculture, upland crops and livestock. Virtually all households own some livestock. AIT/AOP (1998b) estimated the value of livestock at 73 percent of the average annual income, which represents a substantial reserve of money that can become quickly available through sale of livestock in case of a sudden need for cash. Chickens were most commonly used for household consumption, whereas buffaloes, cattle and pigs were reportedly not used for that purpose. NRD-2C data support these findings (Figure 5.25).

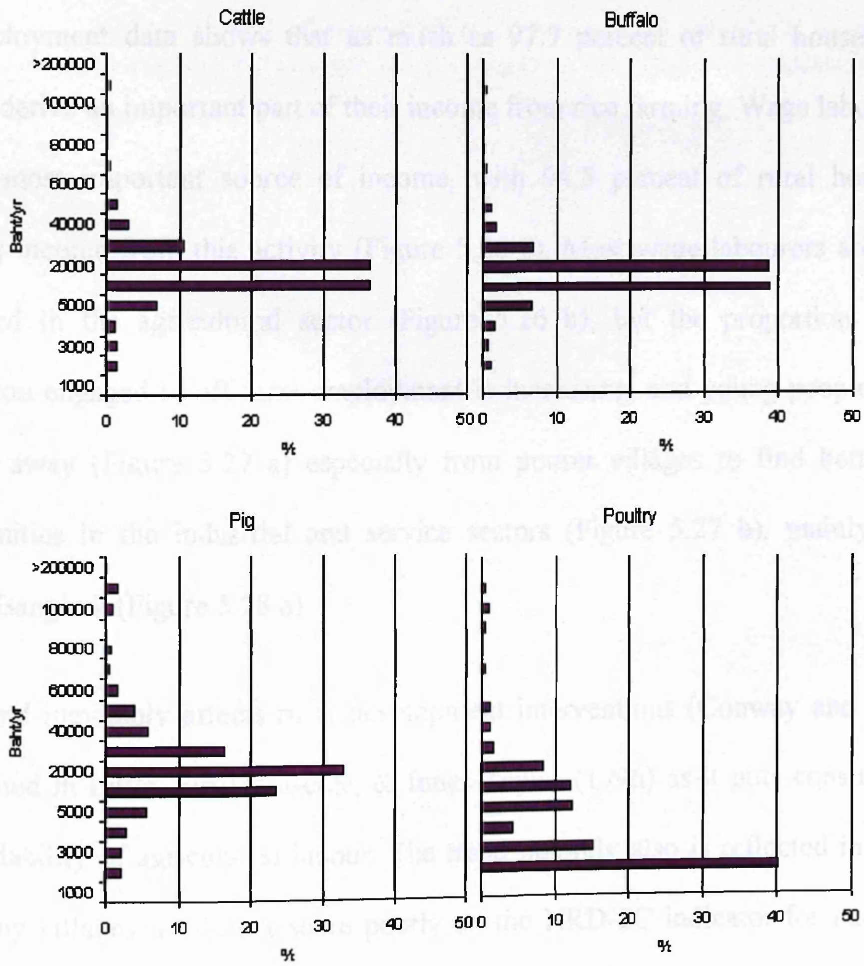


Figure 5.25 Income distribution from livestock (Data source: NRD-2C)

Figure 5.25 confirms that the income distribution for poultry is similar to that for fisheries and aquaculture, whereas that for buffaloes, cattle and pigs approaches average values of around 15,000 baht and ranges between 3000 – 35,000 baht and 7000 – 40,000 baht per year as reported by (AIT/AOP, 1998b) for buffalo and cattle respectively.

The AOP survey data indicate that socio-economic situation of trap pond owners broadly reflects that of rural households in the province as a whole. The majority of the respondents indicated that rice production was the most important occupation, but off-farm employment was important as the secondary occupation. Analysis of NRD-2C employment data shows that as much as 97.7 percent of rural households in Sisaket derive an important part of their income from rice farming. Wage labour is the second most important source of income, with 94.5 percent of rural households deriving income from this activity (Figure 5.26 a). Most wage labourers are locally employed in the agricultural sector (Figure 5.26 b), but the proportion of rural population engaged in off-farm employment is increasing, and young people tend to migrate away (Figure 5.27 a) especially from poorer villages to find better wage opportunities in the industrial and service sectors (Figure 5.27 b), mainly in and around Bangkok (Figure 5.28 a).

This trend inevitably affects rural development interventions (Conway and Barbier, 1990, cited in Little, Surintaraseree, & Innes-Taylor (1996) as it puts constraints on the availability of agricultural labour. The trend possibly also is reflected in the fact that many villages in Sisaket score poorly on the NRD-2C indicator for occupation and employment (Figure 5.28 b)

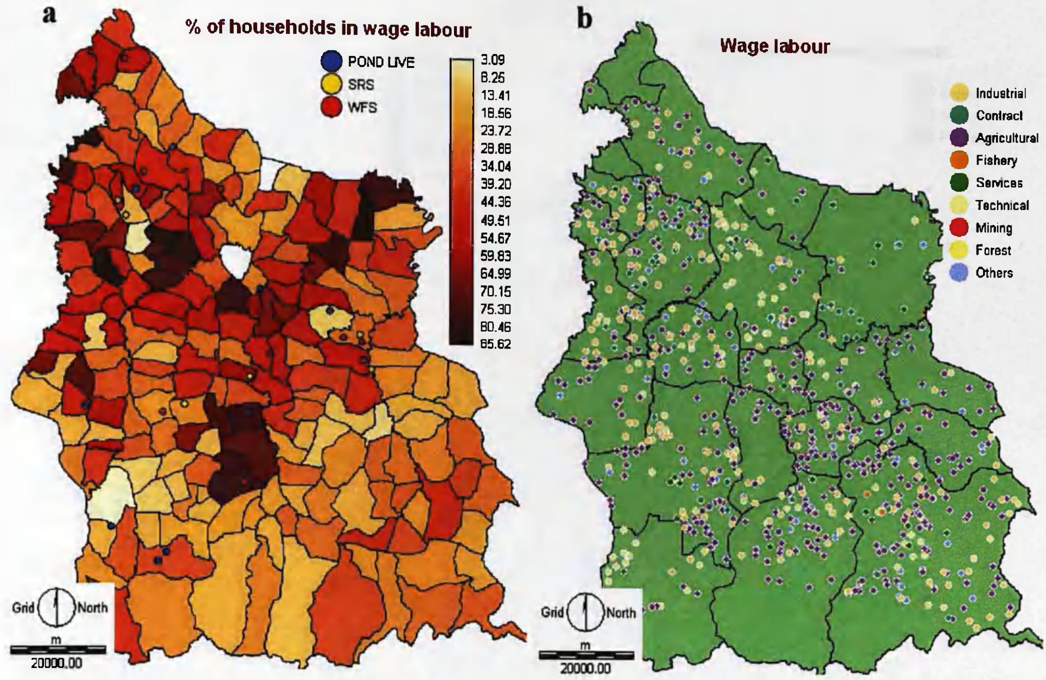


Figure 5.26 a) Percentage of households per tambon involved in wage labour b) Most important wage labour sector at local level (Data source: NRD-2C)

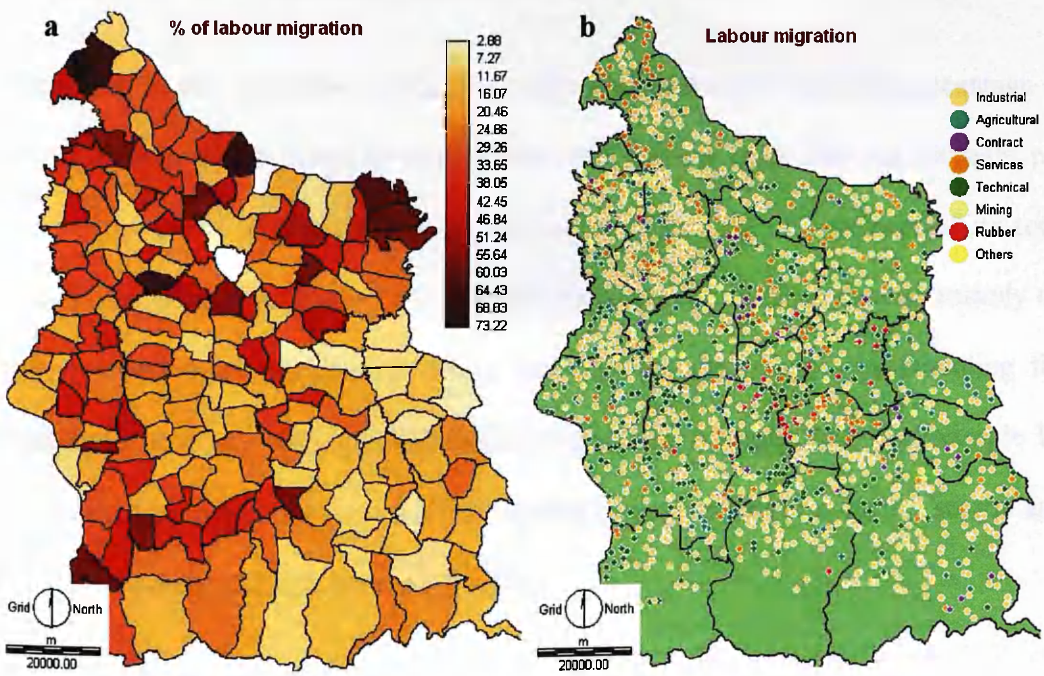


Figure 5.27 a) Percentage of labour migration per tambon
b) Most important labour migration sector (Data source: NRD-2C)

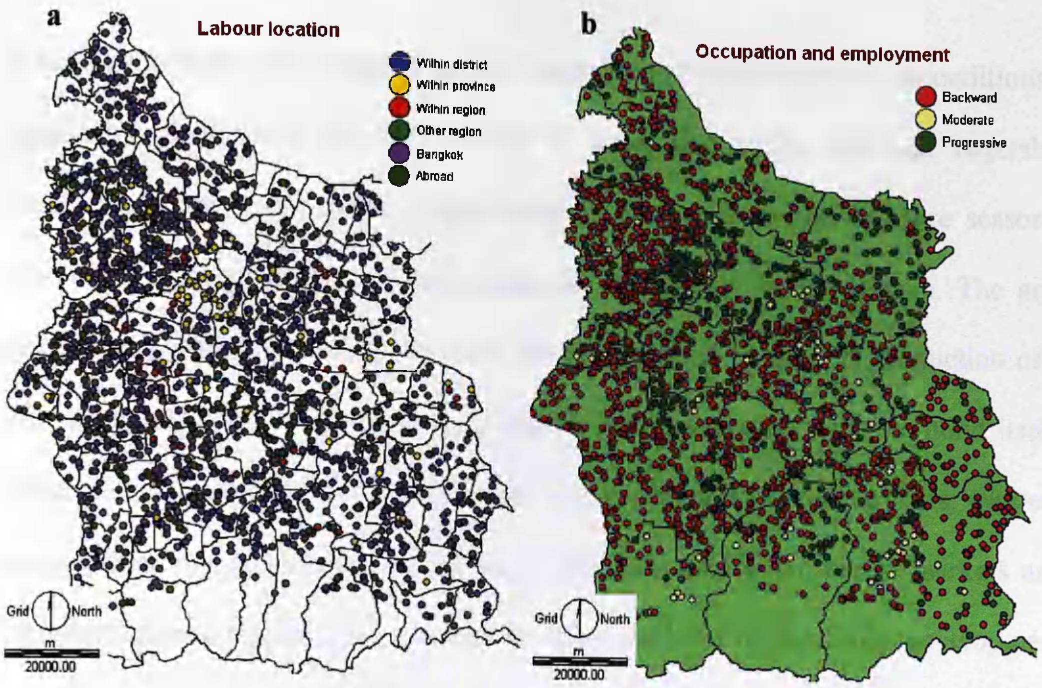


Figure 5.28 a) Destination of labour migration, b) village classification in terms of occupation and employment (Data source: NRD-2C)

According to this indicator a village is considered backward when the percentage of households solely involved in employment with income more than 40,000 baht per year, or involved in more than one occupation, is less than 50 percent of its total households. This may suggest that households remaining on-farm depend entirely on a low productivity agricultural sector for their income, while supplementing the household economy through subsistence farming for domestic use, for example by vegetable cropping and small livestock rearing in the homestead area, dry season and upland cropping, and trap pond exploitation.

5.6.3 Spatial analysis of the potential of pond-dike systems

Integrated agriculture-aquaculture systems (IAAS) have emerged in recent years in Northeast Thailand as a possible alternative to intensive crop monoculture or mixed crop and livestock systems. Farm ponds can play a pivotal role in the diversification of farming systems under rainfed agro-ecological conditions. Under such conditions a pond often is virtually the only source of water supply for fruit and vegetable production (Pant *et al.*, 2004). Many farms in Sisaket have one or more seasonal ponds which, when deep, can keep water till the end of the dry season. The area around such ponds, including the dike, has the potential to support production of a wide range of crops which potentially benefit from integration with the pond itself. Water and mud from the pond can support crop production and reduce costs, whereas crops grown can potentially provide inputs for fish culture. Access to markets and agro-ecological conditions are assumed to affect the level of pond-dike development and therefore POND LIVE categorised pond-dike systems into peri-urban, intermediate and rural areas (Figure 5.29).

Three physically distinct pond-dike systems were identified under different agro-ecological conditions. Two of these systems were crop dominated and consisted of an orchard crop dominated system and a more mixed system with short term crops, particularly vegetables, respectively. The third system focused more on fish production. As a reason for pond construction, aquaculture appeared always to be secondary to the production of crops and the combined use of pond water for irrigating crops both on and off the dike was generally more important than other uses of pond water. Trapping of wild fish appeared to be the most important use in peri-urban areas, while this was unnecessary in intermediate areas because of the abundance of wild fish. Fish culture was more likely to be a major reason for pond construction in intermediate areas, but less so in areas where they were intended for irrigating vegetables for sale in urban markets. The actual use of pond water for livestock, domestic purposes and other reasons appeared to be more important than farmers originally expected when constructing the pond (POND LIVE, 2003).

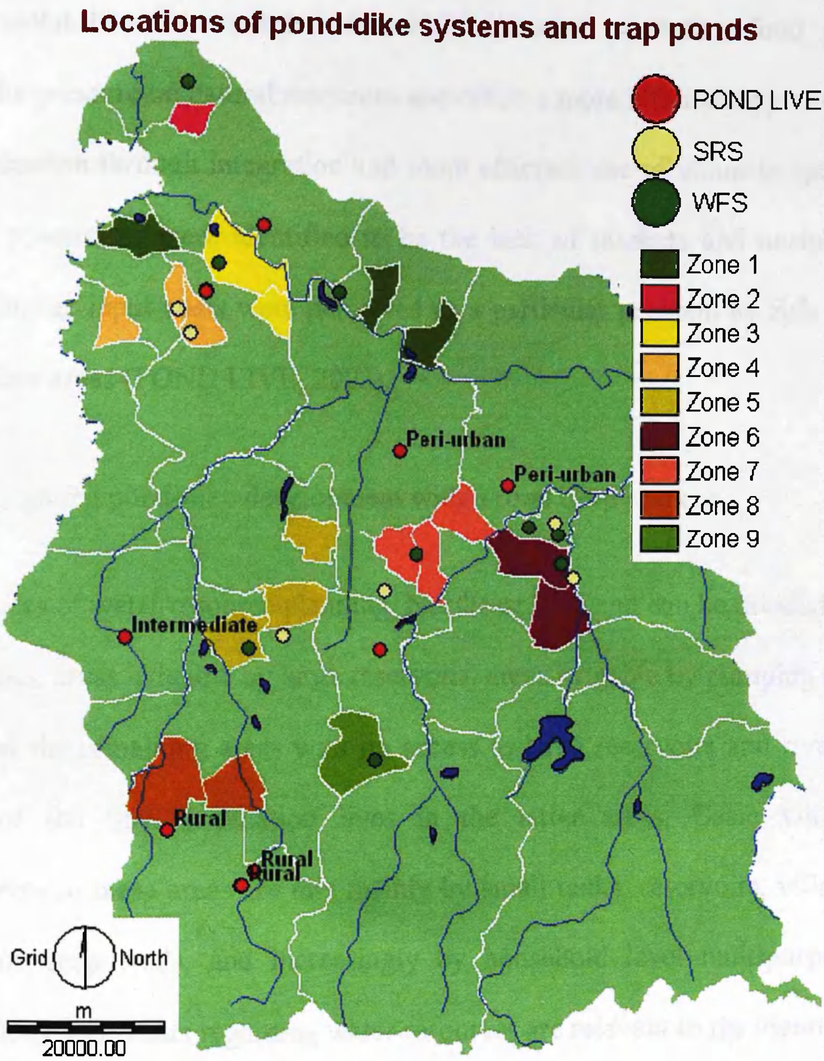


Figure 5.29 Locations of pond-dike systems (POND LIVE) in peri-urban, intermediate and rural areas in Sisaket province, trap ponds surveyed by the SRS project and AOP surveys of wild fish capture among pond holding families (WFS).

It becomes clear from above description that the possible benefits from pond-dike systems, grouped as financial, human, natural and social, vary with location and circumstances, and can be best assessed in a rural socio-economic and agro-ecological context. Financial benefits clearly dominated in peri-urban areas close to markets, but farmers stated that financial benefits were secondary to supplying food for home consumption and strengthening relationships with family and neighbours. Environmental benefits were less important although pond-dike food production reduces the pressure on natural resources and offers a more efficient approach towards food production through integration and more efficient use of valuable space. Major financial constraints were identified to be the lack of markets and unstable prices, whereas higher input costs were perceived as a particular problem by fish farmers in intermediate areas (POND LIVE, 2003).

5.6.4 Targeting pond-dike development within rural development

For purposes of water resource planning, Northeast Thailand can be divided into three major zones: areas irrigable by large reservoirs, areas irrigable by pumping from large rivers, and the remaining areas with no access to large reservoirs and rivers. Eighty percent of the rural population lives in the latter areas. Basic village water requirements in these areas are met mainly by small tanks, reservoirs, village ponds, shallow or deep wells, and increasingly by household level multipurpose ponds (ADB, 2004). Indicators regarding water resources are relevant to the identification of aquaculture development needs and planning. NRD-2C includes indicators about water supply within the infrastructure problem group. The access to clean drinking water and water for domestic use is considered as a constraint when less than 63 percent of total households in a village have sufficient water for these purposes throughout the year. Water for agricultural purposes is constrained when a village does not have sufficient water for practicing cultivation, and 'progressive' when water for cultivation is sufficient all year (Department of Community Development, 2003).

In Sisaket, a clear spatial pattern of problems regarding water for drinking and domestic use does not emerge (Figure 5.30 a) but water use for agricultural purposes is constrained particularly in upland areas (Figure 5.30 b). Under such circumstances ponds can provide an alternative or supplementary water source which can be used for watering crops, rice seedling preparation and emergency irrigation for growing rice, while they can also be used for domestic purposes (POND LIVE, 2003).

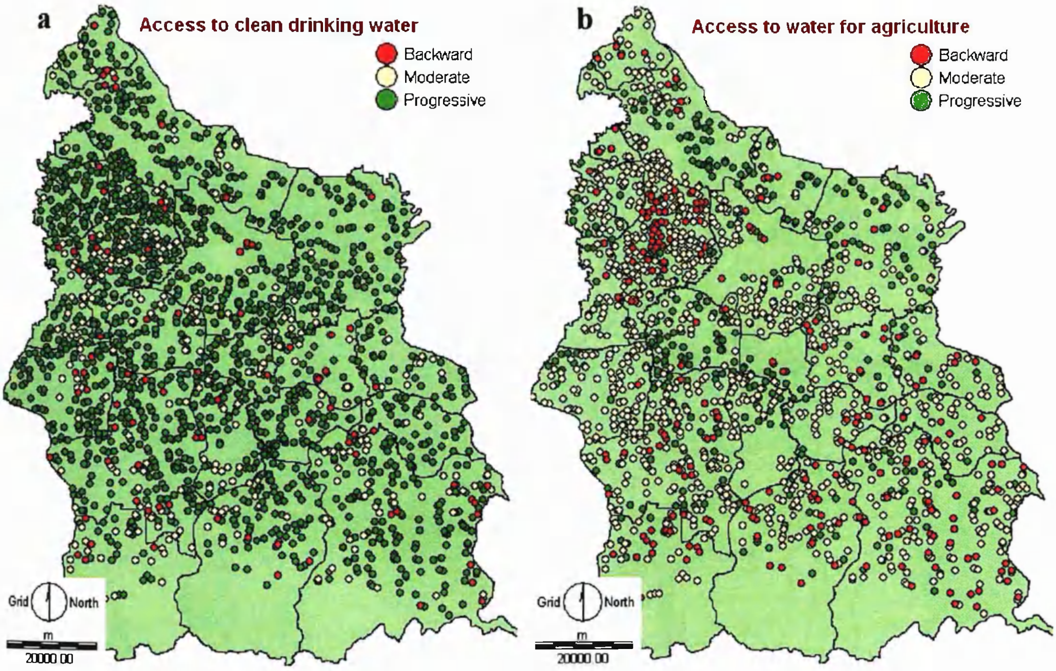


Figure 5.30 a) Classification of villages in terms of access to water for drinking and domestic purposes throughout the year, and b) for agricultural purposes (Data source: NRD-2C)

Indicators on agricultural income and production are included in the employment problem group. For rice production, the main income for most farmers in Sisaket, a village is considered backward when most of agricultural households produce up to 270 kg of paddy per rai (equivalent to 1600 m^2), moderate when production is about 271 – 370 kg per rai and progressive when production is more than 370 kg per rai. No mark is assigned if the number of households producing paddy is less than 20 percent of overall households, or when the paddy area is less than 20 percent of the total village area. In Sisaket, paddy production constitutes an important source of income for virtually all farming households. Only in some upland areas in the south does it constitute less than 30 percent of farm income (Figure 5.31 a). The percentage of households considered 'backward' in terms of rice yield per rai varies widely (Figure 5.31 b).

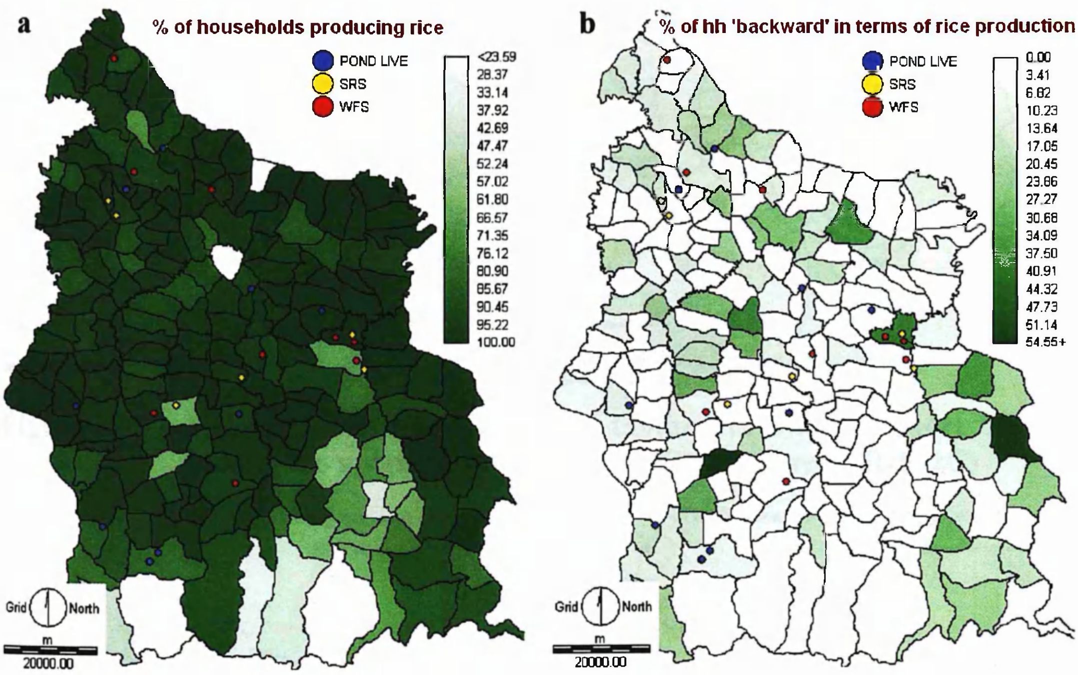


Figure 5.31 Fraction of households per tambon involved in paddy production (left) and percentage of households per tambon considered as 'backward' in terms of yield. (Data source: NRD-2C)

Upland crop production is clearly concentrated in the south of the province (Figure 5.32), as is the case for fruit production from orchards (Figure 5.33 a). Long life upland production is concentrated in the southwest of the province. Production of upland crops such as chilli is more common in rural areas (POND LIVE, 2003) and surveyed pond-dike systems in rural areas commonly engaging in chilli production are located in those areas. A relatively large percentage of households are classified as 'backward' in terms of yields from upland crops (Figure 5.33 b).

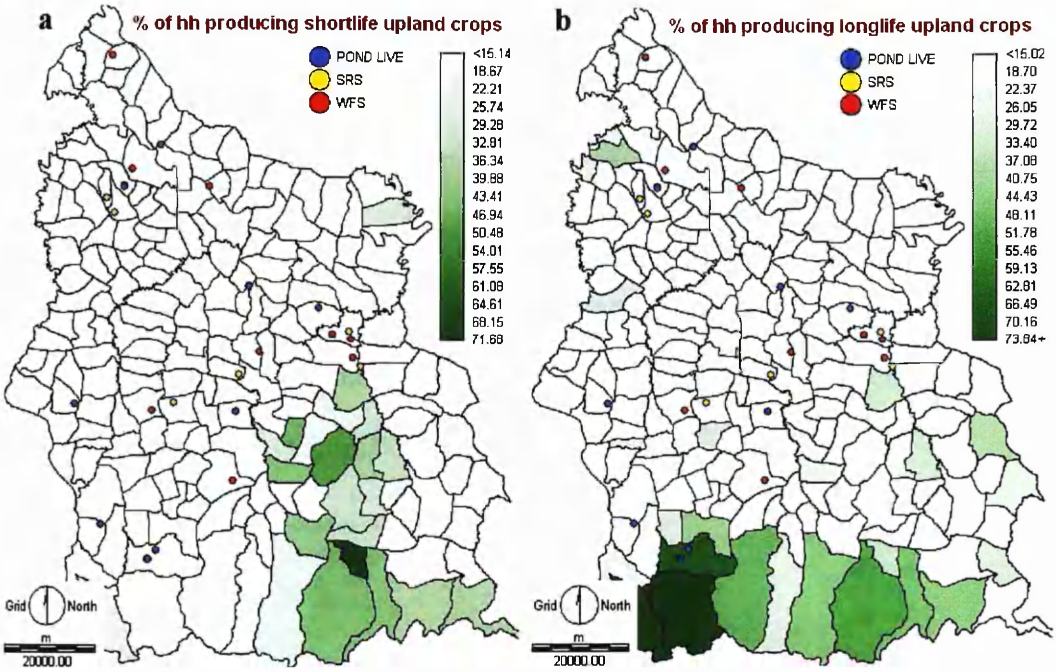


Figure 5.32 a) Fraction of households per tambon involved in short life and b) long life upland crop production (Data source: NRD-2C)

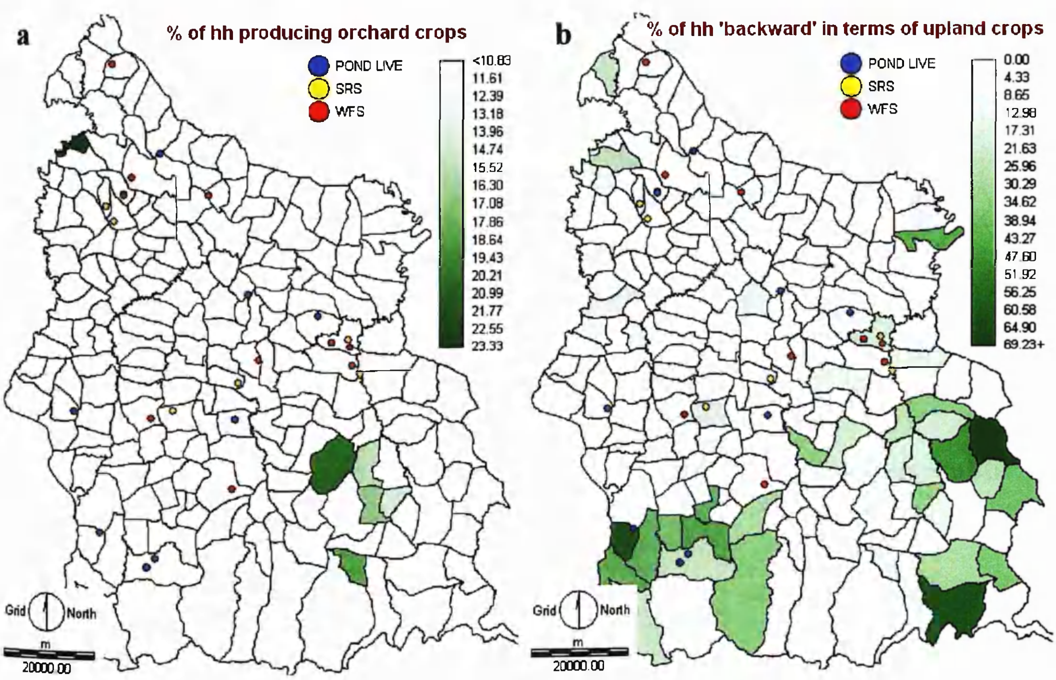


Figure 5.33 a) Percentage of households per tambon involved in orchard crop production and b) percentage of households per tambon considered as 'backward' in terms of upland crop yield (Data source: NRD-2C)

Commercial vegetable production appears to be concentrated in the northern part of the province, particularly in the floodplain area north of the Mun river (Figure 5.34 a). This coincides more or less with the location of peri-urban pond-dike systems with access to markets, which tend to focus on commercial vegetable production. Dry season crop production is an important activity in areas with relatively good access to water resources all year, such as agro-ecological zone 5 (Figure 5.34 b) and coincides with commercial vegetable production. From an income point of view a village is considered 'backward' if most of the households earn less than 20,000 baht per year from their major crop (Figure 5.35).

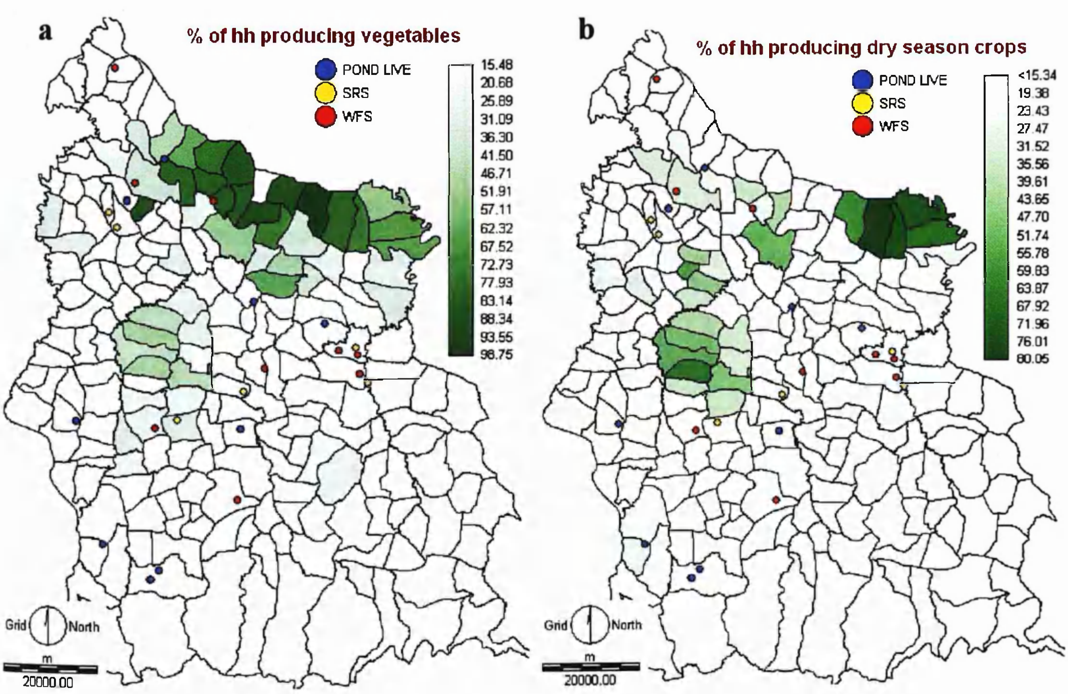


Figure 5.34 a) Percentage of households involved in commercial vegetable b) Production and dry season crop production (Data source: NRD-2C)

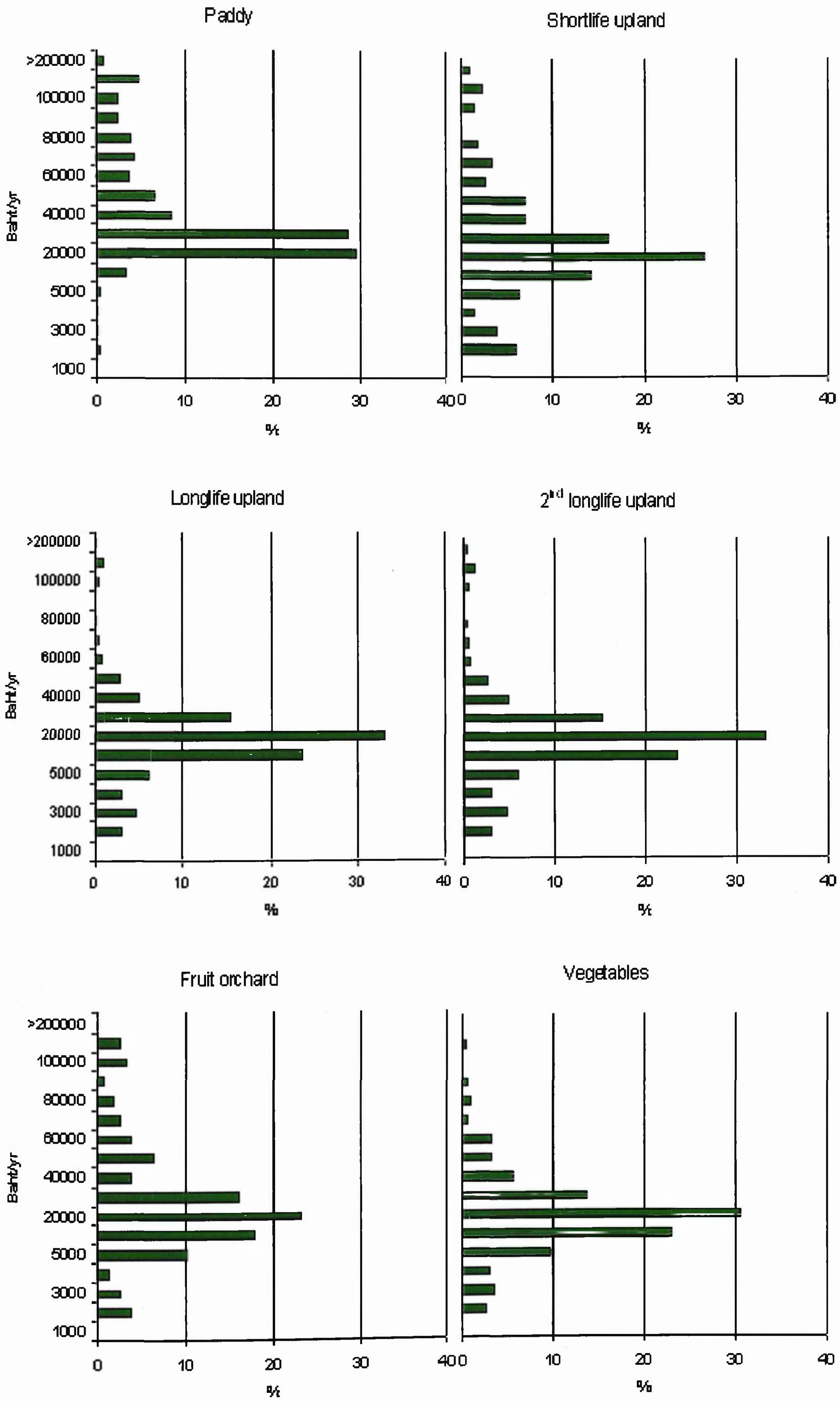


Figure 5.35 Annual income from major agricultural activities, Sisaket province

5.6.5 Results

The spatial distribution of different production systems appears to correspond quite well with the agro-ecological zonation. On the basis of the spatial distribution of commercial crop production and water use, the promotion of distinct pond-dike systems can be targeted according to the potential benefits they might provide under particular agro-ecological conditions. The large percentage of households throughout the province that practice agriculture in the homestead area for domestic use (Figure 5.36 a), and the more limited adoption of integrated agriculture (Figure 5.36 b) together with the farmer perception of benefit from pond-dike systems suggests that there is large scope for its further adoption by agricultural households, especially in areas where current constraints exist regarding the use of water for agricultural purposes.

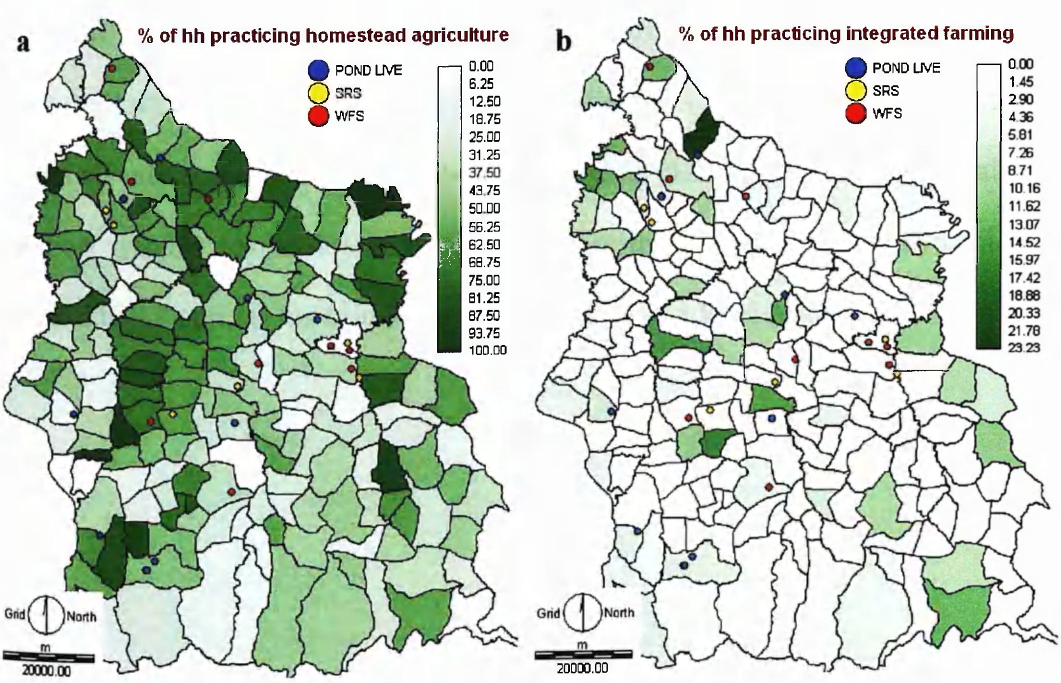


Figure 5.36 a) Percentage of households practicing agriculture in the homestead area for domestic use and b) practicing integrated farming (Data source: NRD-2C)

In areas where water for agricultural purposes is not limiting and where rice field capture fishery is still viable the adoption of pond-dike farming systems is possibly of a lesser priority but the benefits of pond-dike integrated farming systems, even though its use for fish production is secondary, can be substantial in seasonally drought prone areas where access to wild fish resources is limited.

A spatial rural development database can provide a useful basis for planning of aquaculture development through systems that are appropriate and relevant to local socio-economic conditions. The NRD-2C development indicators are adjusted every four years, which makes comparison between different years difficult. Although this complicates monitoring and evaluation of rural development trends over time, the data provide a rather static though useful set of explanatory spatial socio-economic variables that can be relevant to the planning of aquaculture development in such a way that it is appropriate to the prevailing rural development context. The database does not take agro-ecosystems dynamics and related seasonal variations in wild fish resources into account and should therefore be used in conjunction with an analysis of agro-ecosystems seasonality in order to capture the aquatic resource dynamics that will guide the options for aquaculture development in a local context.

6 Seasonality of agro-ecosystems

6.1 Agro-ecosystems classification

6.1.1 Introduction

Fish farming in rice paddies and growing vegetables on pond dikes can provide a focal point for agricultural diversification and increased sustainability, particularly in low yielding and risk prone rain fed agro-ecosystems. The harvest of fish and other aquatic animals such as crabs, prawns, frogs and edible insects from rice fields is part of the seasonal calendar in many Southeast Asian countries. The harvest of the wet season rice crop for many rural communities is preceded by the peak rice field fish catch and followed by fish harvesting from trap ponds in and around rice fields (Gregory & Guttman, 2002). In frequently flooded areas fisheries can provide a seasonal alternative livelihood production strategy when agricultural production is disrupted by flooding whereas on-farm water storage facilities in drought prone areas can enhance dry season cropping through supplementary irrigation as well as increase the otherwise limited potential of aquatic resource exploitation through stocking of aquatic animals The interrelationships are schematically represented in Figure 6.1.

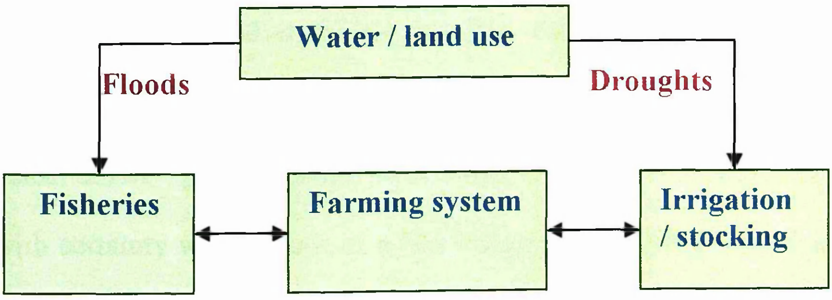


Figure 6.1 Land-water relationships and seasonal livelihood production strategies

A spatial analysis of agro-ecosystems was performed using a Geographic Information System (GIS) and remote sensing imagery in order to target aquatic resources development at rain fed farming systems. In such areas the development of pond based aquatic resources can be prioritised as a means to diversify and complement existing farm production, while providing a method of water storage during seasonally heavy rainfall. Increased diversity of produce can balance risks among the various farming subsystems and the pond can provide emergency water supply to the other subsystems in times of drought. Wild fish catches in paddy fields are of prime importance to rural livelihoods in the region and are mainly used for household consumption, which is often not recorded in national statistics. Its classification according to agro-ecological zone is of relevance as the data can potentially be used to extrapolate into broader geographic areas and thus provide insights on where pond-dike development for aquaculture or trapping of wild fish has the largest potential to satisfy household and commercial fish demand.

The use of remote sensing imagery to directly provide information on the location of ponds other than through field verification by geo-locating the actual position of ponds with a Global Positioning System (GPS) proved difficult to accomplish at the available resolution of Landsat ETM+ satellite data. After geo-locating, it was possible to visually distinguish pond areas larger than 225 m^2, which is the resolution of the Landsat ETM+ panchromatic band (band 8). Computer algorithms can not establish with certainty whether one or a few image pixels at that resolution represent a pond. It is impossible to visualise even smaller ponds, such as trap ponds at the same resolution, but the likelihood of trap ponds being present can be estimated on the basis of an agro-ecosystems approach by establishing the spatial distribution of paddy fields from satellite imagery.

6.1.2 Global Land Cover Characterization

The agro-ecosystems classification in the study area was initially based on the Global Land Cover Characterization (GLCC) dataset, retrieved from the International Geosphere Biosphere Programme-Data and Information System (IGBP-DIS). Out of the 255 seasonal land cover classes defined by GLCC for Eurasia, 68 land cover classes can be distinguished within the study area, including 'Inland water' and 'Ocean'. Within these, 38 classes have study area coverage of more than 100 km^2. The GLCC class covering the largest area is labelled as 'Cropland (rice, cotton)' and covers approximately 27,500 km^2 of the study area. The second till seventh largest land cover classes are all dominated by cropland and consist of approximately 15,000 km^2 of 'Cropland (rice)', 12,000 km^2 of 'Cropland (Double Crop Rice, Wheat) with Deciduous Woodland', 11,500 km^2 of 'Cropland (Rice) with Woodlands', 11,000 km^2 of 'Irrigated Crops (Rice)', 8750 km^2 of 'Cropland - Shrubland Mosaics' and 8650 km^2 of 'Grassland-Woodland-Cropland Mosaics'. The largest non-agricultural land cover class in the study area is 'Tropical Evergreen Rainforest' covering approximately 7900 km^2 of the study area. Nine major classes of rice dominated cropland can be distinguished over the study area (Figure 6.2).

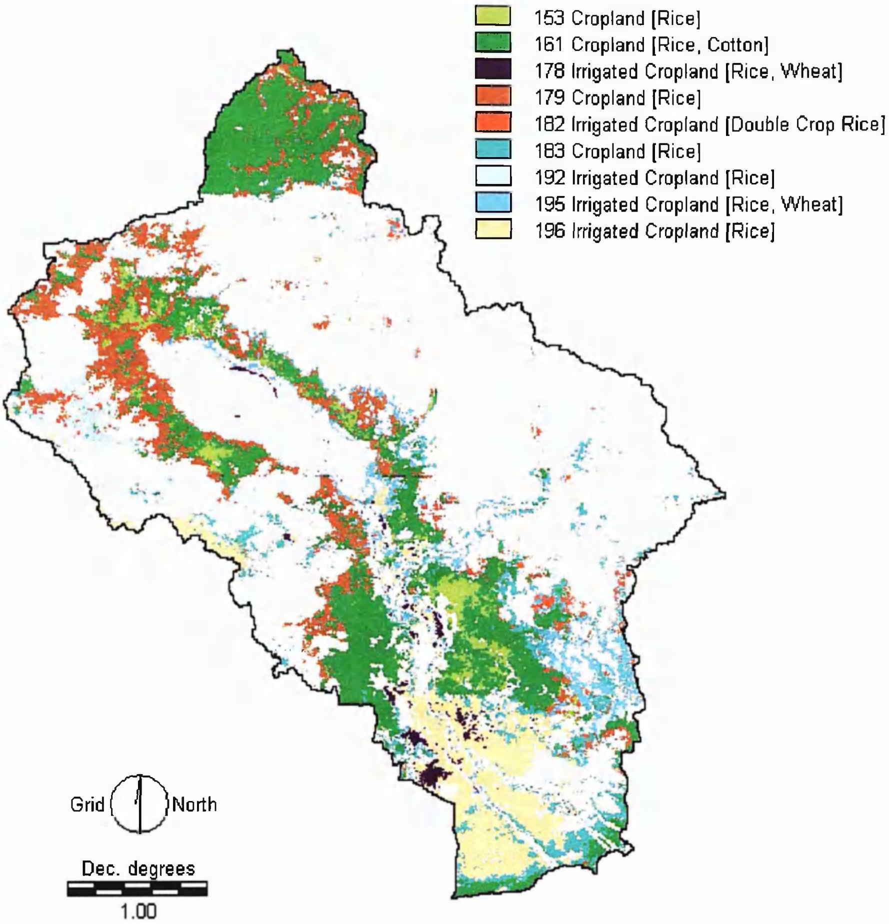


Figure 6.2 Spatial distribution of major rice based agro-ecosystems in the study area (source: GLCC)

Most of the study area, except the South, is dominated by three classes of rice-based cropland. Irrigated cropland systems, mainly rice, dominate the southern part of the study area, notably the Mekong Delta, whereas its occurrence over the rest of the study area is patchier. Some categories of land cover appear under the same or very similar description in the original GLCC dataset. For example class values 153, 179 and 183 appear to be all labelled as 'Cropland (Rice)'. Classes covering a minor area, or appearing dispersed over the study area while having a description similar or equal to that of major coverage classes were merged with the latter.

6.1.3 Seasonality

Agro-ecosystems seasonality analysis was performed in order to assess which of the nine distinguished farming systems classes are characterised by low productivity, i.e. one crop harvest per year, and where floods and drought constrain the potential for increased agricultural productivity. A preliminary evaluation of agro-ecosystem seasonality in the study area was based upon the use of NDVI spectral patterns. The major agricultural land use classes were subjected to a seasonality analysis in order to test for any significant differences in growing season and mean monthly greenness, and to decide whether or not to regard them as different classes. For each land cover class mean monthly greenness was computed from 12 monthly NDVI composite images covering the period of April 1992 till March 1993. The imagery is derived from heritage AVHRR instruments and is available through IGBP-DIS. The trend in mean monthly NDVI of each land use class provides an indicator for seasonality in the agro-ecosystems. Monthly mean NDVI values of rice based cropland systems in the study area over the one year period demonstrate that NDVI values reach a maximum near the end of the rainy season around November, followed by a sharp decline coinciding with the harvesting season (Figure 6.3). The unimodal distribution is indicative for a single crop system of wet season rice. Lowland rain fed rice is the main rice crop. The major land use class in the study area, 'Cropland (rice, cotton)' belongs to this group. It is cultivated during the wet season, which lasts approximately from May till December and is characterised by a relatively long fallow period during the dry season. Where a dry season crop is present it is cultivated from November till approximately May, taking advantage of receding flood waters.

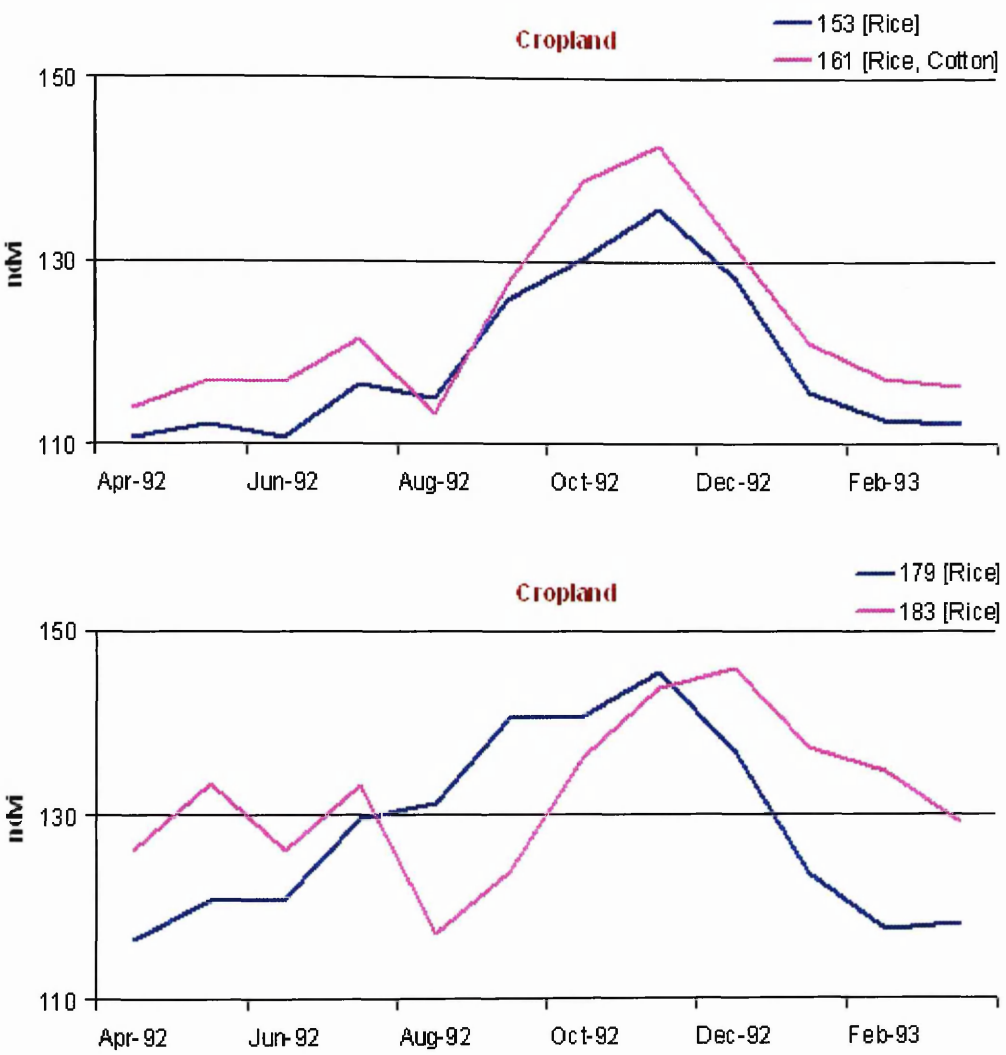
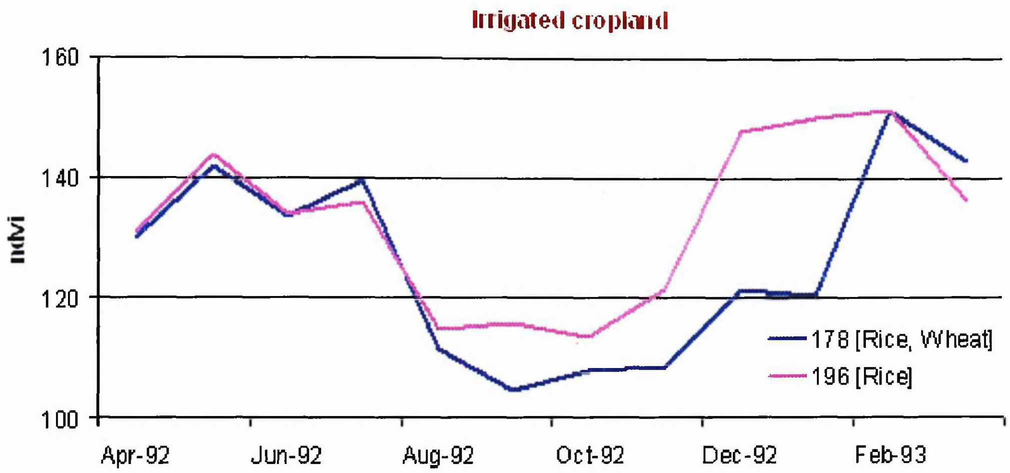


Figure 6.3 Monthly NDVI representing seasonality in four major single crop rice based agro-ecosystems in the study area

Monthly NDVI trends for irrigated cropland and double crop rice systems demonstrate bi-modal distributions with a first peak around July – early August and a second peak around November – December (Figure 6.4). The dip in NDVI in August – September corresponds with the period between rice transplanting and harvest, when the rice crop is inundated. Irrigated rice production under inundated conditions is particularly reflected in land use classes 195 and 196, corresponding to rice production in floodplain areas and the seasonally inundated Mekong Delta respectively.



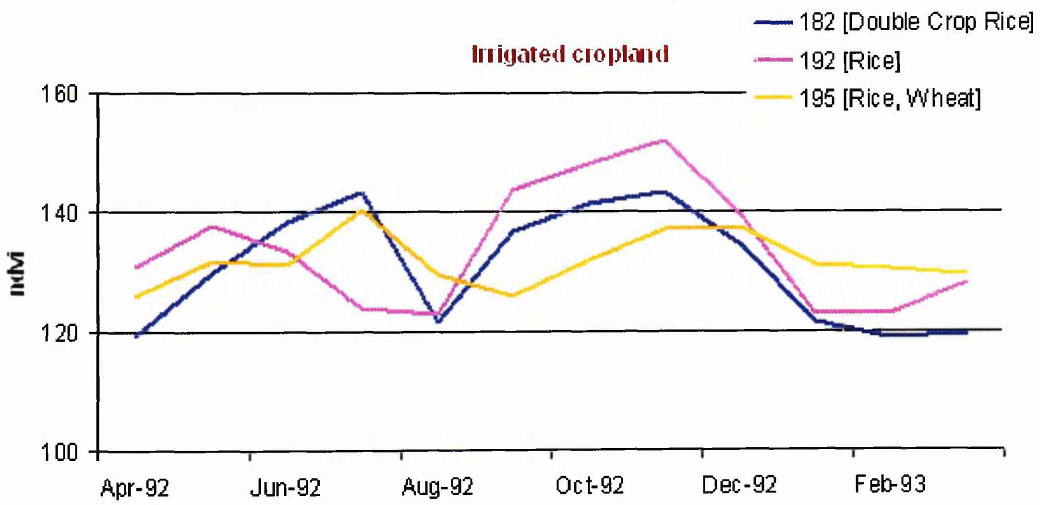


Figure 6.4 Seasonality of major irrigated rice based agro-ecosystems

A correlation analysis (Table 6-1) was performed in order to determine the degree of association among the nine classes. A test for equality of NDVI means between pairs of cropland classes was performed using Welch's approximate t-test, which assumes unequal class variances (Sokal & Rohlf, 1995). The correlation is visually represented in a dendrogram (Figure 6.5).

Table 6-1 Seasonal correlation (r_{ij}) between rice-based agro-ecosystems (upper diagonal) and pairwise test of equality of mean NDVI (t': Welch's approximate t-test of equality of means assuming unequal viarances, lower diagonal)

r_{ij} / t'	[153]	[161]	[178]	[179]	[182]	[183]	[192]	[195]	[196]
[153]		0.97	-0.73	0.94	0.65	0.56	0.80	0.39	-0.44
[161]	4.02*		-0.62	0.87	0.70	0.67	0.82	0.46	-0.35
[178]	4.83**	1.85		-0.82	-0.39	0.01	-0.58	0.08	0.72
[179]	8.62**	4.46**	1.53		0.72	0.32	0.72	0.37	-0.60
[182]	10.67**	6.34**	2.91*	1.80		0.34	0.66	0.61	-0.38
[183]	13.38**	8.42**	4.12*	3.41*	1.47		0.40	0.67	0.44
[192]	13.31**	8.92**	4.89**	4.38*	2.64*	1.42		0.13	-0.48
[195]	15.72**	9.40**	4.07*	3.42*	1.14	0.71	2.26*		0.23
[196]	10.35**	6.87**	3.90*	3.10*	1.61	0.52	0.60	1.04	

t' * significant at P < 0.05,** significant at P < 0.001

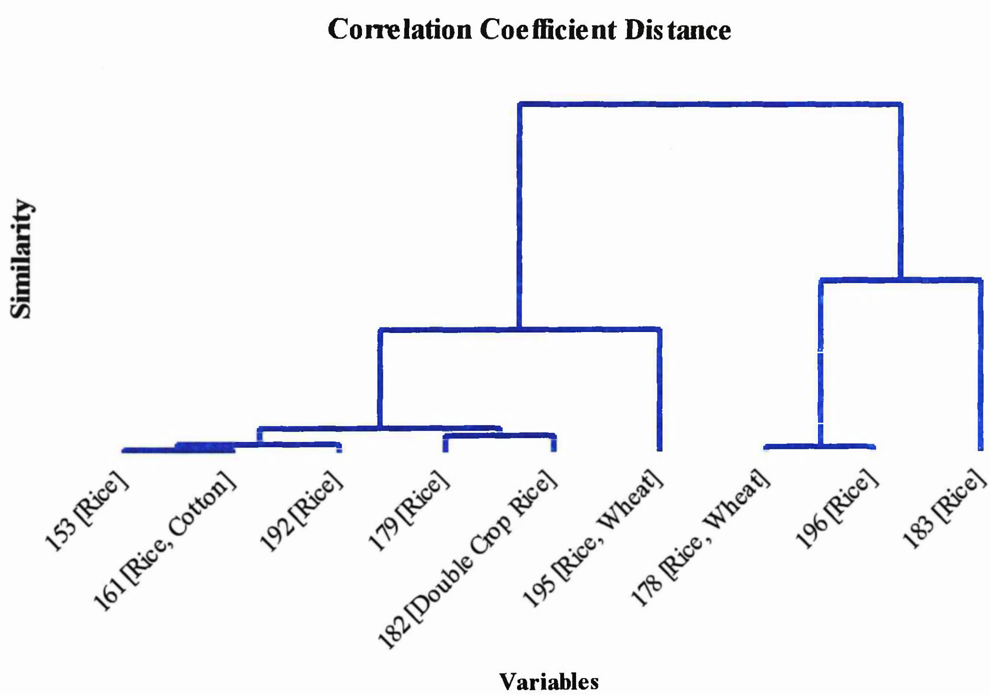


Figure 6.5 Correlation between major rice-based agro-ecosystems

Paired comparison of the classes confirms that class 153 [Rice] and class 161 [Rice, Cotton] are seasonally highly correlated (r[153], [161] = 0.97), but have a significantly different (P < 0.05) mean NDVI. Class 179 [Rice] also closely correlates with class 153 and class 161, but its mean NDVI is significantly higher (P < 0.001).

Seasonal greenness in the group of rain-fed or flood recession rice systems constituted by classes 153, 161 and 179 is negatively correlated to that in irrigated rice systems, notably class 178 [Rice, Wheat] and class 196 [Rice]. The outcomes confirm the presence of a range of rice-based agro-ecosystems over the study area.

6.1.4 Unsupervised classification

An unsupervised classification algorithm was employed in order to identify typical patterns in the spectral reflectance data that could be used to detect agro-ecosystem seasonality in the absence of reliable information from ground truth or prior land use classification. The one year time series of NDVI composites was subjected to a Principal Components Analysis (PCA) in order to detect spatial and temporal patterns in land cover and –use, and crop growing seasons. PCA provides a comprehensive indicator of change events in time series of spatial environmental data. The technique is used to identify both cyclic seasonal elements of change and isolated change events (Eastman & Fulk, 1993).

The results of standardized PCA can be interpreted spatially through examination of the component images and temporally from the graph of the component loadings. The images are ordered in terms of the amount of variance explained in the original data. Each component represents a set of distinctive reflectance patterns that are an expression of spatial and temporal patterns in major land cover classes. The loading graphs illustrate the correlation between each of the 12 monthly images and the component being diagrammed. If a month shows a strong positive correlation with a specific component, it indicates that that month contains a latent spatial pattern that has strong similarity to the one depicted in the component image. A strong negative correlation indicates that the monthly image has a latent pattern that is the inverse of that shown. The strength of a component will be determined by both the magnitude of the variability it explains and the area over which that variability occurs. Small magnitude changes may come out in early components if they affect large areas (Eastman & Fulk, 1993).

Component 1 (CMP 1) typically represents the characteristic value over the series, in this case the spatial characteristics of NDVI integrated over all seasons. The component image shows a tendency of lower NDVI values over major rice-growing areas (Figure 6.6 a). Component 2 (CMP 2) illustrates the most prevalent element of variability in NDVI that is uncorrelated with the characteristic pattern in CMP 1 (Eastman & Fulk, 1993). Major temporal changes over the agricultural target area, related to flood events and seasonal production, are expressed in this component (Figure 6.6 b). The monthly loadings (Figure 6.7, Table 6-2) reveal an overall positive correlation with CMP 1, which is weaker during the wet season months when widespread flooding occurs. The loading graph demonstrates a positive correlation of wet season months with CMP 2, while dry season months correlate negatively with this component (Figure 6.7, Table 6-2). The negative anomaly in the southern tip of the study area over parts of the Mekong Delta reveals seasonally inundated areas, which is reflected in a considerable drop in NDVI (Figure 6.6 b). Plotting the CMP 2 monthly loading graph together with mean monthly NDVI values for major agro-ecosystems reveals the correlation between seasonality and crop production (Figure 6.7).

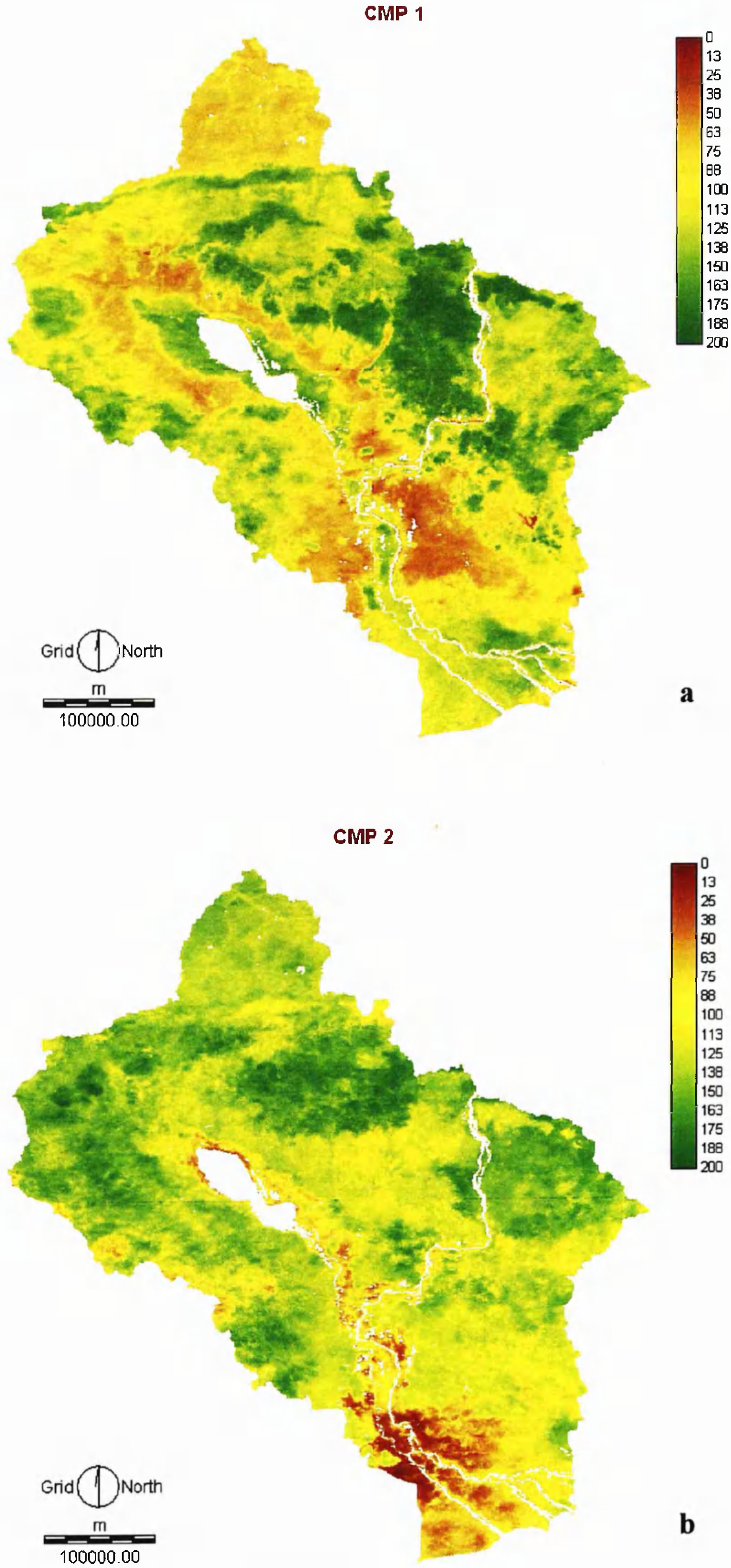


Figure 6.6 PCA spatial outputs: a) component 1 (CMP 1) and b) component 2 (CMP 2)

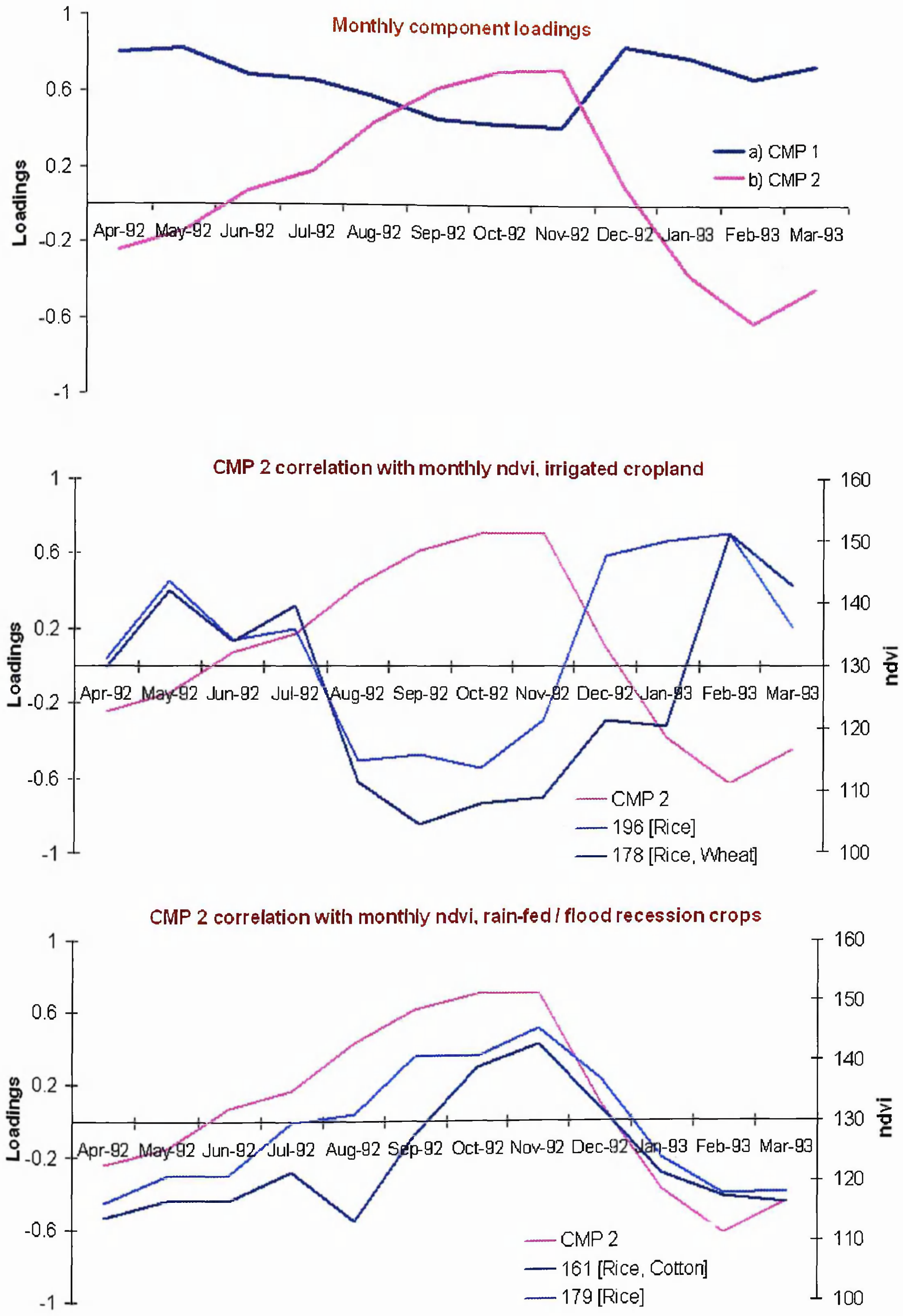


Figure 6.7 Monthly component loadings for CMP 1 and 2 and correlation of CMP 2 with average monthly NDVI of irrigated and rain-fed cropland

Table 6-2 PCA Components (x) and Monthly Loadings (y)

Comp.	1	2	3	4	5	6	7	8	9	10	11	12
% Var	45.46	20.34	7.55	5.09	4.40	3.95	3.30	3.12	2.28	1.78	1.59	1.14
Monthly loadings	Correlation coefficient (r)											
Apr-92	0.80	-0.24	0.26	0.10	0.11	-0.08	0.21	-0.24	0.00	-0.30	-0.08	0.03
May-92	0.82	-0.15	-0.08	0.30	-0.12	-0.08	0.23	-0.08	-0.23	0.25	-0.08	-0.01
Jun-92	0.68	0.07	-0.50	0.14	0.02	-0.47	-0.13	0.03	0.14	-0.04	0.06	0.00
Jul-92	0.66	0.17	-0.50	0.14	-0.07	0.46	-0.11	-0.16	0.07	-0.06	-0.03	-0.01
Aug-92	0.57	0.44	-0.28	-0.48	0.32	0.02	0.25	0.09	-0.04	0.04	-0.05	0.03
Sep-92	0.45	0.62	0.16	-0.35	-0.41	-0.11	-0.11	-0.27	-0.04	0.02	0.02	0.01
Oct-92	0.43	0.71	0.19	0.17	0.29	-0.01	-0.31	0.07	-0.26	-0.05	-0.03	-0.01
Nov-92	0.42	0.72	0.34	0.22	0.05	0.04	0.09	0.05	0.33	0.13	-0.05	0.05
Dec-92	0.85	0.10	0.10	0.03	-0.22	0.11	0.13	0.32	-0.06	-0.11	0.26	0.00
Jan-93	0.79	-0.38	0.10	-0.15	-0.16	0.01	-0.13	0.26	0.06	-0.03	-0.26	-0.13
Feb-93	0.67	-0.63	0.11	-0.11	0.05	0.05	-0.20	0.02	0.01	0.09	0.02	0.28
Mar-93	0.74	-0.45	0.20	-0.12	0.25	0.04	-0.10	-0.17	0.08	0.13	0.17	-0.19
Eigenvalue	5.46	2.44	0.91	0.61	0.53	0.47	0.40	0.37	0.27	0.21	0.19	0.14

CMP 2 appears to explain most of the seasonality in rice-based agro-ecosystems, thus providing a good indicator for spatial distribution and temporal patterns in agro-ecosystems for the study area. The positive anomaly over most of the rice growing areas is indicative of an increase in NDVI from a wet season rice crop. The positive correlation with wet season crop production in rain-fed systems corresponds to increasing NDVI values for these systems from August till mid-November. CMP 2 displays an inverse relationship with irrigated cropland, notably classes 178 and 196. Particularly in the Mekong Delta, these irrigated crop areas are inundated during the wet season.

The number of components in PCA equals the number of variables. The number of components to be interpreted in the analysis in order to identify general patterns can be determined on the basis of the eigenvalue, the sum of squared component loadings that indicate the proportion of the variance accounted for by each component. Usually only the components with the largest eigenvalue are interpretable. A component with an eigenvalue less than 1.0 in theory accounts for less of the total variance than does any of the original variables, because 1.0 represents the standardised variance of the original variables (Johnston, 1978). Thus on the basis of the eigenvalues calculated for the 12 component loadings (Table 6-2), analysis of CMP 1 and CMP 2 would suffice to explain the principal patterns in NDVI variability over the study area.

CMP 1 accounts for a considerable percentage of the variance in NDVI over most of the year, but CMP 2 explains a larger proportion of the variance in September till November, respectively 38, 51 and 50 percent. Together the two components account for most of the variance over the year, but subsequent components still carry a considerable proportion of the variance in the data. Component 3 and 4 appear to reveal seasonality in forest- and woodland areas. Twenty-five percent of the variance in June and July and 23 percent of the variance in August are expressed in these components respectively. Discrimination of evergreen and deciduous forest is possible during summer season (April to August) when deciduous trees shed their leaves (Giri, Defourny, & Shrestha, 2003). Twenty-two percent of the variation in the June and July loadings is accounted for by CMP 6 (Figure 6.8). The first six components together explain 86.8 percent of overall variability over the study area, and were subjected to a cluster analysis.

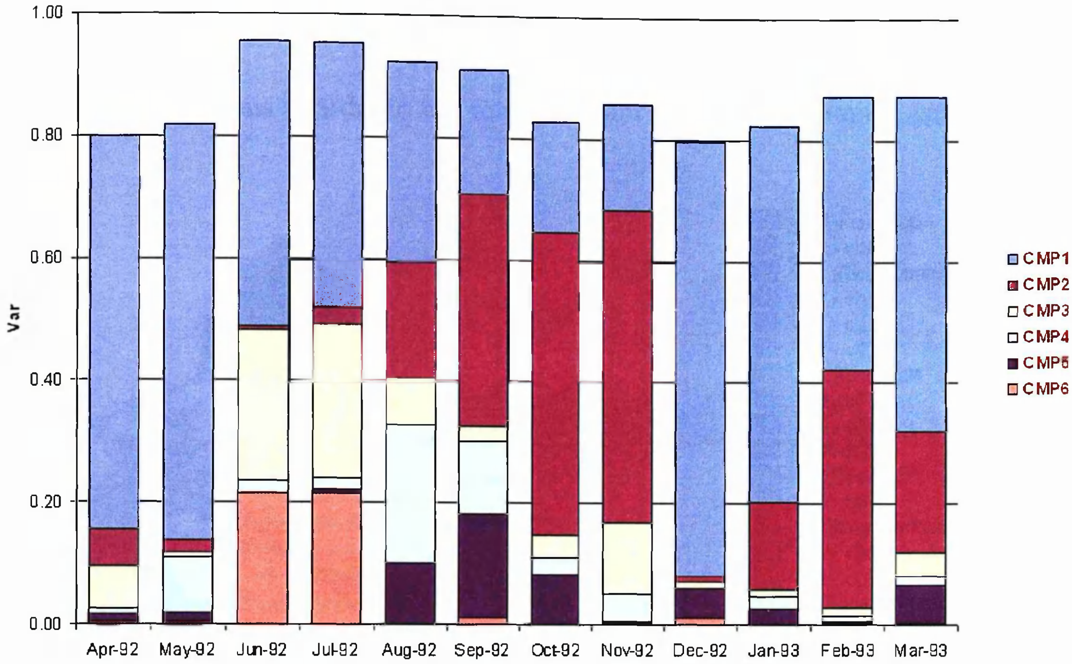


Figure 6.8 Amount of variance explained in the first six components

6.1.5 Cluster analysis and land use classification

An iterative self-organising cluster routine was used in order to extract clusters of pixels with similar reflectance characteristics from the six principal components that capture most of the variability in spectral reflectance over the study area. As the number of clusters to be uncovered through this procedure is determined by the user, it was decided to yield initially 40 major clusters in order to broadly mirror the 38 major land use classes that were derived from the original GLCC dataset. Analogous to the procedure for seasonality analysis in major agricultural land use classes, mean monthly greenness was computed for each cluster from the 12 monthly NDVI composite images of April 1992 to March 1993.

A cross classification procedure was applied in order to extract clusters that appeared to correspond spatially with major rice based agro-ecosystems (Figure 6.9).

Corresponding clusters were subjected to the same statistical procedure as applied to major agro-ecosystems in order to test for significant differences from the latter.

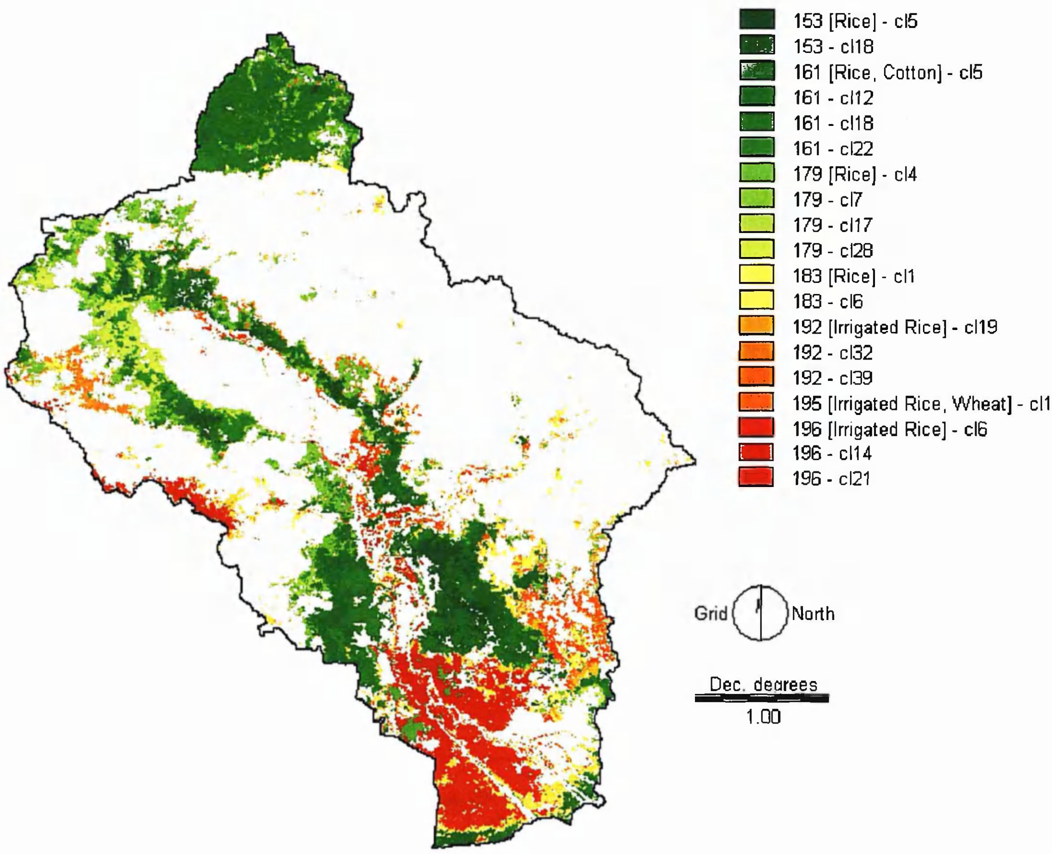


Figure 6.9 Spatial correlation of rice agro-ecosystems and outputs from cluster analysis

Spectral response patterns of rain-fed agro-ecosystems (Table 6-3), especially classes 153 [Rice], 161 [Rice, Cotton] and 179 [Rice] appeared to be highly correlated with spatially corresponding clusters. Where monthly means and variances of NDVI differ significantly ($P < 0.05$) between clusters and spatially corresponding classes (Table 6-3; t' and F respectively) it is likely that the original classifications represent pixels from a mixture of clusters generated by the unsupervised classification.

Table 6-3 Seasonal correlation (r_{ij}) between rain-fed rice-based agro-ecosystems and overlapping clusters derived from unsupervised classification (upper diagonal) and pairwise test of equality of mean NDVI (t': Welch's approximate t-test of equality of means assuming unequal viarances, lower diagonal)

Rain-fed / flood recession crops (*t'* *significant at P < 0.05, **significant at P < 0.001)

cluster	*coverage (%)*	r_{ij}	*t'*	*F*
153 [Rice]				
cl18	43.8	0.964	0.91	1.49
cl5	33.8	0.966	2.03	1.02
cl28	11.3	0.962	4.69**	2.41
161 [Rice, Cotton]				
cl5	27.3	0.986	2.13	1.29
cl12	26.4	0.962	2.23*	1.27
cl18	13.4	0.988	4.50**	1.19
cl22	12.2	0.937	2.54*	1.04
179 [Rice]				
cl4	34.4	0.975	1.41	1.10
cl28	17.2	0.984	2.36*	1.77
cl17	11.2	0.938	4.13*	1.71
cl7	10.5	0.968	3.14*	1.10
183 [Rice]				
cl6	19.4	0.827	1.66	1.24
cl1	17.9	0.777	4.01*	1.75
cl14	11.2	0.575	0.08	1.57

Given the very high temporal correlation (Figure 6.10) these differences, unless highly significant (P < 0.001), did not justify rejection of the hypothesis that such clusters correctly represent occurrence of rain-fed rice agro-ecosystems. Except for high correlation coefficients in class 196 [Rice], the correlation between irrigated systems and their spatially corresponding clusters (Table 6-4) was less clear, both in terms of the spatial overlap and in terms of significant differences apparent in monthly NDVI. Even so, seasonal tendencies remain visible (Figure 6.11). A higher positive correlation between classes and clusters was found for larger and less fragmented agro-ecosystem classes 161 and 196, indicating that class coverage for these systems can be estimated with higher thematic accuracy. These findings are consistent with those in earlier thematic land cover validation exercises (Scepan, 1999).

Table 6-4 Correlation of irrigated rice agro-ecosystems with clusters derived from unsupervised classification

Irrigated crops				
cluster	*coverage (%)*	r_{ij}	t'	F
178 [Rice, Wheat]				
cl24	22.7	0.830	2.54*	1.50
cl14	18.2	0.674	3.95*	2.34
cl36	18.2	0.555	2.22*	1.77
cl37	9.1	0.640	0.47	4.41*
182 [Double Crop Rice]				
cl11	23.5	0.875	9.05**	1.67
cl4	17.6	0.816	0.42	1.05
cl15	17.6	0.887	6.28**	1.64
cl8	11.8	0.905	6.44**	1.26
192 [Rice]				
cl39	22.5	0.871	4.32*	1.46
cl32	12.5	0.756	4.45**	1.42
cl19	10.0	0.694	5.35**	1.17
cl1	7.5	0.523	5.01**	2.72
cl7	7.5	0.742	1.15	1.09
cl15	7.5	0.593	3.92*	1.56
cl39	22.5	0.871	4.32*	1.46
195 [Rice, Wheat]				
cl1	26.4	0.711	4.56**	1.97
cl2	18.7	0.787	8.51**	3.18
cl14	9.9	0.431	0.68	5.43*
196 [Rice]				
cl33	17.9	0.927	0.02	2.04
cl14	17.5	0.954	0.43	1.78
cl21	14.6	0.564	2.33*	1.01
cl6	12.7	0.698	0.73	2.26
cl36	10.4	0.869	2.09	1.35

t' * significant at $P < 0.05$,** significant at $P < 0.001$

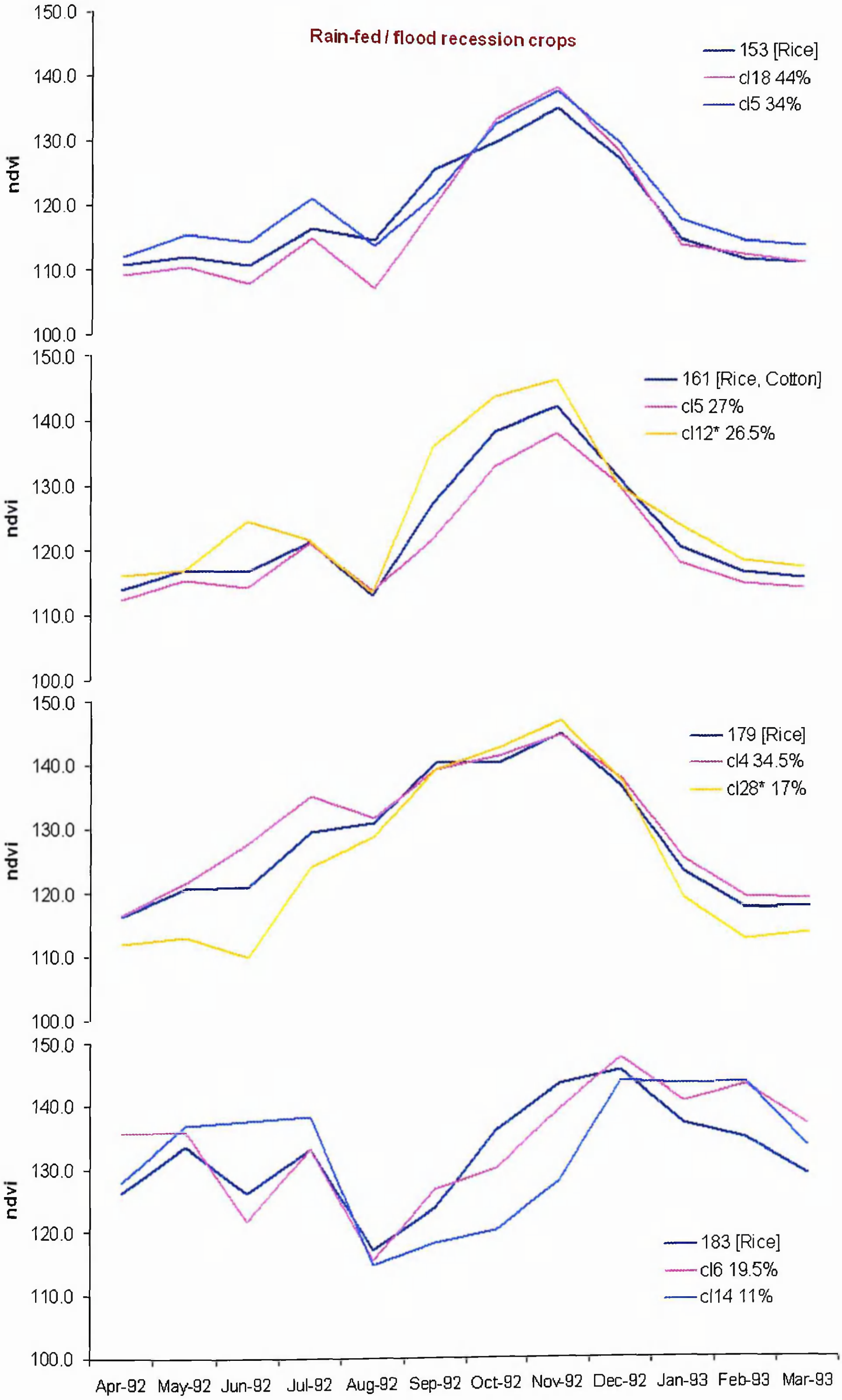


Figure 6.10 Monthly variation in NDVI of clusters derived from unsupervised classification and spatially corresponding rain-fed rice agro-ecosystems derived from GLCC data

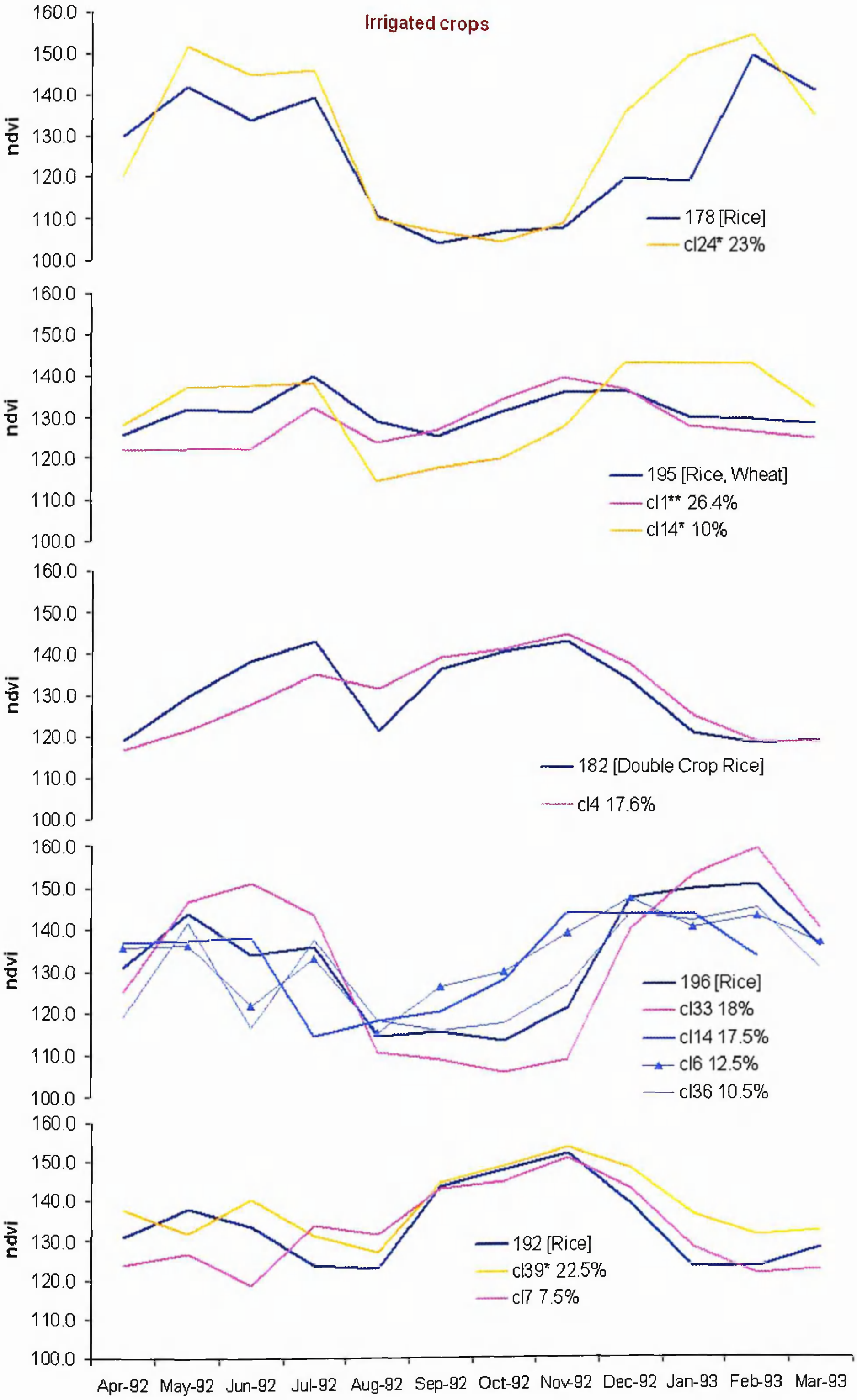


Figure 6.11 Monthly variation in NDVI of clusters derived from unsupervised classification and spatially corresponding irrigated rice agro-ecosystems derived from GLCC data

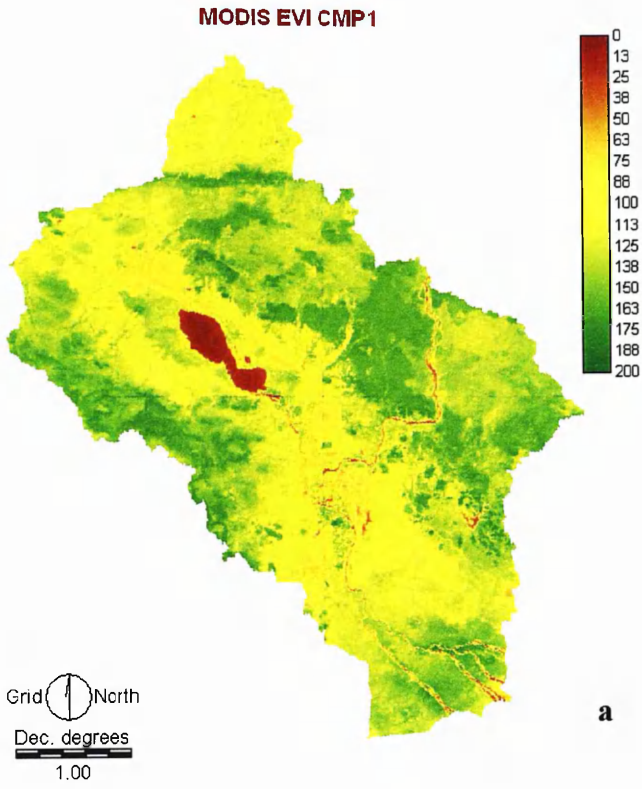
High spatial and temporal variability in rice agro-ecosystems, as well as variability across systems can be due to many environmental factors such as cyclic inter-annual climate events and annual seasonality, soil conditions, topographic variables and related differences in flooding regime, that together determine the rice cultivation calendar and cropping strategies. The results from the cluster analysis procedure clearly demonstrate the seasonality in rain-fed systems. Interpretation of clusters that spatially correspond to systems labelled as 'irrigated' is more complicated but this is likely to reflect uncertainties in the original systems classification rather than being a poor indicator of actual systems variability. The analysis of seasonal variations in mean NDVI within these clusters reveals the annual Mekong lowland flood regime and its interactions with agricultural production systems. Irrigation schemes in the study area commonly take advantage of receding floods. Irrigation of rice systems is largely supplementary and based on small scale irrigation schemes, but permits potentially a move from single- to double cropping (Chea, Cramb, & Fukai, 2004).

6.1.6 Land use classification from MODIS vegetation products

A general problem in the interpretation of NDVI profiles is atmospheric contamination, which varies in space and time. Research within the International Geosphere Biosphere Programme (IGBP) found levels of 27 percent and 42 percent NDVI contamination in dryland and irrigated cropland respectively, suggesting an association of higher levels of contaminated NDVI with humid rice production areas in tropical and subtropical regions (Loveland *et al.*, 1999). The same authors attributed high land cover classification uncertainty, attaining only 29 percent regional accuracy for Southeast Asia to this factor.

Current emphasis in Earth observation involves operational 'external' noise removal through improved calibration, atmospheric correction, cloud and cloud shadow removal, and standardization of sun-surface-sensor geometries. The MODIS sensor represents a significant gain in spatial detail (Hansen *et al.*, 2003). The MODIS 16-day composites of Vegetation Indices (VI) at 1 km resolution are corrected for molecular scattering, ozone absorption and aerosols. Moreover, the enhanced vegetation index (EVI) has improved sensitivity into densely forested regions and agricultural areas (Justice *et al.*, 1998).

A contemporary time series of MODIS vegetation products, spanning the period from 24 February 2000 to 14 October 2004 was acquired through the EOS data gateway. The time series, consisting of 1 km NDVI and EVI 16-day composites, 107 images each, were subjected to PCA. The higher discriminative power of EVI compared to NDVI is evident from the higher spatial contrast in average or typical VI visible in EVI CMP 1 (Figure 6.12 a, b). EVI and NDVI covary in the same direction in CMP 1. The cyclic seasonal nature of vegetation change events is expressed in CMP 2 (Figure 6.13) but EVI and NDVI loadings appear to mirror each other (Figure 6.14). Seasonal greenness of non-flooded areas is high during the rainy season, whereas flooded areas are characterised by low VI values. The EVI expresses a highly positive correlation with temporal flood events in the Mekong Delta and a highly negative correlation with seasonal greenness of non-flooded areas in the rainy season (Figure 6.14, Julian date 2003289, corresponding to mid-October 2003), whereas the contrary is true for the NDVI. As expected CMP 1 and CMP 2 account for most of the variance in the data.



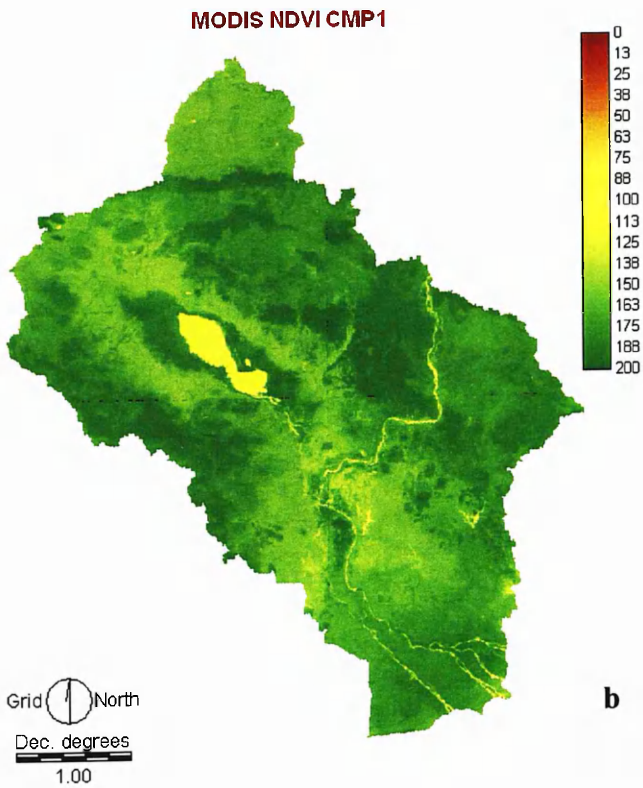


Figure 6.12 **PCA component 1, representing spatial Vegetation Index (VI) characteristics integrated over seasons, MODIS 1-km. a) EVI and b) NDVI**

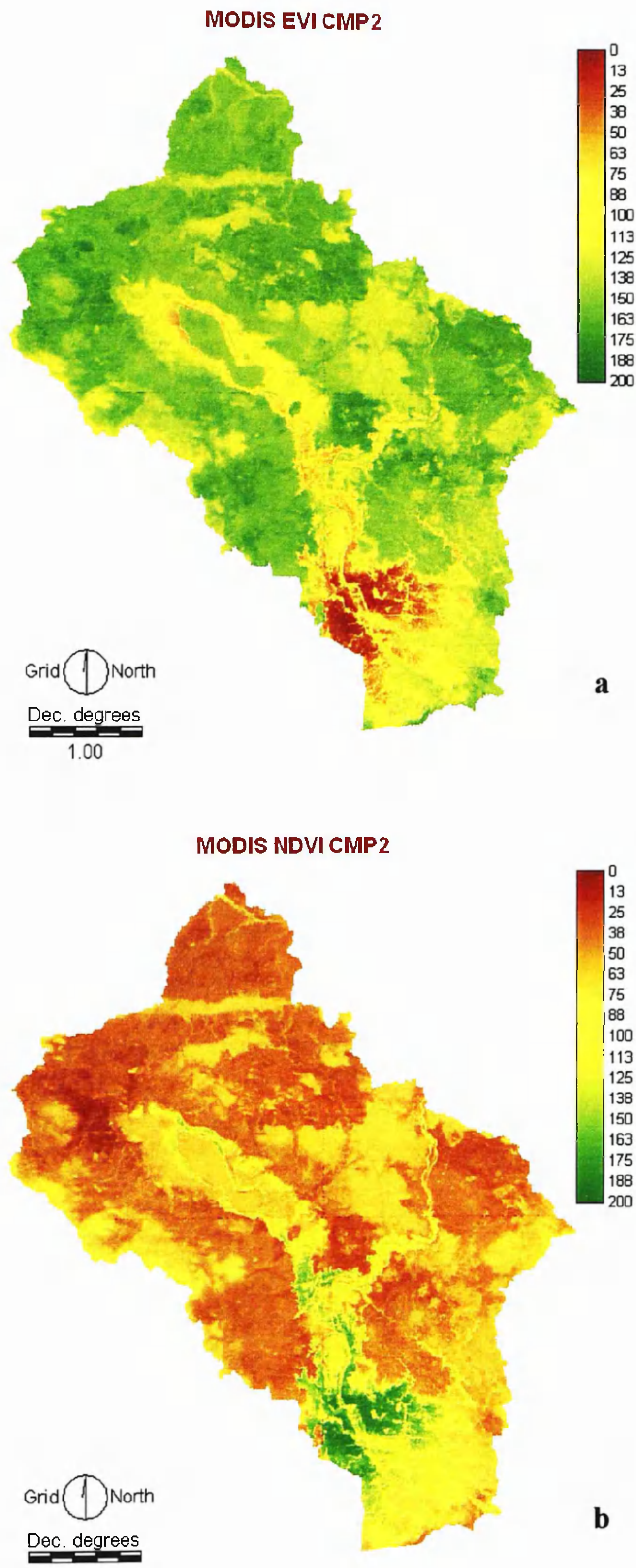
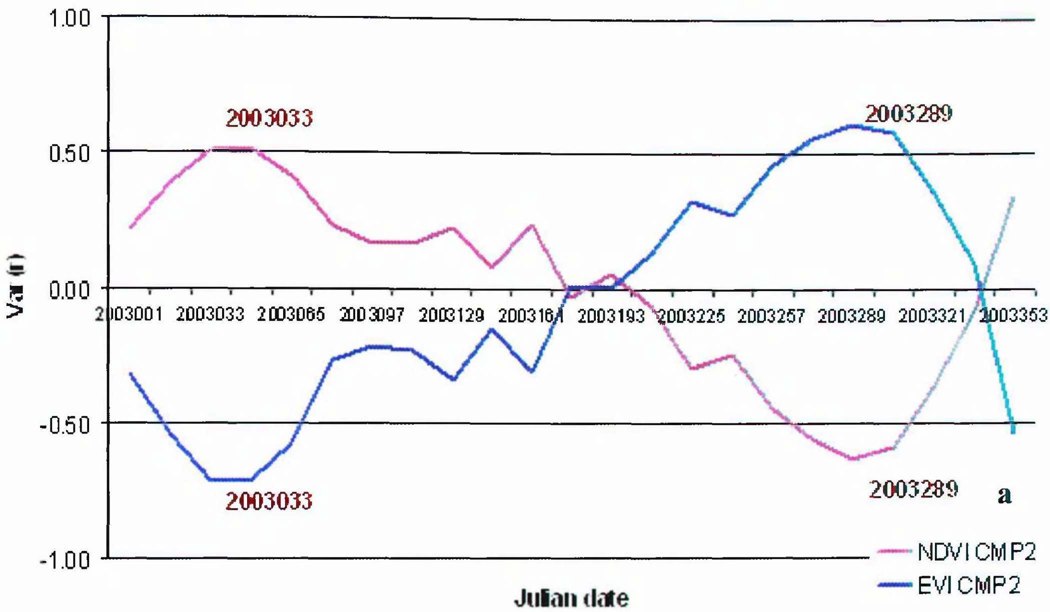


Figure 6.13 a) EVI and b) NDVI seasonality expressed in PCA component 2 highlighting seasonal flood events in the South



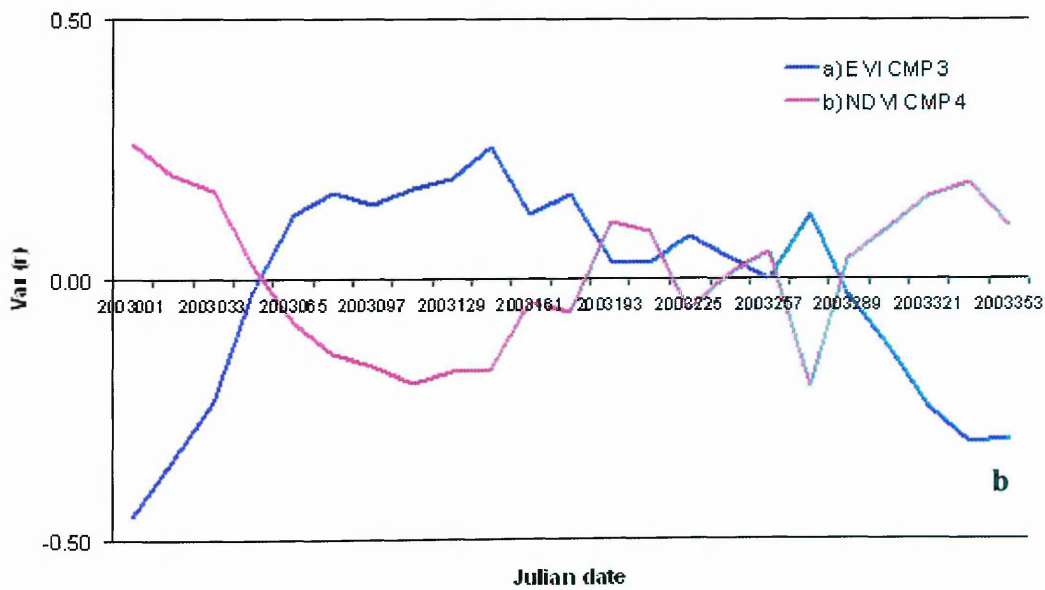
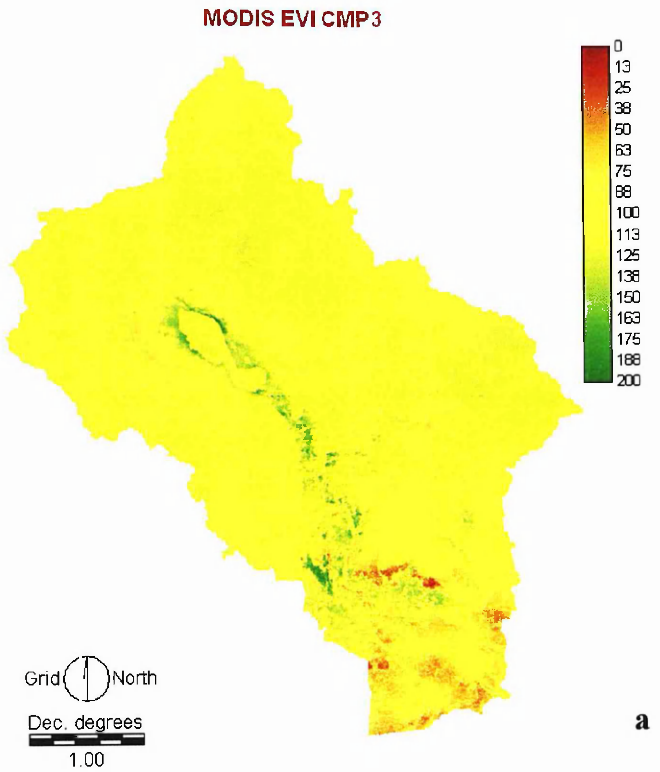


Figure 6.14 EVI and NDVI 16-day component loadings for CMP 2 (a) and EVI CMP 3 vs. NDVI CMP 4 loadings (b) for the year 2003

Rather than with NDVI CMP 3 the vegetation change events expressed in EVI CMP 3 appear to correlate negatively with those in NDVI CMP 4 (Figure 6.14 b; Figure 6.15), while CMP 4 correlates negatively with NDVI CMP 3 (Figure 6.16).



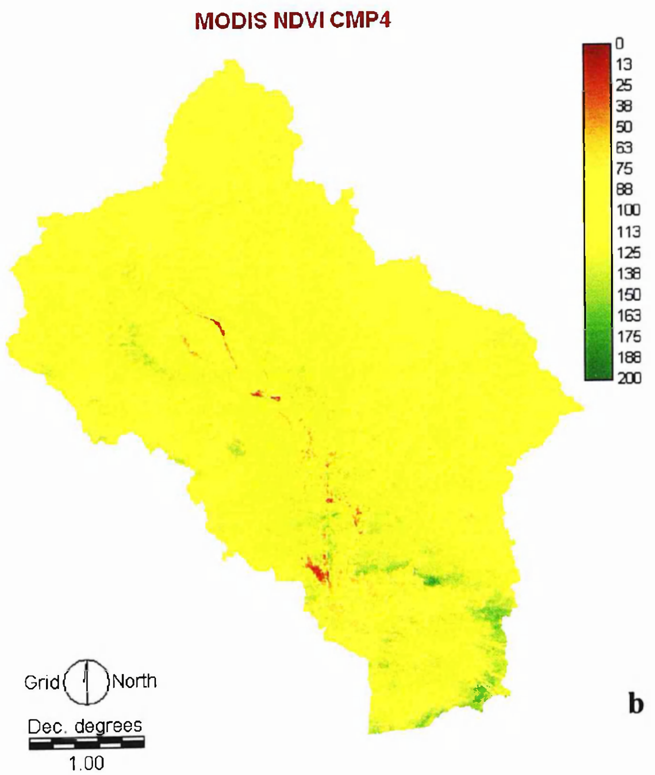
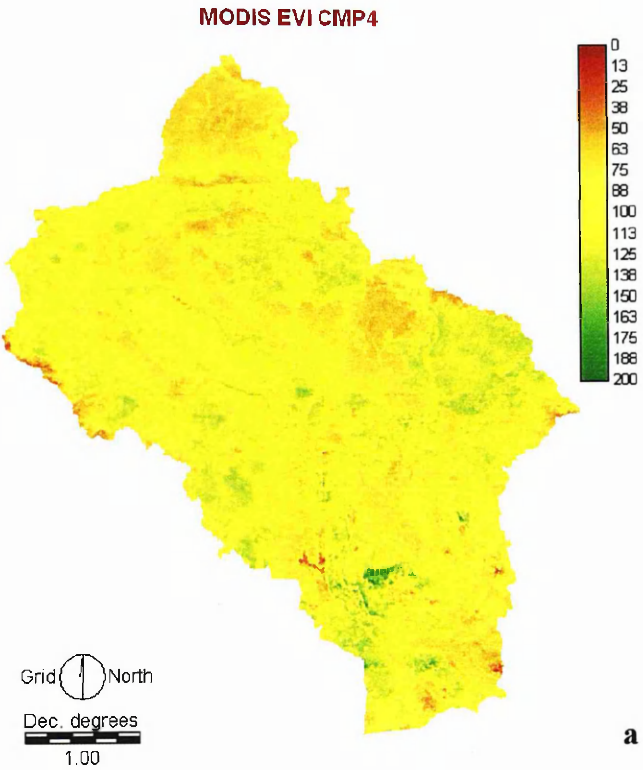


Figure 6.15 a) EVI component 3 and b) NDVI component 4 expressing seasonal VI variability in lowland areas



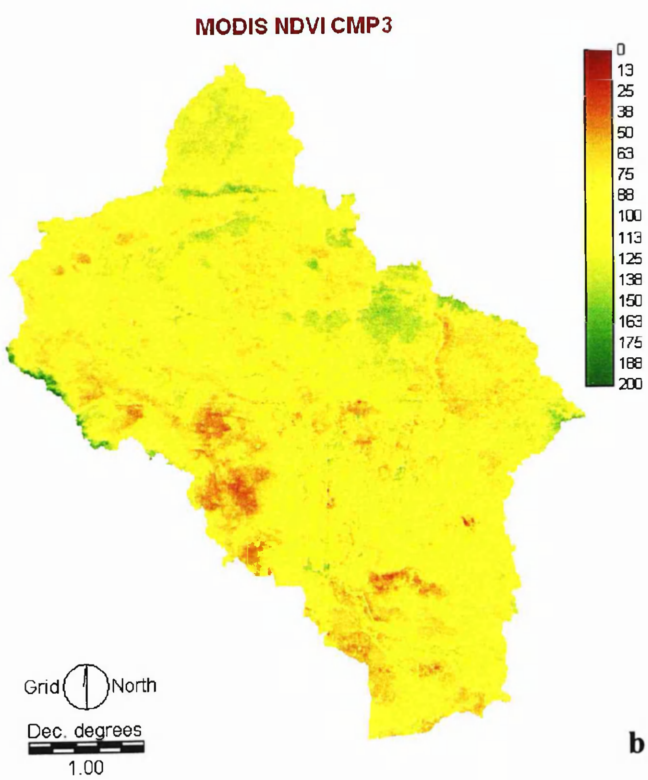


Figure 6.16 a) EVI component 4 and b) NDVI component 3 expressing differential change events in upland areas and evergreen and deciduous forest

These components express differential change events in upland areas and evergreen and deciduous forest. CMP 5 covaries for EVI and NDVI and is indicative of areas that reflect change events over the dry season. This demonstrates that localised, but considerable vegetation change events can be expressed in successive components. EVI CMP 5 (Figure 6.17) correlates positively with the 16-day composite for 2 – 17 February 2003 which displays high levels of greenness in the upper portion of the Vietnamese Mekong Delta (Figure 6.18 a). The same component correlates negatively with the 16-day composite for 7 – 22 April near the end of the dry season, displaying markedly decreased greenness over the same area and an onset of greenness around the Tonle Sap Great Lake and the forested areas in eastern central Cambodia (Figure 6.18 b).

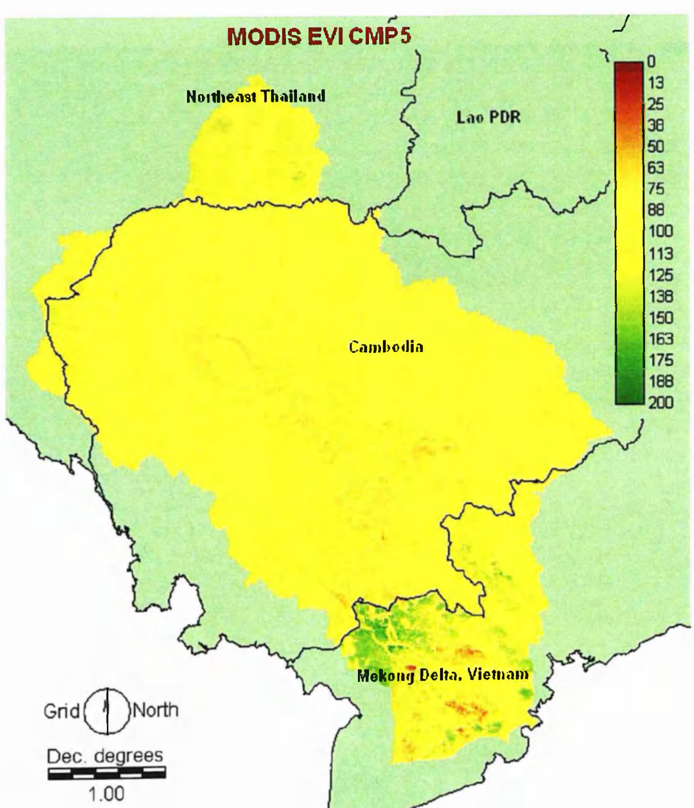


Figure 6.17 Dry season variability expressed in PCA component 5

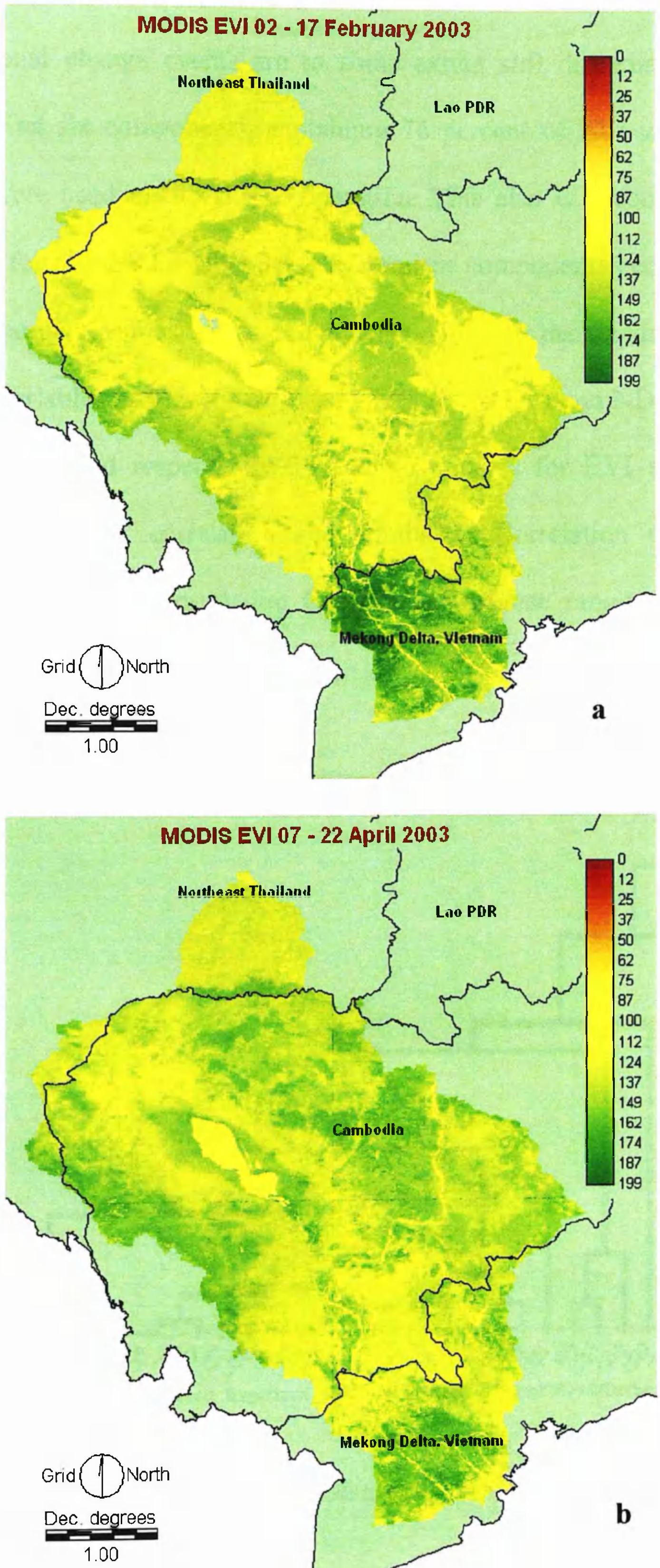


Figure 6.18 Vegetation change events over the dry season

Localised seasonal change events are to some extent still discernable in CMP 6. Therefore the first six components, explaining 76 percent of EVI variability in the image series, were used in the cluster operation. This also was consistent with the routine applied for the 1992 – 1993 data. Subsequent components become difficult to interpret, and the eigenvalues of the components approach the standardised variance of the original variables (1.0) in CMP 9 and CMP 10 for EVI and NDVI respectively. Cluster analysis yielded respectively 34 and 40 clusters for EVI and NDVI. The clusters were tested for correlation and similarity. Correlation was graphically expressed in terms of the Correlation Coefficient Distance ranging from +1 to -1 (Figure 6.19).

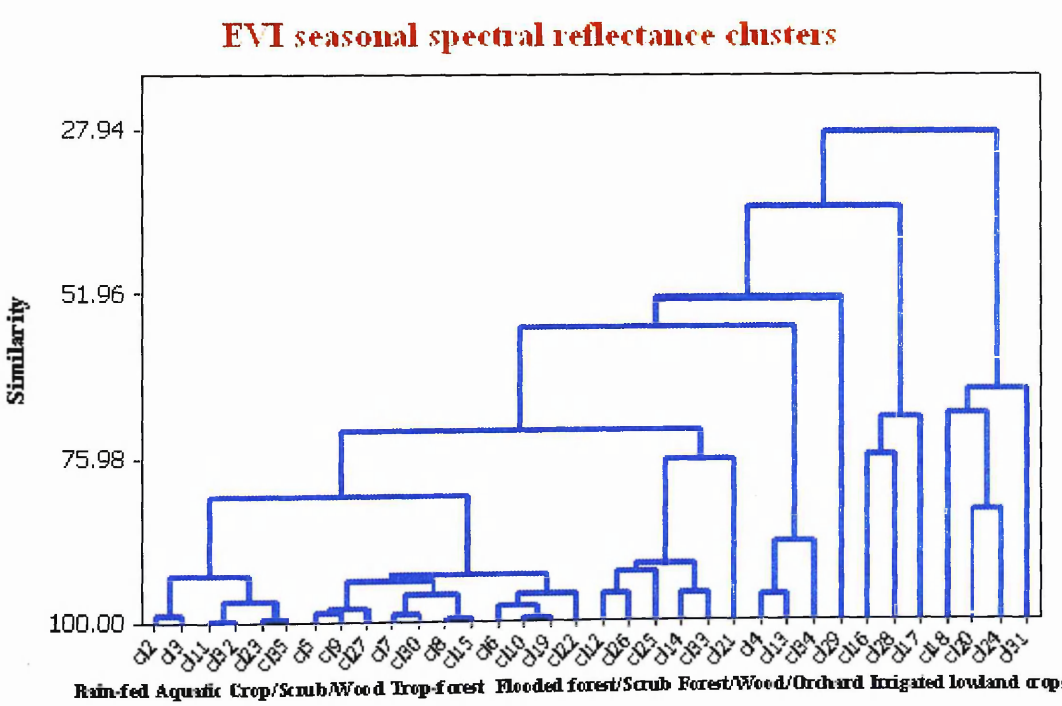


Figure 6.19 Correlation Coefficient Distance (x) and similarity (y) of land cover

Clusters which were highly positively correlated and highly similar (>98.5 percent) were pooled. Because of its improved sensitivity an EVI time series covering the period from 16 October 2002 till 14 October 2004 was used in order to detect seasonality over two vegetation growth cycles. The 16-day composites were recomposited into overlapping 32-day maximum value composites in order to reduce any remaining EVI contamination due to 'external' noise.

6.1.7 Results of agro-ecosystem identification based on EVI

Temporal patterns, based on a moving average of 32-day composite EVI values for each cluster confirm the presence of two distinctly negatively correlated land cover groups that spatially correspond to areas covered by major rice based agro-ecosystems (Figure 6.20).

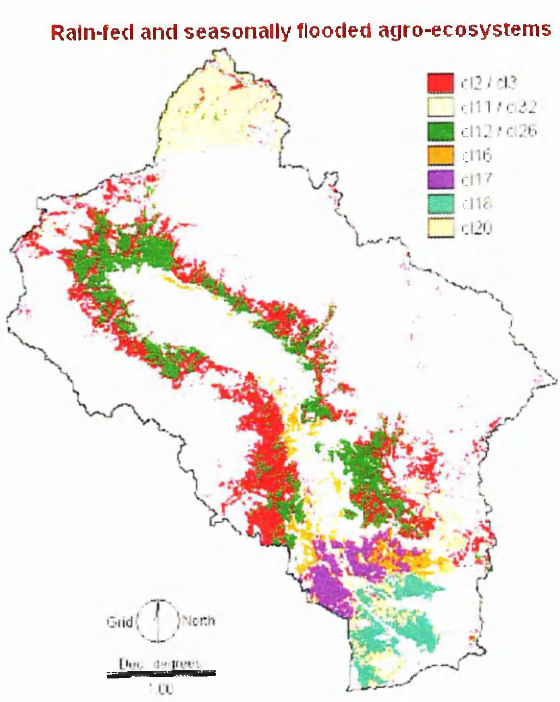


Figure 6.20 EVI derived clusters corresponding to rice based agro-ecosystems

The patterns reveal an increase in EVI corresponding to a wet season cropping pattern in the areas covered by pooled clusters cl2 / cl3 and cl12 / cl26 (Figure 6.21 a, b), and cl11 / cl32 (Figure 6.21 c). Clusters cl2 / cl3 and cl12 / cl26 are closely correlated but the former is characterised by significantly higher EVI values except at peak greenness. The bimodality during the wet season can be indicative for an early wet season crop harvest followed by the principal flood recession crop season, or may simply be a drop in EVI reflection due to seasonal inundation of a single crop. The spatially distinct cl11 / cl32 group (Figure 6.20) reflects typical wet season single crop characteristics (Figure 6.21 c).

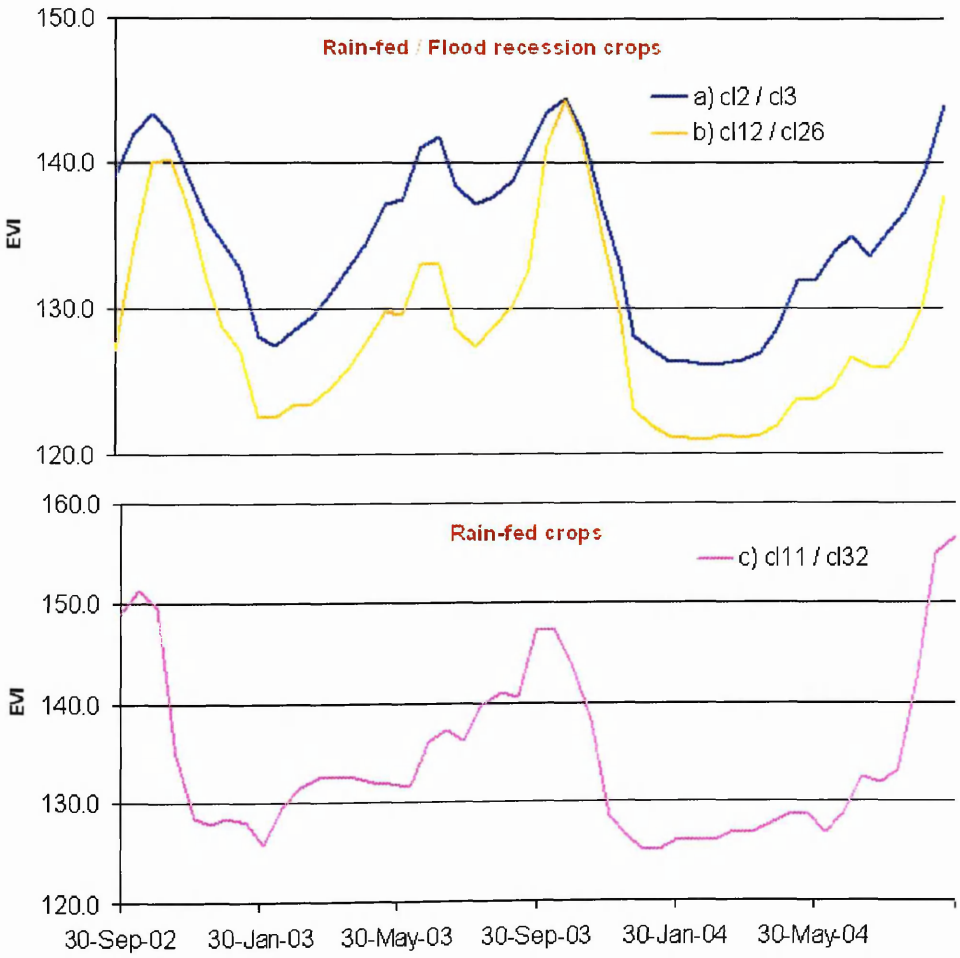


Figure 6.21 Seasonal patterns in rain-fed agro-ecosystems

Within the geographical area where this agro-ecosystem dominates, traces of cl2 / cl3 and cl12 / cl26 systems are visible (Figure 6.20). These correspond to floodplain areas, which supports the hypothesis that these systems benefit from supplementary irrigation and potentially can produce an additional crop.

Temporal patterns within clusters cl16 and cl17 (Figure 6.22 a, b) reveal distinct bimodality followed by a sharp drop in greenness, indicative for flooded conditions during the rainy season. A similar pattern is apparent within clusters cl18 and cl20 (Figure 6.22 c, d).

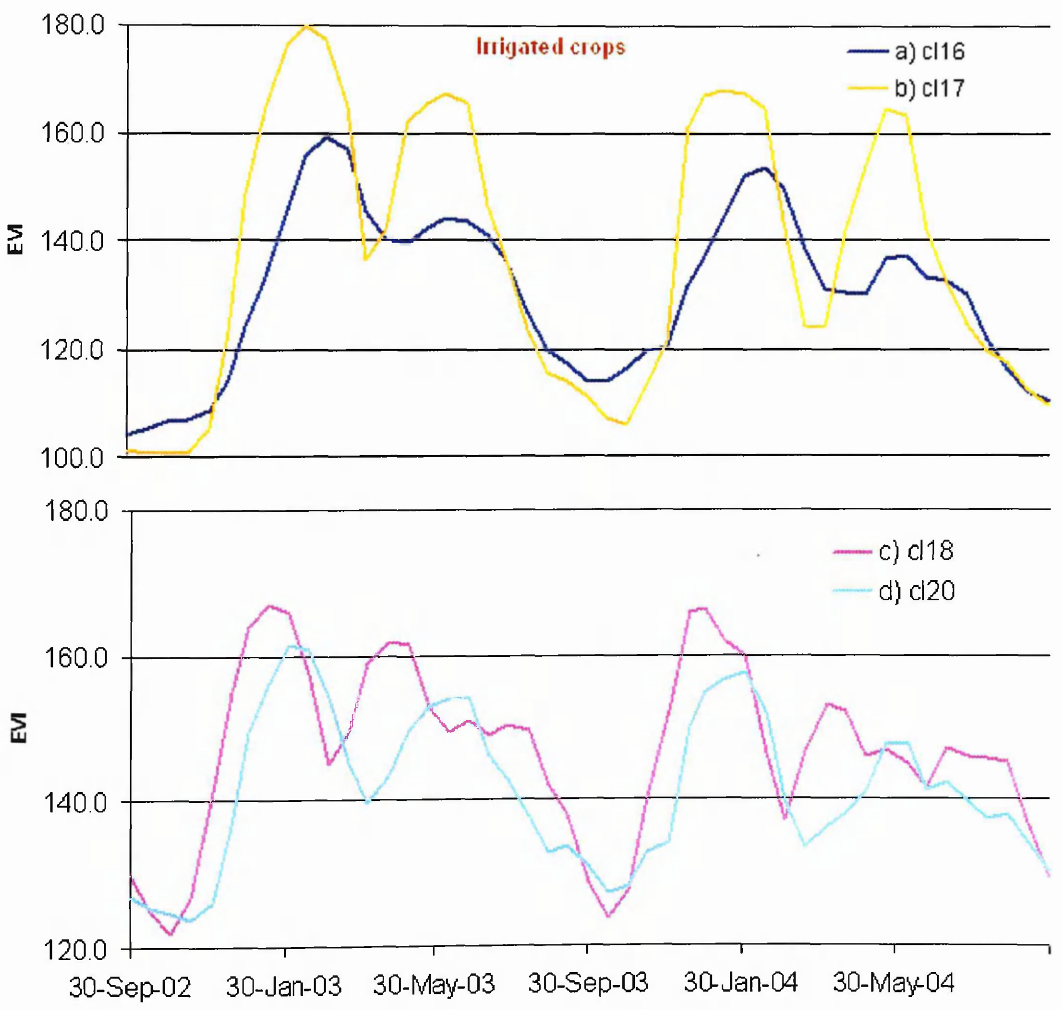


Figure 6.22 Seasonal patterns in irrigated agro-ecosystems

The four clusters therefore represent a highly negative correlation with rain-fed agro-ecosystems, which is expressed in a large correlation coefficient distance (Figure 6.19) between the two groups. Analogous to the results obtained from the AVHRR monthly NDVI composites in paragraph 6.1.5 the similarity amongst groups of irrigated agro-ecosystems is considerably less than that amongst rain-fed systems (Figure 6.19).

6.1.8 Floodplain- and aquatic ecosystems

When inundated, floodplain and lowland areas link to riparian and lacustrine aquatic ecosystems, and become part of the expanding wet season aquatic ecosystems in the lower Mekong, Tonle Sap and Mekong-Bassac areas of the basin (Figure 6.23).

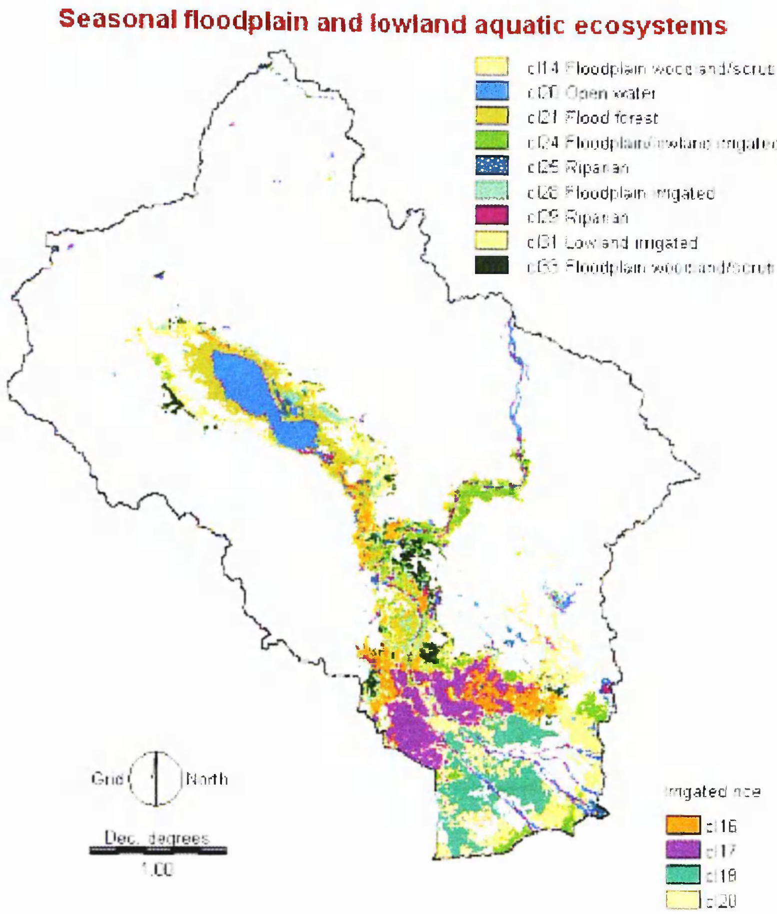


Figure 6.23 Lacustrine, riparian and seasonal aquatic ecosystems

Apart from irrigated and wet season rice, such systems host a range of other land cover classes, such as flood forest and scrub areas that are important nursing grounds for wild fish, and are essential to aquatic resources production. Seasonally flooded systems can be distinguished by the characteristic dip in VI coinciding with the wet season flood event (Figure 6.24 a), whereas seasonality is characterised by higher VI values during the rainy season in systems which never flood (Figure 6.24 b). VI values in tropical evergreen forest areas appear to fluctuate erratically (Figure 6.24 c), which makes seasonality difficult to discern in these systems.

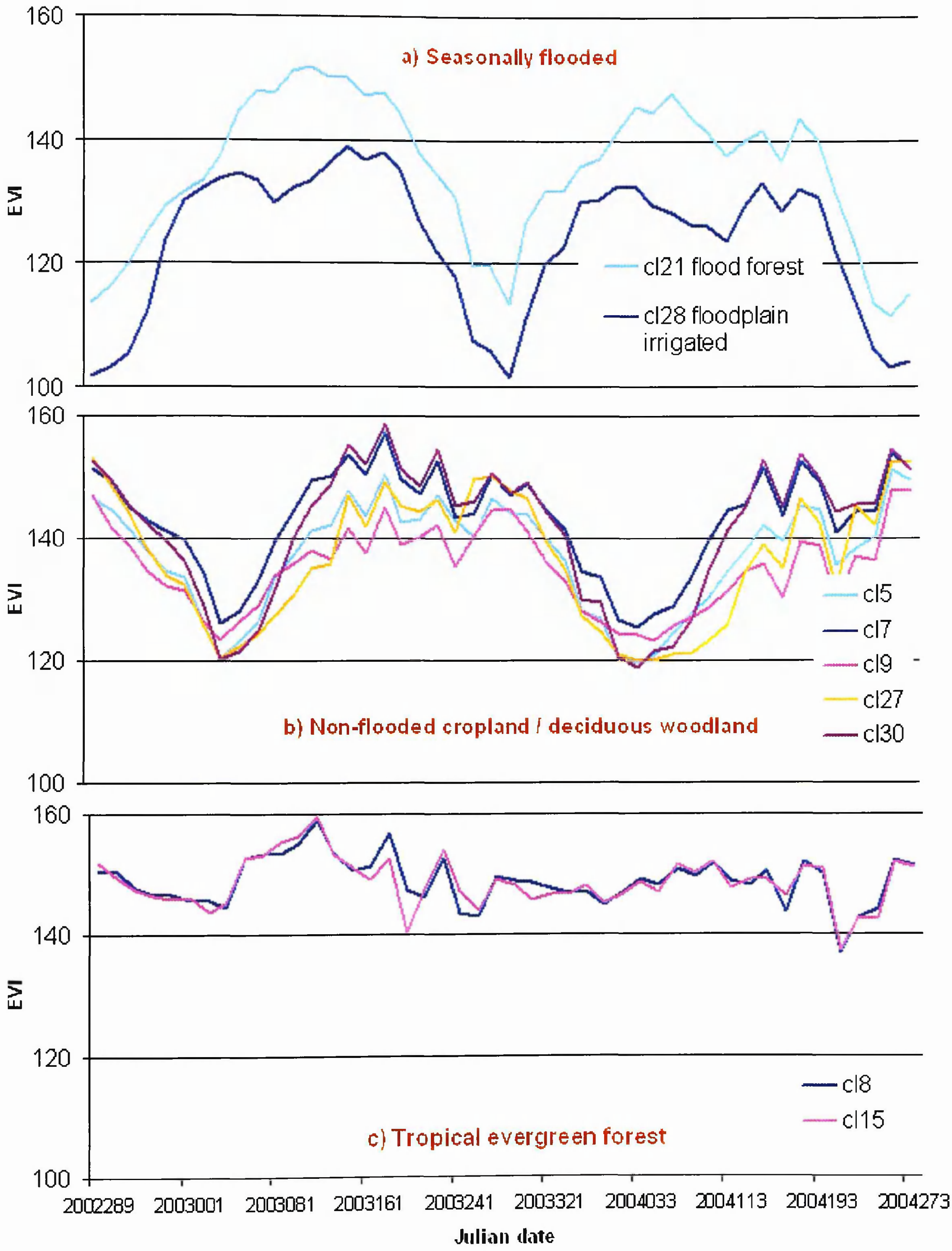


Figure 6.24 **Seasonal VI patterns in distinctive flooded and non-flooded systems**

6.1.9 Agro-ecosystems classification summary

A combination of principal components analysis and VI time series analysis can reveal distinct seasonal vegetation patterns and offers an effective methodology for classification of seasonal agro-ecosystems. The components that explain most of the temporal and spatial variation in VI were used as input in a cluster analysis. An analysis of seasonal variations in VI reveals which clusters represent clearly distinctive seasonal patterns that are characteristic for rain fed and irrigated agro-ecosystems. A plot of the range of land cover classes on a correlation coefficient distance axis groups rain-fed agro-ecosystems at one extreme of the spectrum and seasonally flooded agro-systems at the opposite extreme, thus emphasising the highly negative correlation between these systems (Figure 6.19). Non-flooded mixed cropland and woodland systems that nevertheless exhibit distinct seasonality, as well as deciduous forest systems, are positively correlated with seasonality in rain-fed agro-ecosystems. Tropical evergreen forests are uncorrelated with either rain-fed or seasonally flooded systems, due to the erratic seasonal VI pattern. Seasonally flooded forest and scrubland systems and mixed systems prone to flooding exhibit positive correlation with seasonally flooded lowland and floodplain agro-ecosystems. Cluster classification on the basis of similarity reveals that temporarily flooded systems represent greater dissimilarity amongst those systems.

6.2 Agro-ecosystems seasonality and aquatic resource use

6.2.1 Satellite derived seasonality and field verification

The developed land cover classification and agro-ecosystems seasonality indicator is effective in detecting rain-fed systems, and can therefore be used as a tool to target pond-based aquatic resources development at areas that are seasonally drought prone. It is also capable of detecting seasonal aquatic ecosystems, as well as more permanent water bodies that are important for fisheries and other forms of aquatic resource exploitation, which may interact with the local needs and opportunities for aquaculture. The methodology was repeated at the higher resolution of 500 m, which led to a significant gain in detail and allowed to study the agro-ecosystems dynamics at a more local level for specific target areas. Cluster analysis at 500 m resolution yielded 74 clusters over the study area. A four year cycle of average 16-day vegetation greenness (EVI) was calculated for clusters with largest coverage over the target provinces in Southeast Cambodia and Sisaket province in Northeast Thailand, and those locally covering the visited sites.

The agro-ecosystems were classified on the basis of information about local resource use obtained from ground truth visits and secondary data, in combination with Landsat ETM+ imagery covering the field visit area (Figure 6.25) for specific dates within the four-year period. The Landsat image acquisition dates as well as the dates of field visits were plotted on the EVI graph for each cluster in order to compare field observations and Landsat image information against seasonality in the locally prevailing agro-ecosystems and resultant temporal variations in aquatic resource use. Additional data about the local likelihood and depth, extent and season of flooding were obtained from GIS data (courtesy MRC) and USGS Shuttle Radar Topography Mission (SRTM) elevation data at 3 Arc Second (approximately 90 m) resolution.

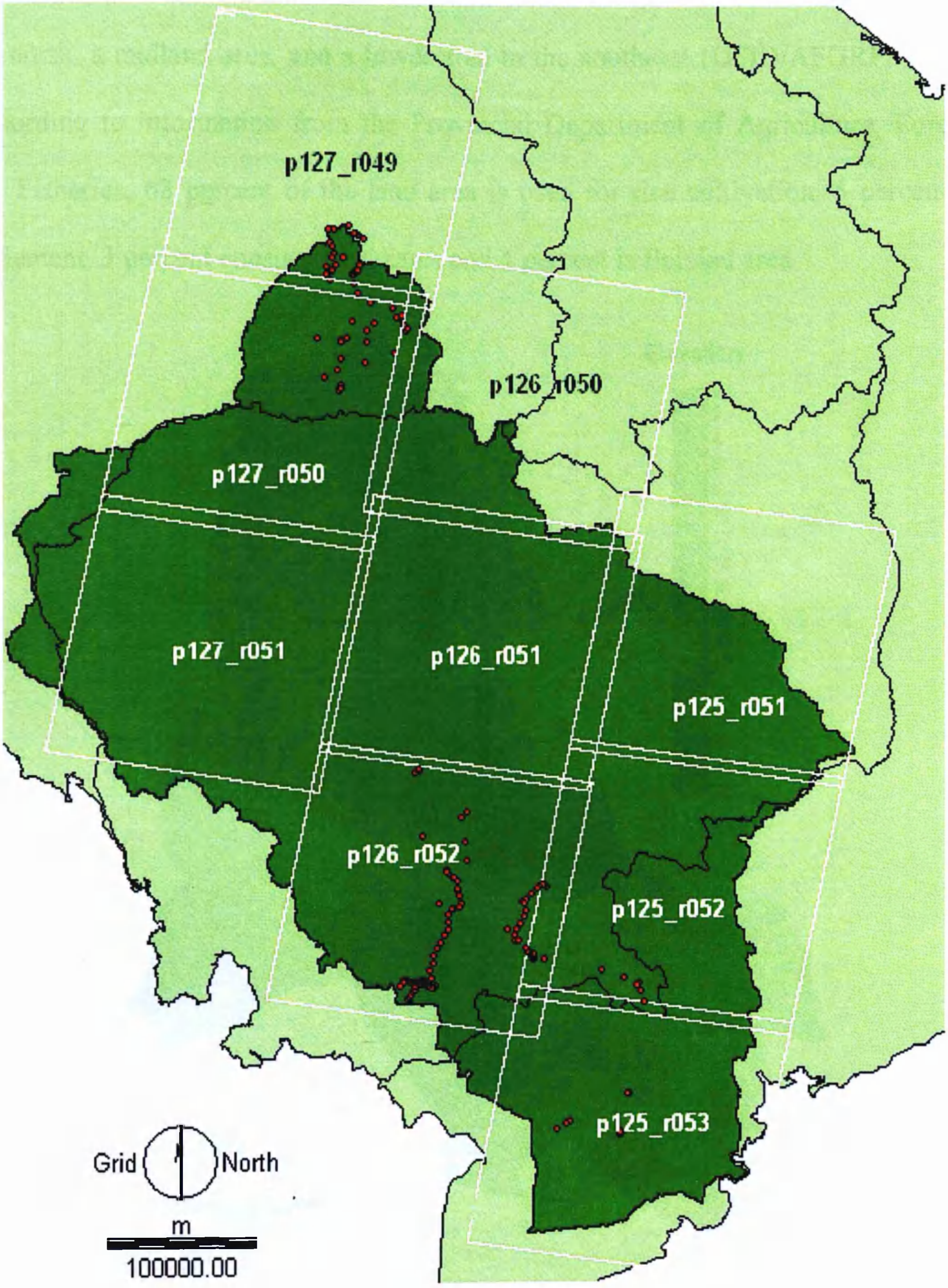


Figure 6.25 Landsat TM and Landsat ETM+ scene coverage (white) of the target area (dark green), and geographic positions of visited sites, taken by GPS (red dots)

6.2.2 Seasonality and aquatic resources in Svay Rieng, Cambodia

Svay Rieng province (Figure 6.26) is topographically characterised by a higher area in the north, a midland area, and a lower area in the southeast (DFID/AFGRP, 2002c). According to information from the Provincial Department of Agriculture, Forestry and Fisheries, 68 percent of the land area is used for rice cultivation, 5 percent for settlement, 3 percent consists of streams and 4 percent is flooded area.

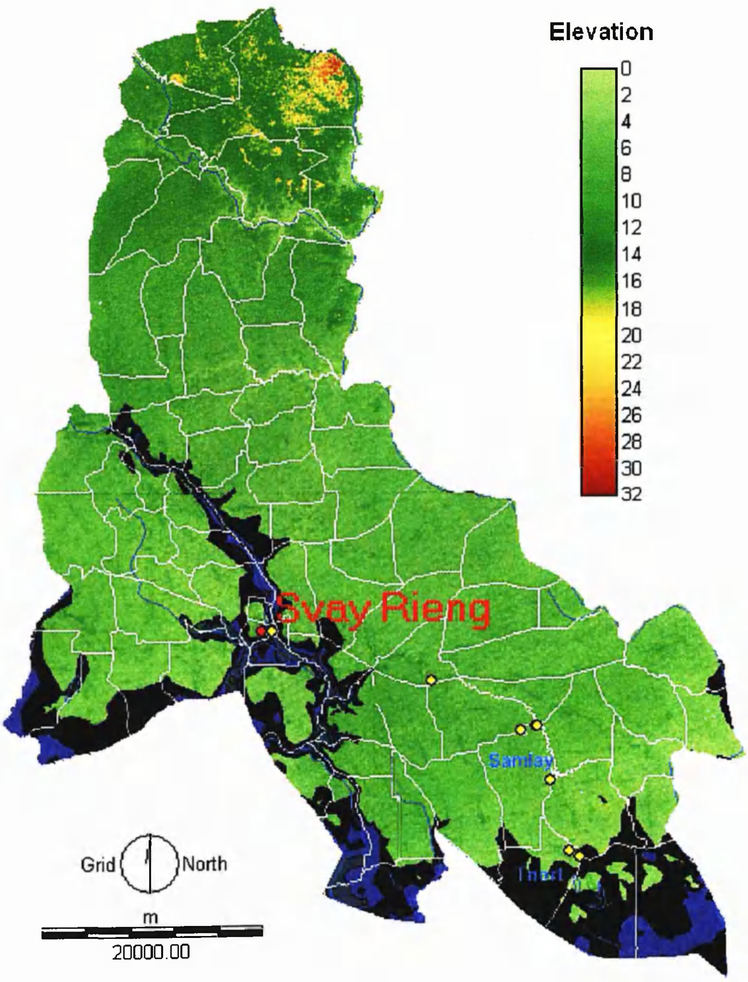


Figure 6.26 Topographic map and flood extent during a major flood event, Svay Rieng province, Southeast Cambodia. Source of DEM; SRTM (elevation in meters). Flood polygons (dark blue / black); MRC. GPS waypoints of February 2003 field visit indicated in yellow.

From the analysis of seasonal land cover over the province, the higher area appears to be characterised by a mixture of clusters, whereas the midland area is strongly dominated by one cluster, no. 60. A mixture of clusters is also found for lower lying areas in the south, with cluster 40 dominating in the south-central part of the province and cluster 74 dominating in the south eastern part. Areas bordering Vietnam in the south are dominated by clusters 8, 16 and 43 (Figure 6.27).

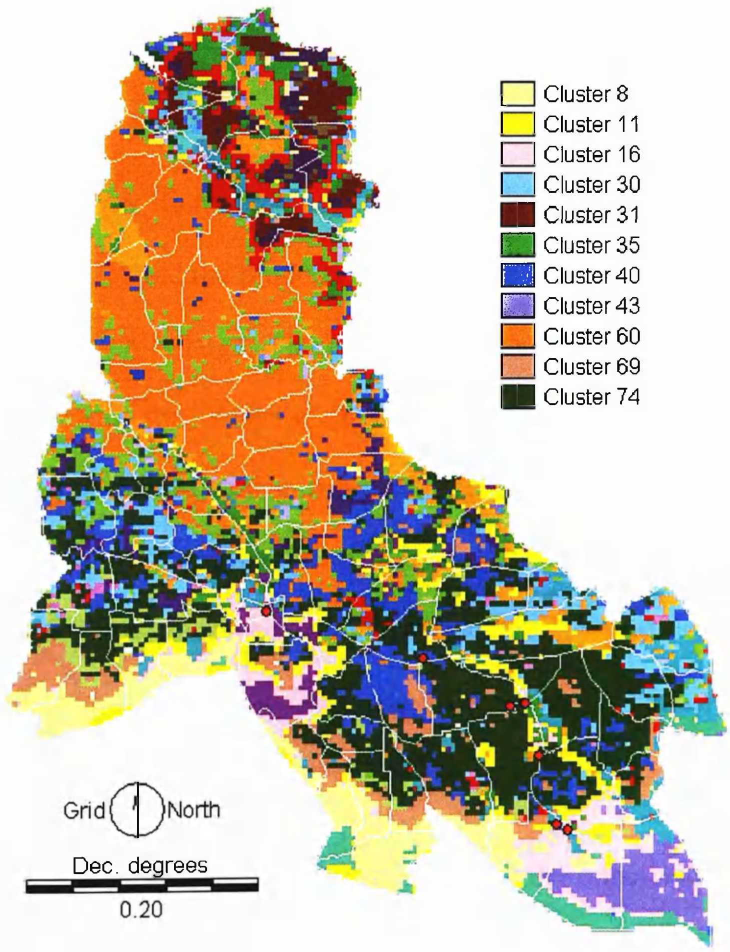


Figure 6.27 Seasonal land cover clusters for Svay Rieng province, derived from MODIS Enhanced Vegetation Index (EVI) composites, 500 m resolution

Clusters 40 and 74 exhibit seasonal variations in EVI which are indicative of single crop rain-fed agro-ecosystems. EVI values gradually increase during the wet monsoon season, roughly from the end of July, till they reach a peak value around the beginning of November. After that period, when the main rice harvest begins, EVI values start to fall, reaching minimum values at the end of January during the dry season. EVI values start to rise again late April at the end of the dry season and reach a second but lower peak around June in the years 2000 and 2004 which might be indicative for an early onset of rains in those years, and the planting of an early wet season rice crop. Clusters 8 and 16 are representative for irrigated agro-ecosystems, with low EVI values being indicative for flooded conditions in mid September.

The soil quality in Svay Rieng province is reported to be poor (Tana, 1993), cited in (DFID/AFGRP, 2002c) and the production level of rice is low, although the total land area for rice production is large. The province is characterised by little variation in rural livelihoods, with the majority of its residents depending primarily on rice production. There is an increasing trend of migration to the capital, particularly among younger people. Three sources of income can be classified in the province. Ninety percent of the income comes from agricultural production, 7 percent from general services and 3 percent of the income comes from industry and handicraft (DFID/AFGRP, 2002c).

Water resources in the province are abundant during the rainy season but perennial water bodies are scarce in some parts (Gregory & Guttman, 2002). The aquatic systems in the province serve multiple purposes for the farmers. Water is used for crops, livestock, aquatic resource exploitation and domestic purposes. Capture fisheries resources are no longer meeting the provincial demand, although this is challenged by a study of (Guttman & Kunty, 1997) which suggests the province is a "net exporter" of fish. Areas with different aquatic resource availability in terms of rice field fish supply have been classified by AOP as fish deficit areas, fish surplus areas and intermediate areas. Fish deficit areas have few natural water resources, few and small ponds, typically less than 100 m^2, soils with poor water retention properties and a tendency to cause acute pond turbidity, and few nutrient rich on-farm by-products which could be used as pond inputs. In such fish deficit areas farmers had the greatest need for fish and therefore these areas were considered as having a greater priority for small scale aquaculture development although they did not appear to have much potential for aquaculture at first sight.

In Svay Rieng province, Kampong Ro district was visited during the dry season, in February 2003 (Figure 6.28). Kampong Ro district is a lowland area dominated by rice farming systems. Rice cultivation is the main source of income, followed by livestock. Vegetable cultivation and mat weaving also contribute to the agricultural income. The district is considered as medium rich in aquatic resources, particularly ricefield fish stocks. This influences small scale fish culture as ricefield fish species often offer a readily available alternative to cultured fish (Bunra & Gregory, 1995). Ricefield fish is used mainly for local consumption. Larger fish such as snakehead, catfish and climbing perch dominate the district market and command a higher price (Guttman & Kunty, 1997). Bunra and Gregory's study suggests that the development potential of small scale aquaculture in Kampong Ro and similar lowland areas strongly depends on the seasonal abundance of ricefield fish stocks. The study was based on zonation of trap pond production by grouping trap pond fish harvest data according to low, medium and high trap pond production. Areas of high trap pond production were generally low lying areas below the 4 m contour, which were more productive than areas at a higher elevation. This suggested a relationship between wild fish production from trap ponds and land topography, which was expected as fish would tend to follow the receding flood waters at the end of the rainy season (Bunra & Gregory, 1995).

Within Kampong Ro district two villages were visited as part of the current study, Thom village in Tnort commune (Figure 6.28, waypoints 19, 20 and 21), and Svay Cheak village in Samlay commune (Figure 6.28, waypoints 22 till 25). Both communes are situated in low lying areas. Svay Cheak village is situated close to the river, and experiences flooding every year. The river expands during the rainy season, and forms a floodplain lake (Morales, pers. comm.). A comparison of Landsat ETM+ satellite imagery from different seasons, one dating from 15 April 2001 at the end of the dry season (Figure 6.28) and one from 6 November 2000 at the end of the flood season (Figure 6.29) confirms this observation. Wild aquatic animals play an important role in the area. In Samlay commune, an estimated 30 percent of the population counts fisheries as their main source of income.

The floodplain lake is an important source for aquatic animals, especially during the dry season, when most of the smaller water bodies dry out. Aquatic animals are collected from canals and ricefields during the rainy season, in order to be stocked in household ponds and ditches (DFID/AFGRP, 2002c). They provide income and at the same time contribute to food security. In Thom village nearly all households have trap ponds, which are located in the floodplain lake area, rice fields and near the homestead. Common culture fish include catfish, pangasius and tilapia. Fish culture is practiced mainly for home consumption. In Thom village 11 households culture pangasius. The fingerlings are imported from Vietnam. The fish are fed with duckweed and rice bran, sometimes supplemented by termites.

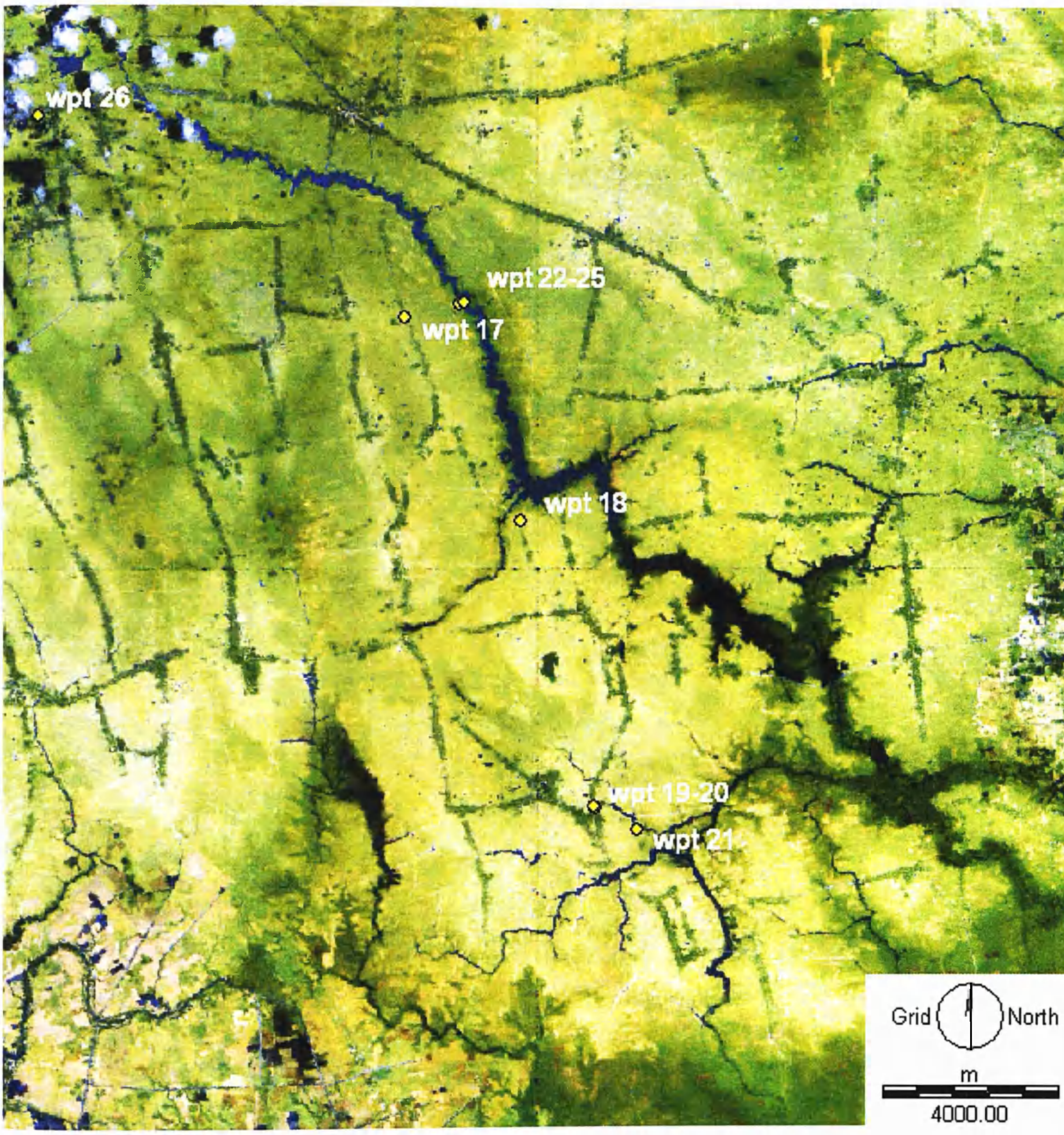


Figure 6.28 Landsat ETM+ composite image (band 7 red, band 5 green, band 2 blue) with projected GPS waypoints (wpt) taken for ground truthing, Svay Rieng province (image date 15 April 2001, ground truthing dates 17-18 February 2003). Waypoints 19, 20 and 21 Tnort commune, waypoints 22 till 25 Samlay commune.

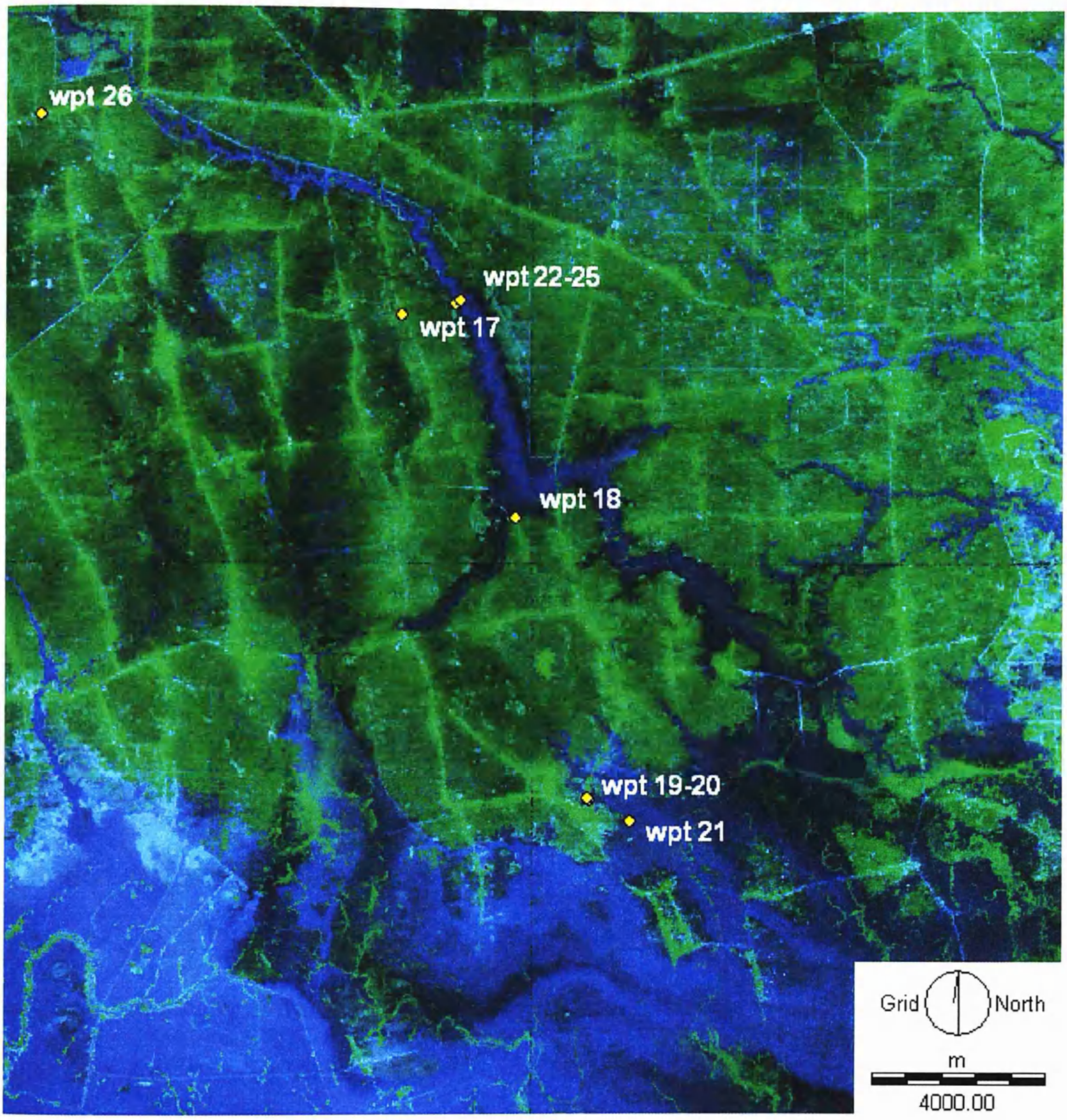


Figure 6.29 Landsat ETM+ sub-scene of Samlay and Tnort commune (waypoints 19, 20 and 21) at the end of the flood season (flooded areas in blue), image date 06 November 2000 (false colour image: band 7 red, band 5 green, band 2 blue)

Agricultural production is generally not sufficient to meet food demand in the area. During the dry season the lake provides water for irrigation in Thom village (DFID/AFGRP, 2002d), but Svay Cheak village is drought prone, even though being one of the lower areas of the district in terms of topography. During the rainy season food supplies are regularly hampered due to flooding. Transient food insecurity is a common and recurrent phenomenon amongst the poorer households in both villages, and is experienced for up to four months prior to rice harvest when stocks of food have run out. One coping strategy mentioned by the village chief of Thom village is the collection of rice discards, remaining after harvest in Vietnam. This activity typically provides a household with an additional 200 kg of rice.

Figure 6.30 and Figure 6.31 depict the rice-based agro-ecosystems seasonality typical for the study area over a four year cycle from April 2000 till April 2004. In the Samlay commune area, dominated by cluster 74, vegetation index (EVI) values are low throughout the dry season, indicating the absence of a dry season crop, and start to increase only around April – May at the start of rice cultivation. The rather irregular VI trend from June till the end of September probably is explained by flooding. EVI values peak as floods recede after September, before the flood recession rice crop is harvested over subsequent months. The date of the field visit to the study area, 17 February 2003, is plotted on the EVI graph in Figure 6.30, and the low EVI is indicative for the fallow conditions encountered during the visit. The Tnort commune area close to Vietnam is dominated by clusters 8 and 16, but Thom village appears to be located somewhere between these areas and cluster 27 (Figure 6.32). The seasonality of this cluster reflects a bimodal distribution that is indicative for a dry season crop and a flood recession crop. Some plots of dry season rice were observed in Thom village, where a canal from the floodplain lake area connects to the rice field and provides water for supplementary irrigation during the dry season.

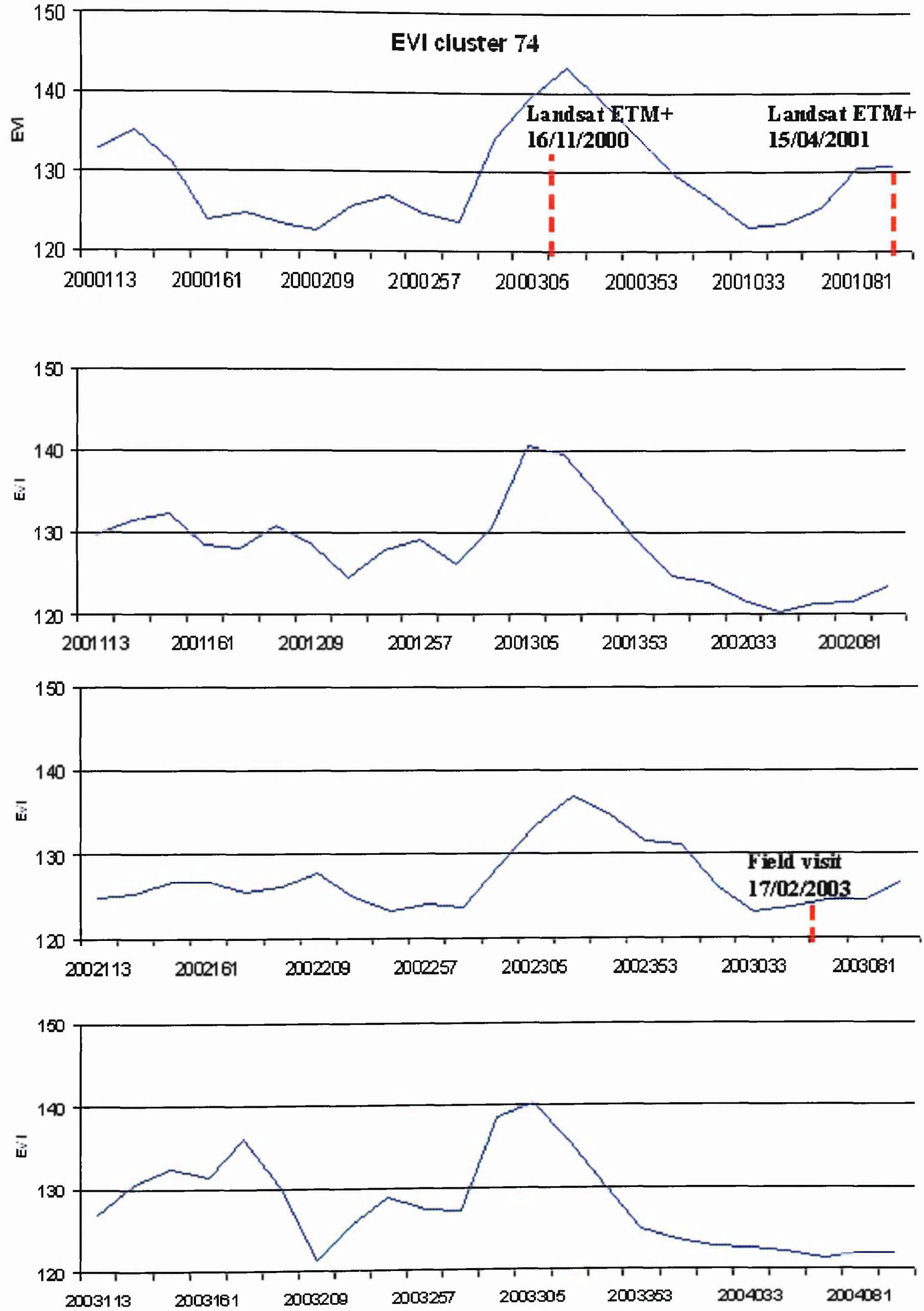


Figure 6.30 Agro-ecosystem seasonality predominant in the Samlay target area (x-axis: Julian date, y-axis: 16-day average EVI)

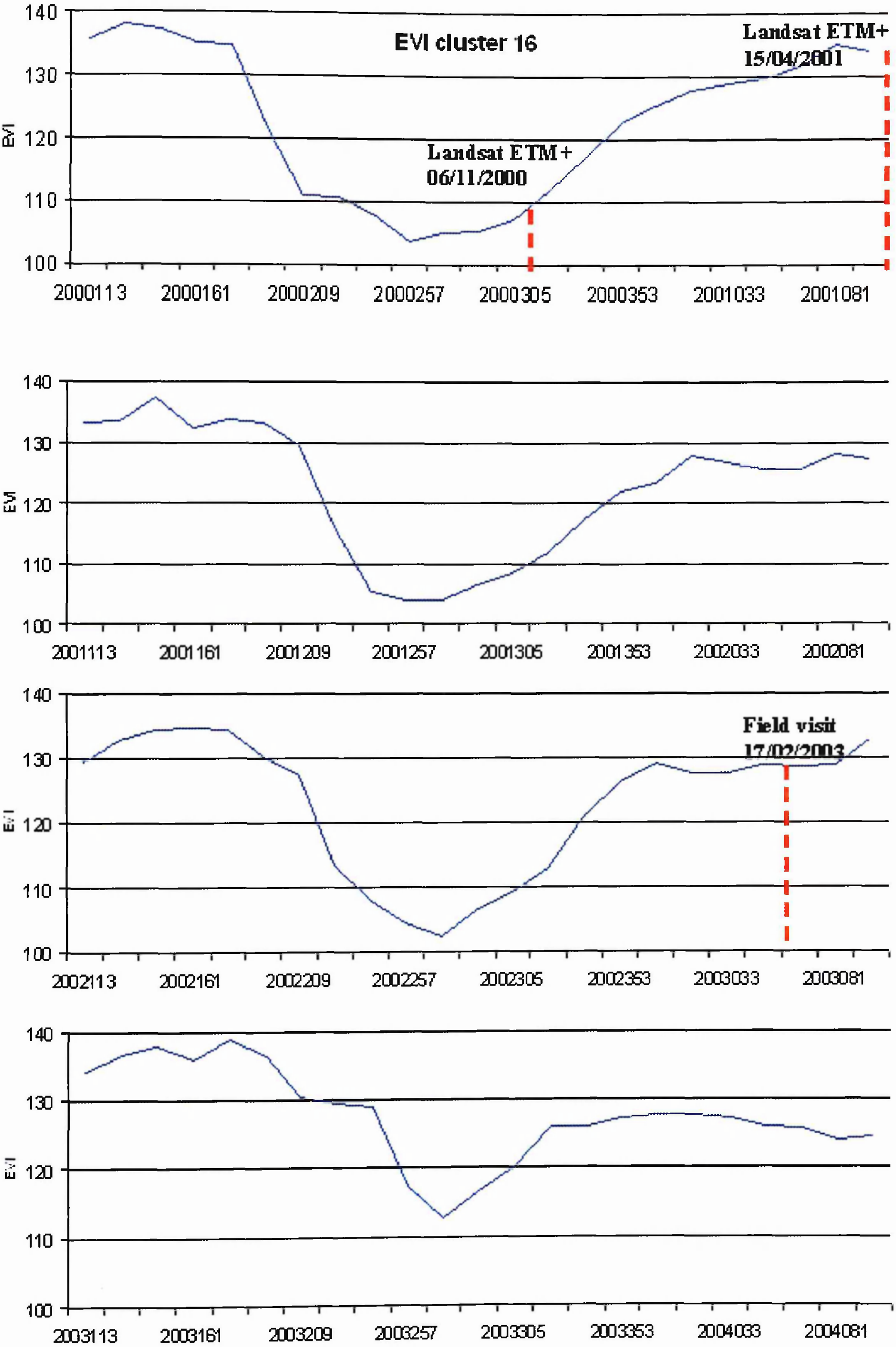


Figure 6.31 **Agro-ecosystem seasonality predominant in Tnort commune (x-axis: Julian date, y-axis: 16-day average EVI)**

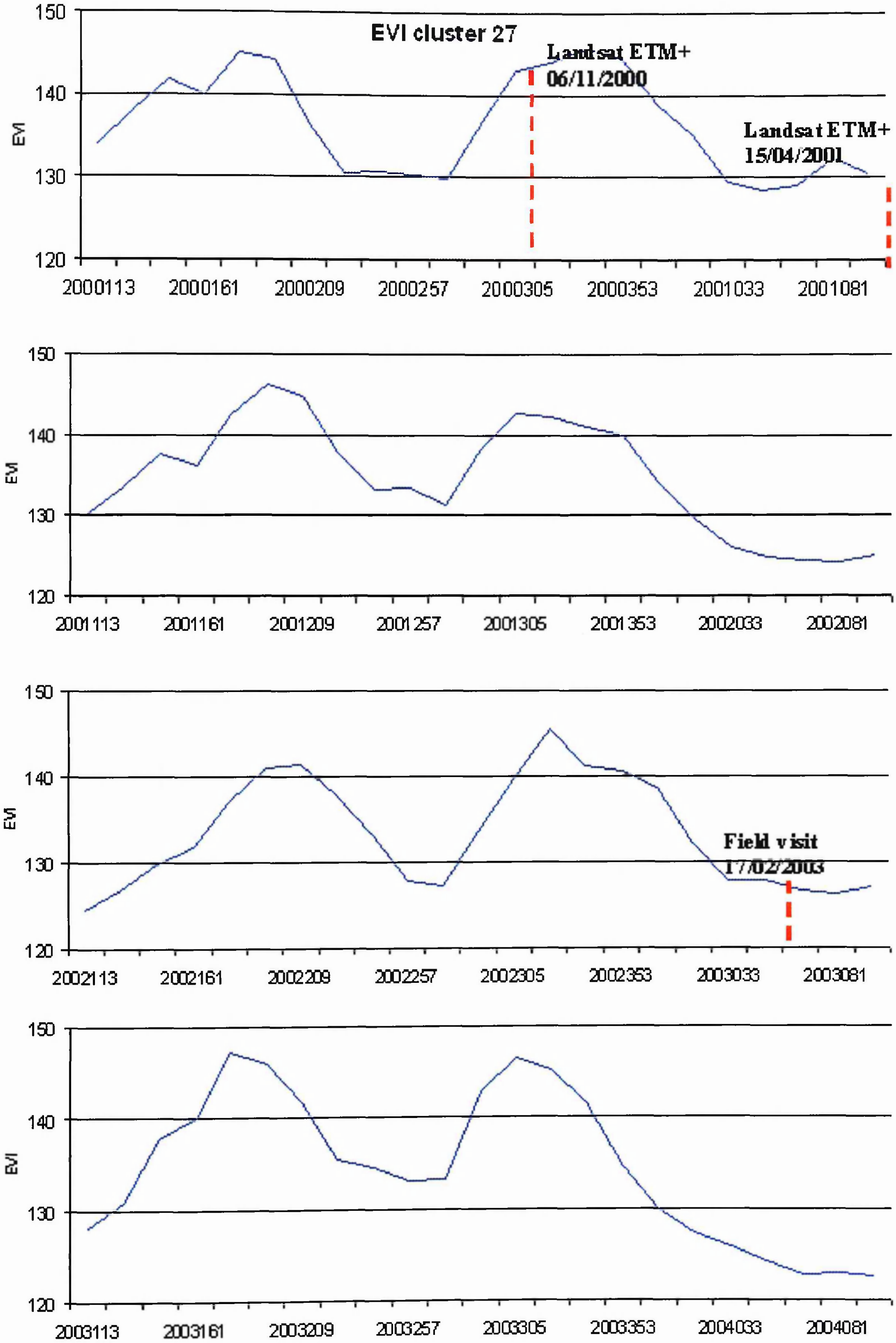


Figure 6.32 Agro-ecosystem seasonality typical for the zone around Thom village, Tnort commune (x-axis: Julian date, y-axis: 16-day average EVI)

The two villages offer a clear example of locally varying agricultural conditions even though the geography and resource base are apparently similar. In both villages livelihoods are predominantly depending on rice based agriculture, vegetable cropping, livestock and fishing, supplemented by seasonal activities. Results from the PRA workshop held in 2001 suggest that Thom village, although situated in a poorer commune (MoP & WFP, 2002), enjoys slightly better agricultural conditions. A dry season rice crop can be grown with supplementary irrigation, whereas drought conditions do not permit this in Svay Cheak. This observation is supported by ground truth data of the field visit and by the results of agro-ecosystems seasonality analysis for the area, based on MODIS VI imagery. Wild aquatic animals are important for household food security and to a lesser extent income in both villages, and fishing activities vary seasonally according to availability and location of aquatic animals. Fishing is considered as an important activity by all socio-economic groups. Aquaculture was only mentioned by the better-off and only in Svay Cheak village (DFID/AFGRP, 2002c).

6.2.3 Seasonality and aquatic resources in Takeo, Cambodia

The topography in Takeo province is characterised by higher elevations in the west (Figure 6.33 a), where the Elephant Mountains rise. The eastern part of the province, particularly the southeast, and some low lying areas in the centre of the province are susceptible to flooding (Figure 6.33 b).

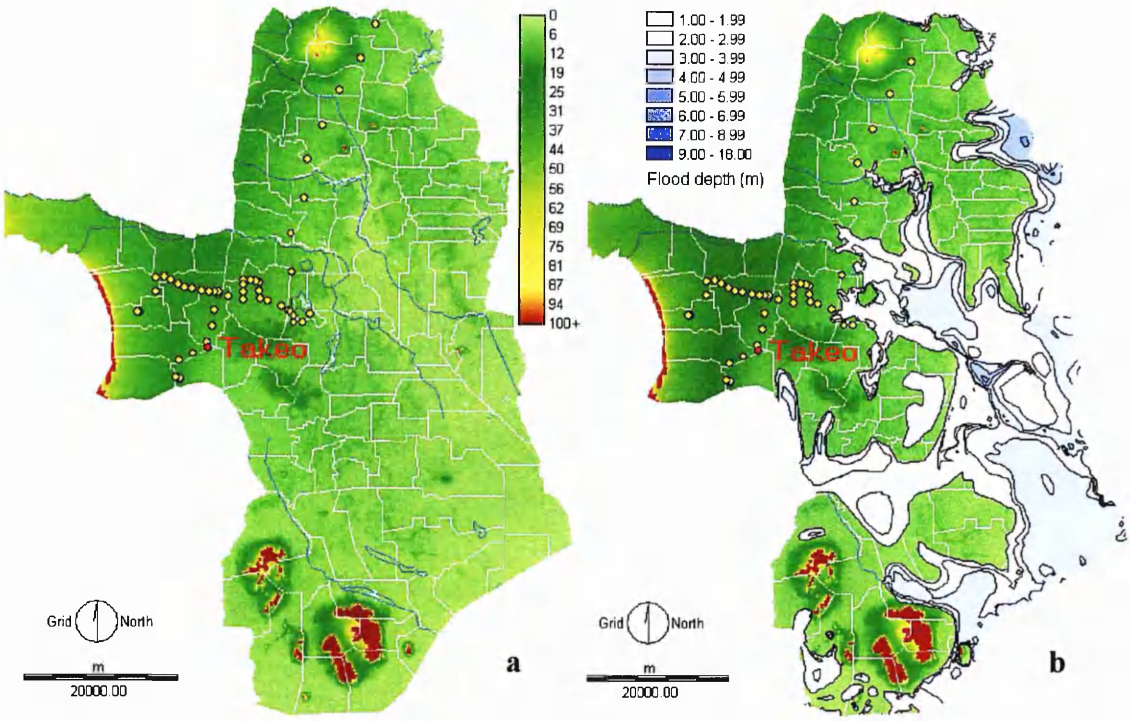


Figure 6.33 a) Topographic map and b) flood extent during a major flood event, Takeo province, southern Cambodia (Source of DEM: SRTM, elevation in meters. Flood polygons: MRC. GPS waypoints of November 2003 field visit indicated in yellow)

The upland and lowland areas are clearly distinguishable in the seasonal land cover classification, with cluster 13 dominating the lowland area susceptible to deep flooding, clusters 8 and 11 dominating the area susceptible to shallow flooding and clusters 30 and 40 dominating the upland area (Figure 6.34). The latter clusters represent single rain fed wet season crop conditions in the upland areas they cover (Figure 6.35), which are similar to the patterns described for clusters 40 and 74 in lowlands in Svay Rieng.

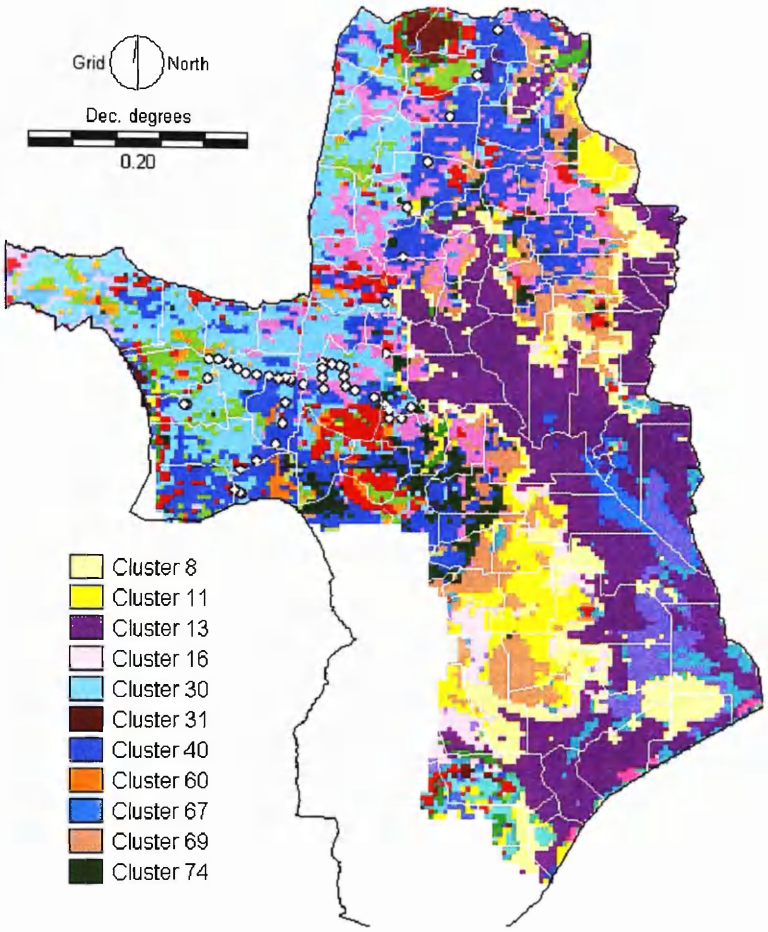


Figure 6.34 Seasonal landcover clusters for Takeo province, derived from MODIS Enhanced Vegetation Index (EVI) composites, 500 m resolution

At the end of November 2003 Tramkok district, located in the west of the province, was visited. The district, an upland area with sandy soil, is relatively poor in water resources, and aquatic resource abundance is reportedly declining (DFID/AFGRP, 2002b). The pattern of rainfall in the area is irregular and varies from year to year. The district counts two principal water bodies and a reservoir. Agriculture in the area is predominantly rainfed. Coconut and rice are the main agriculture crops. Other commonly produced crops in the district are watermelon, eggplant and cucumber.

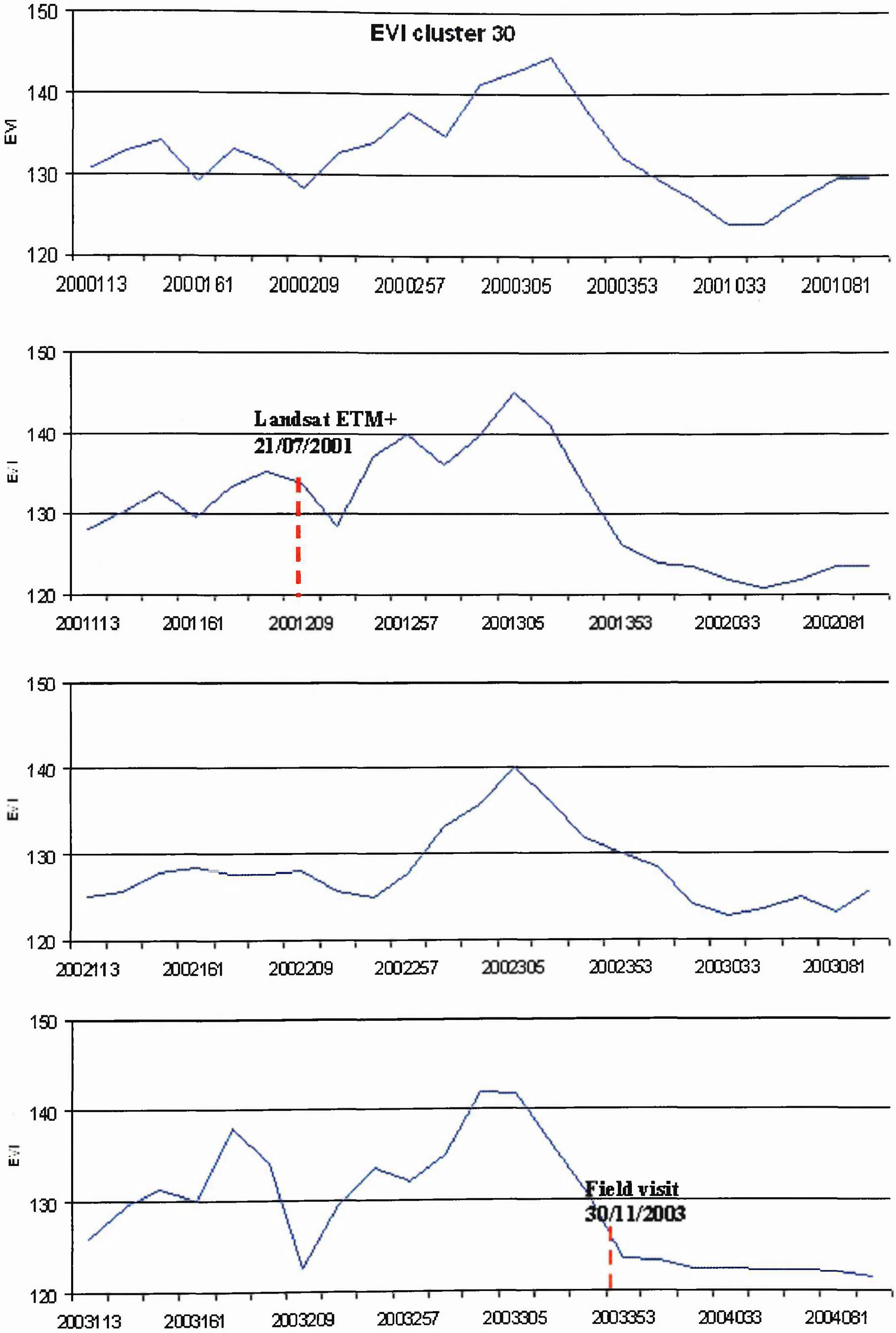


Figure 6.35 Agro-ecosystem seasonality predominant in Tramkok district, Takeo province (x-axis: Julian date, y-axis: 16-day average EVI)

Two villages included in the SRS project, Prey Tadoc village in Samraong commune and Ang Tasom village in Nheng Nhang commune respectively, were visited (Figure 6.36) as well as a rural settlement in Kus commune.

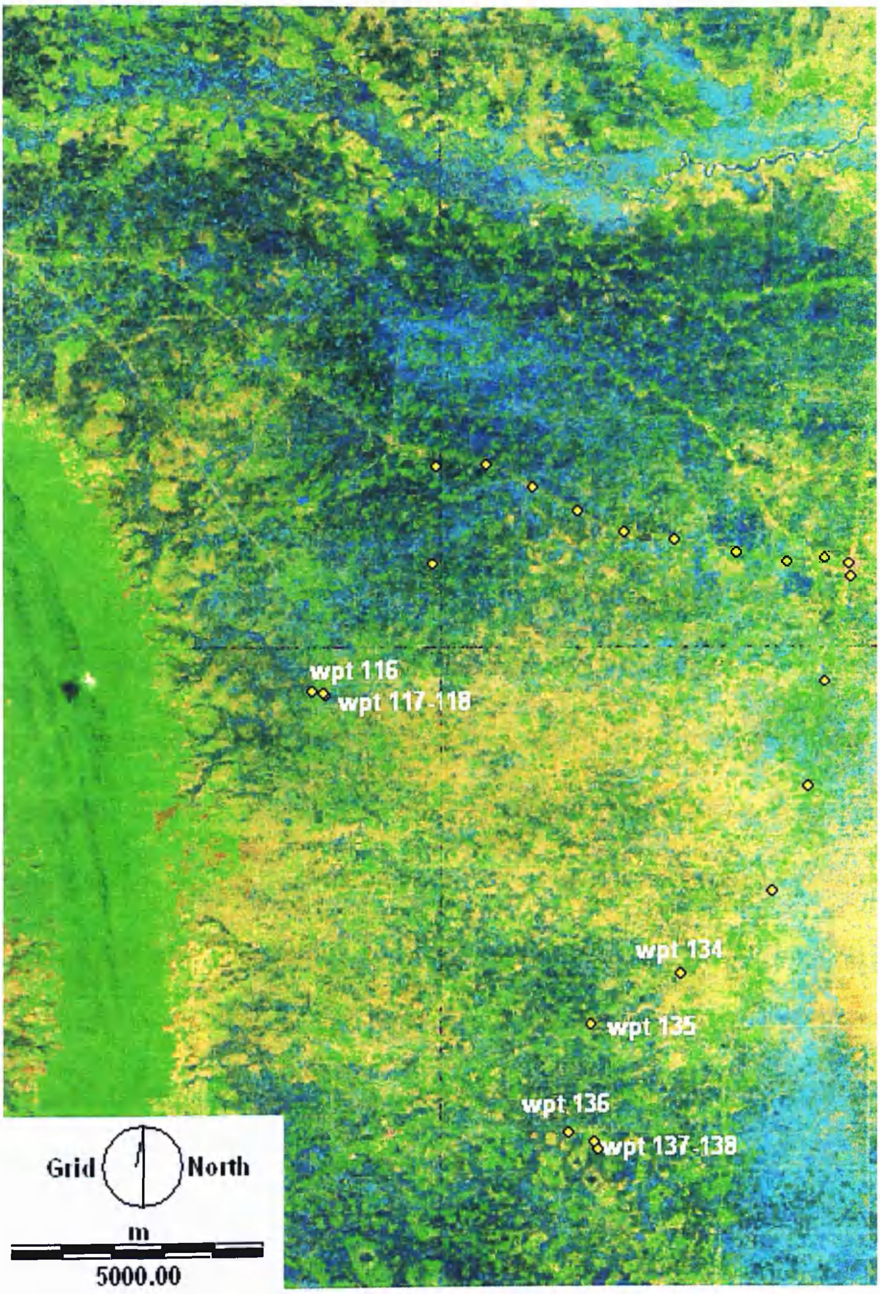


Figure 6.36 Landsat ETM+ composite image (band 7 red, band 4 green, band 2 blue) with projected GPS waypoints (wpt) taken for ground truthing, Takeo province (image date 11 July 2001, ground truthing dates 29-30 November 2003). Wpt 116 – 118: Prey Tadoc, wpt 134 -135: Kus, wpt 136 – 138: Ang Tasom

Kus had not been selected as an SRS project site after a preliminary PRA was undertaken. Prey Tadoc is a representative village in the drier upland area of the district. Agricultural production consists of rice and upland crops such as watermelon and cassava. Soil conditions are suitable for banana and coconut, which are cultivated near the homestead. Livestock is an important source of household income. Other income sources are wage labour, collection of wood and forest products in the nearby mountains and handicraft. Small household ponds, excavated in order to create a levee for settlement, are commonly found near the homestead. A community pond provides drinking- and household water, as well as water for livestock. Two ring wells and 3 private pump wells are available in the community. Ang Prey Tadok reservoir, is the only source of water for the village in the dry season. The reservoir is a source of broodstock and the community plans to create a broodstock pond cum dry season fish refuge in the reservoir, by fencing off an area with tree branches. The reservoir is the only source of aquatic animals in the dry season, during which the area experiences a shortage of fish. The limited availability of aquatic resources in Prey Tadoc may explain why fishing was not ranked as very important. Collection of available aquatic resources nevertheless contributes to local food supply. The decreasing trend of aquatic resource availability in the area has been contributed to increased human population and therefore increased but unmanaged fishing activity (DFID/AFGRP, 2002b; Khong Sophoan personal communication).

Ang Tasom is representative for the lower upland area of the district. Water resources are more abundant than in Prey Tadoc village. The main water supply comes from a large canal. Other community water resources are a reservoir and four community ponds. Privately owned water resources include trap ponds and ditches, but in contrast to Prey Tadoc village few households have a pond near the homestead. Ponds, including the community ponds, tend to dry up during the dry season. Five households were reported to culture fish. Fishing was mentioned among the four most important economic activities in the village and, unlike other target villages, value was ranked high as a criterion (DFID/AFGRP, 2002a). Agriculture, mainly single crop paddy, is the principal source of income. Other crops include mungbean, water melon, and cucumber. Livestock is also an important source of income with the importance of pigs mentioned to be on the increase. Other sources of income are handicraft and wage labour, either locally within the commune or in Phnom Penh.

Poverty in the two villages bears characteristics such as little or no land ownership, transient food insecurity before the start of the harvesting season and high debt burdens, which are similar to those in other Cambodian communities. Very poor households in Ang Tasom were reported to have only enough food for six months of the year and even households in the middle income group experience food security problems for at least three months (DFID/AFGRP, 2002a)

6.2.4 Seasonality and aquatic resources in Prey Veng, Cambodia

Prey Veng province occupies 2.6 percent of Cambodia's land surface area, but accounts for 12.5 percent of the country's rice growing area. Agriculture is by far the main source of income. Only 15 percent of the household income comes from non-agricultural sources. Farming systems are characterised by both wet and dry season rice production. The province lies on the eastern side of the Mekong floodplain and its flat topography makes the area highly vulnerable to flooding (Figure 6.37), with more than 80 percent of the province being inundated in 2000 and 2001. The annual flood cycle is a very important aspect of agricultural production but can also pose serious risks. It affects water purity and sanitation, increases health risks to people and livestock and destroys crops and housing (CARE International, 2002).

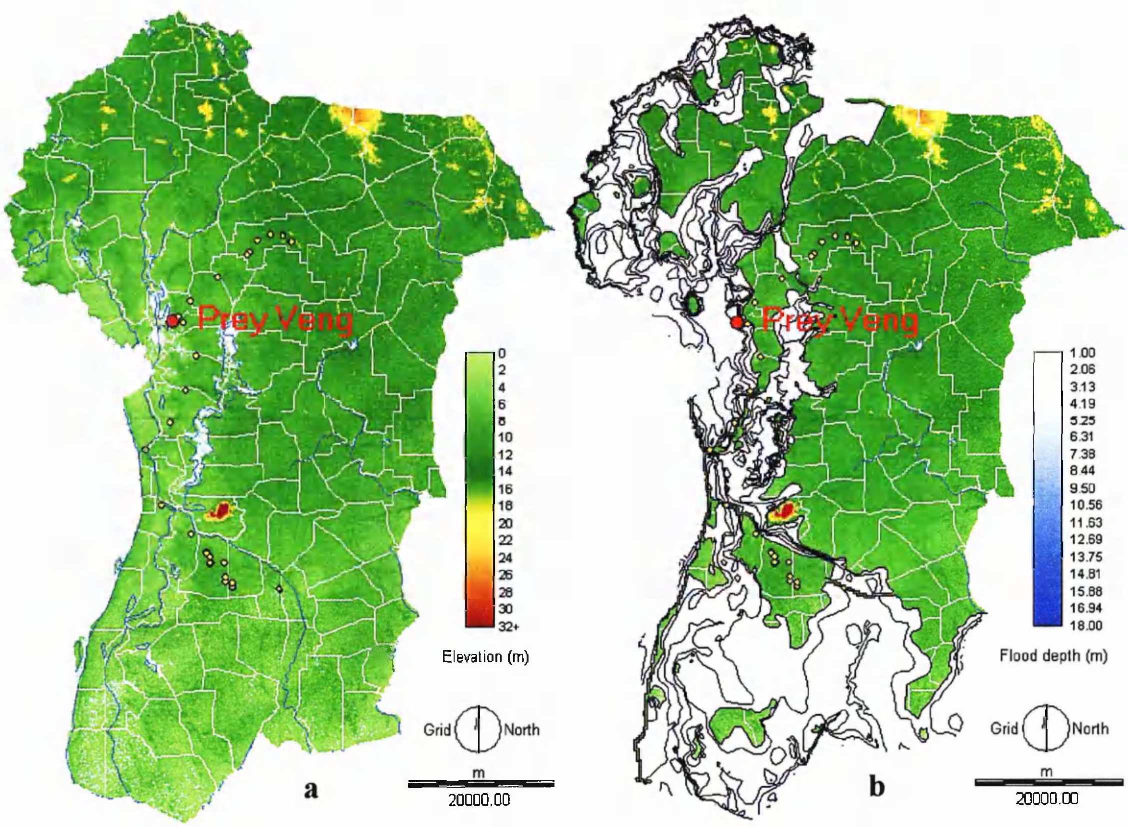


Figure 6.37 a) Topographic map and b) flood extent during a major flood event, Prey Veng province, Southeast Cambodia (Source of DEM: SRTM, elevation in meters. Flood polygons: MRC. GPS waypoints of November 2003 field visit indicated in yellow)

Large areas of Prey Veng province were particularly badly affected by the September 2000 flood, one of the worst in recent history, leaving a death toll of 347 people and killing thousands of livestock. The floods caused large scale destruction of infrastructure, property and crops, especially the wet season rice crop. Production earlier in the season was initially affected by drought, which prevented early planting of rice. The first wave of floods in late July damaged the dry season crop that was almost ripe for harvesting (FAO, 2000; CARE International, 2001). This affected a large number of people who already were on the borderline of subsistence and transient food insecurity and who had to resort to risky and unsustainable coping strategies in order to overcome household food shortages. A successive extreme flood took place in 2001, followed by another drought in 2002.

A risk mitigation and disaster management project, implemented by CARE International, provides ample evidence of the impacts of major floods on rural livelihoods but also indicates variation in local conditions. Poverty in Prey Veng province is typically associated with transient food insecurity of lowland rural communities, which depend on rice-based farming systems that are vulnerable to both flood and drought. Most areas in the south of the province are susceptible to flooding but some areas are also vulnerable to droughts when there is little rain during the wet season. In such areas irregularly occurring droughts resulting from highly localised rainfall patterns during the wet season often put production at risk (CARE International, 2001). These areas are characterised by clusters 69 and 74 (Figure 6.38). The seasonal EVI trend of cluster 69 is indicative for a wet season crop and a flood recession crop, whereas cluster 74 reflects single wet season crop conditions. Cluster 13 dominates the lowland area susceptible to deep flooding in the western part of the province (Figure 6.38 and Figure 6.39), and clusters 8 and 11 dominate the areas susceptible to shallow flooding, both in the south and in the northwest of the province. The land in the east of the province rises above the flood plain of the Mekong. Most of Mesang district in eastern Prey Veng, bordering Svay Rieng province, does not flood. The wet season rice crop in this district is often badly affected by drought (CARE International, 2001). From the seasonal land cover classification it is apparent that this area, dominated by cluster 60, includes the midland area extending eastward into neighbouring Svay Rieng province. The importance of dry season cropping varies across the province. WFP reported that almost 70 percent of rice production came from dry season crops in Reap commune located in Pre Reang district, northwest Prey Veng, (CARE International, 2001).

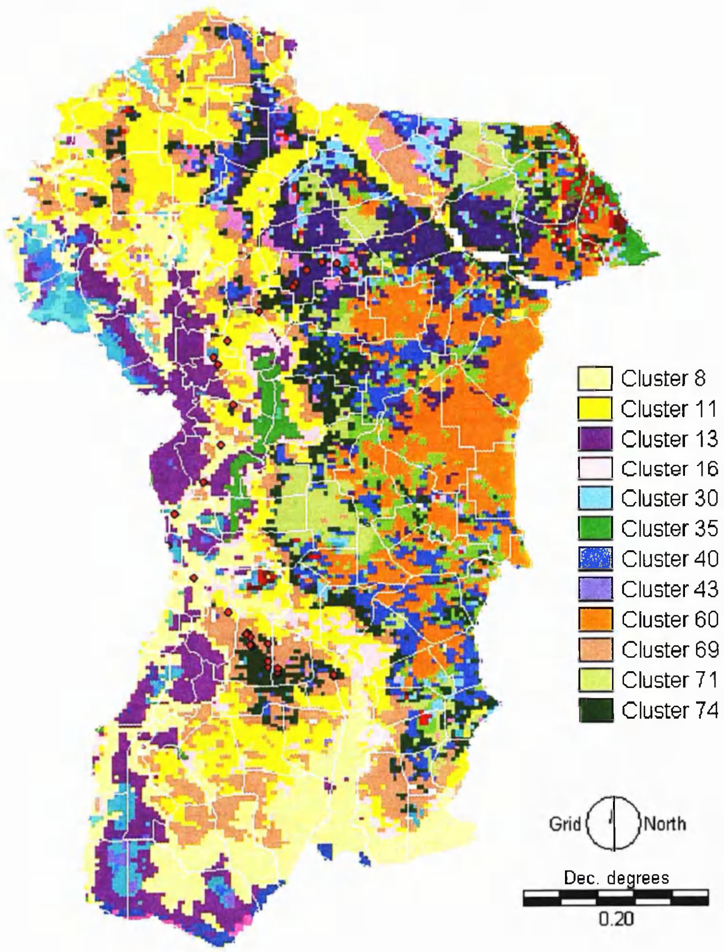


Figure 6.38 Seasonal landcover clusters for Prey Veng province, derived from MODIS Enhanced Vegetation Index (EVI) composites, 500 m resolution

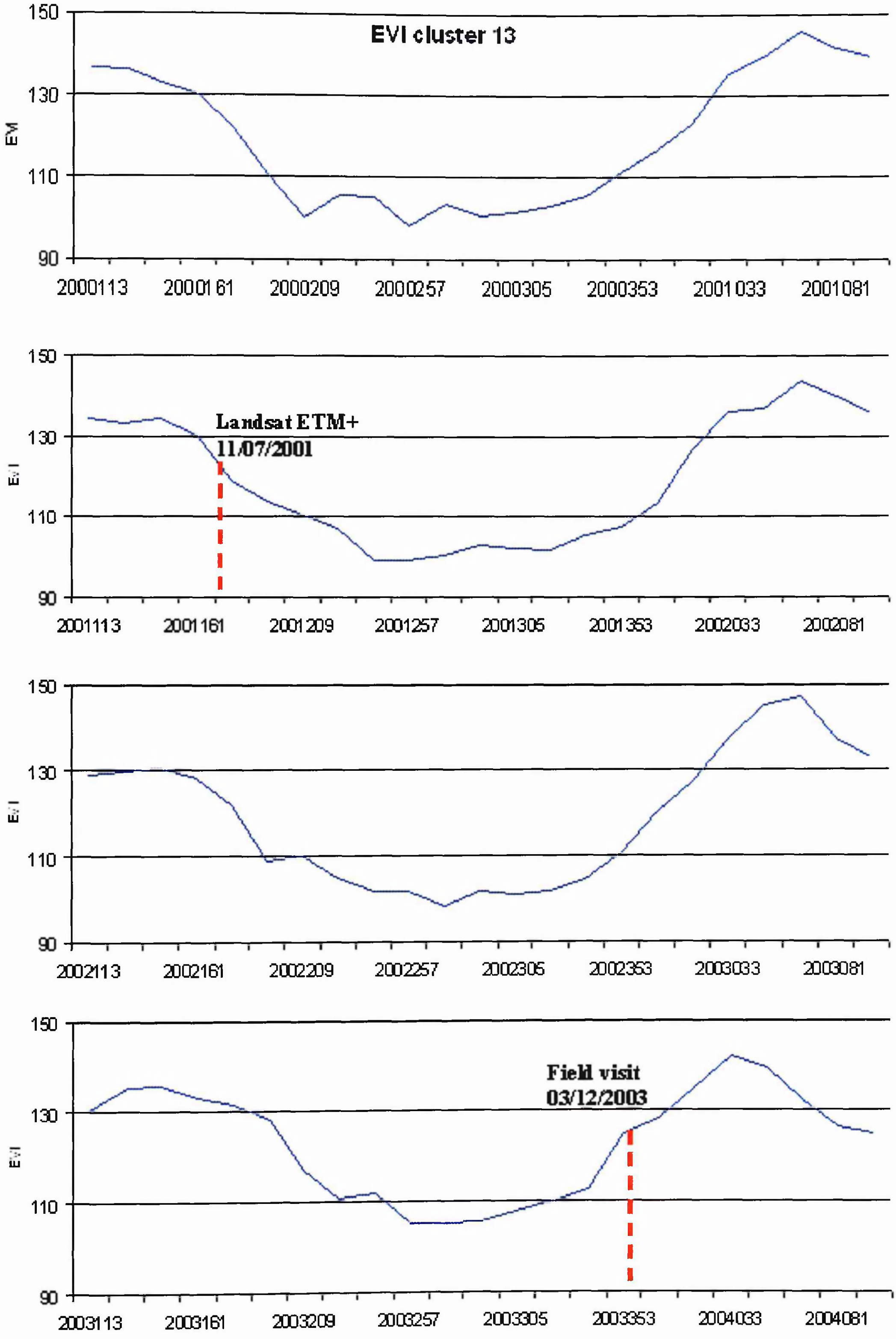


Figure 6.39 Agro-ecosystem seasonality in areas affected by deep flooding, Prey Veng province (x-axis: Julian date, y-axis: 16-day average EVI)

A field visit was undertaken in Prey Veng province on 3 and 4 December 2003 (Figure 6.40) in order to explore the locally varying conditions. In Tanung village, located in Cheaklang commune (waypoints 186 – 194), a sustainable community agriculture system has been established since 1985. The system incorporates an Integrated Pest Management (IPM) school and a Commune Fisheries Extension Committee which produces yearly ca. 100.000 fingerlings of mrigal, silver carp, and common carp, which are mainly sold within the commune at 50 riel per fingerling. Two mixed integrated farms were visited. The farms produce fish, livestock, vegetables and fruits such as morning glory, mango, water melon, egg plant, cucumber, mungbean, garlic, chili, sugarcane and rice. Rice yields are typically 2 – 2.5 tons / ha / yr. Vegetables are grown on-farm from November to February during the dry season. Pond yields were reported to be respectively 600 kg and one metric ton (mt) of common carp, silver carp, silver barb, and tilapia for the two farms. The pond areas were roughly 400 m^2 each. The fish are fed vegetable fodder and rice bran, produced on-farm. Although the ponds could supply water for supplementary irrigation, the mixed integrated farm income, generated mainly from fish and vegetables, enabled the farmer to install a private pump well for supplementary crop irrigation, while other villagers who do not have this facility experience food insecurity for 3 to 4 months.

Preah Sdach district is the poorest district in Prey Veng and one of the districts on which CARE focused its study. The district was heavily affected by flooding in both 2000 and 2001. The CARE study focused on two research villages in Boeng Daol commune, which are affected by flooding every year (CARE International, 2001). For the current study an area located in the drought prone zone characterised by cluster 74 was visited. The area was characterised by single crop rice farming systems, often with small on-farm ponds (Figure 6.40, waypoints 197 – 213).

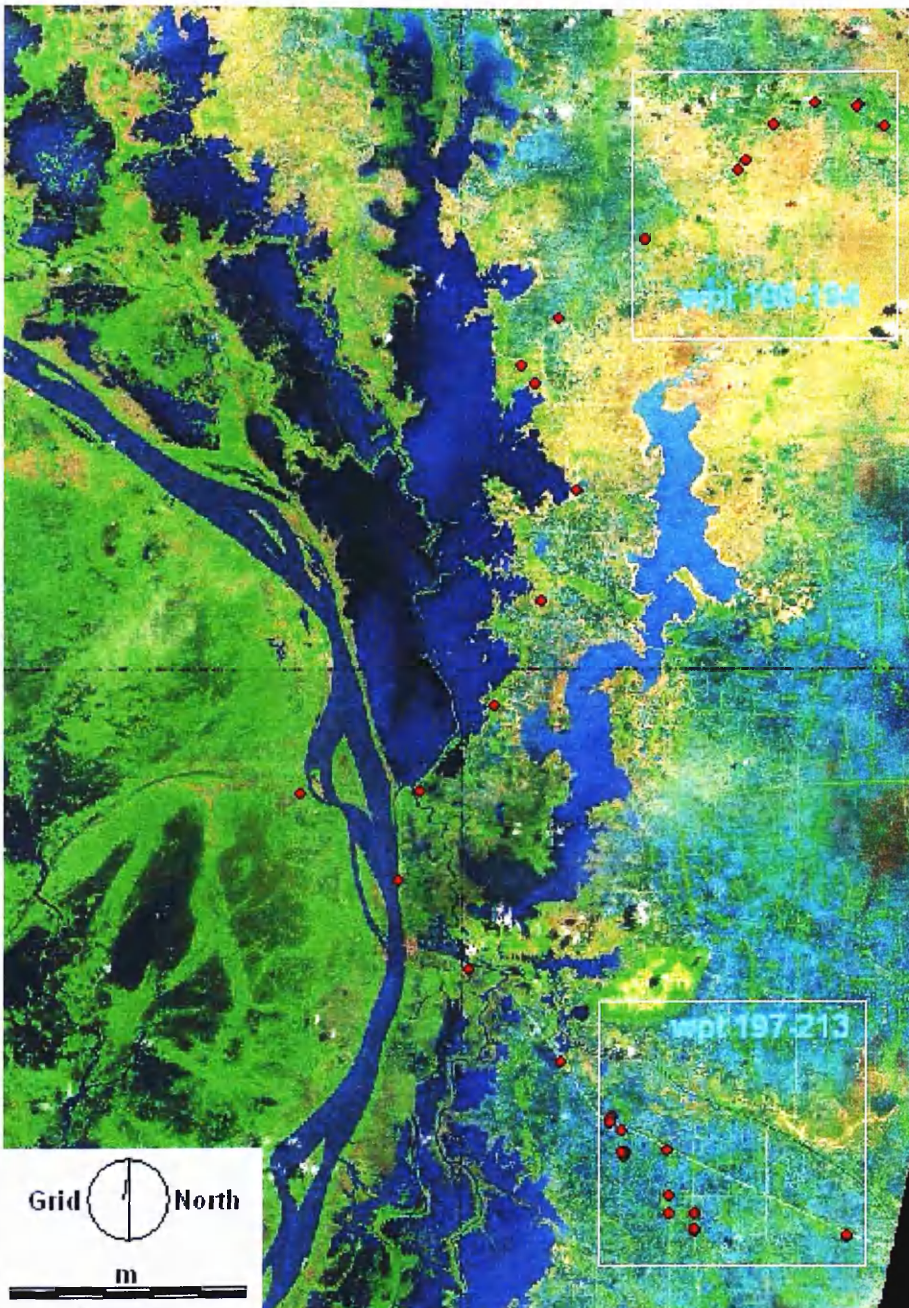


Figure 6.40 Landsat ETM+ composite image (band 5 red, band 4 green, band 2 blue) with projected GPS waypoints (wpt) taken for ground truthing, Prey Veng province (image date 11 July 2001, ground truth dates 03-04 December 2003). Wpt 186 – 194: Prey Veng district, wpt 197 – 213: Preah Sdach district

The NGO Padek supplies fingerlings to the area. Small-scale farmers often have limited availability of on-farm feed resources, in which case integrated fish farming practices might help to effectively reduce feed cost and increase fish production (Edwards & Allan, 2004). A mixed integrated farming system with rice, vegetables and pond was visited in Romchak commune (Figure 6.40, waypoints 202 and 203). The pond was quite exposed and had a turbid appearance. A few other ponds at nearby farms were observed, but most were not in use for aquaculture for various reasons, of which lack of inputs was apparently the most important one.

6.2.5 Seasonality and aquatic resources in Sisaket, Northeast Thailand

As pointed out in section 5.6.4, seasonality is an important factor to be taken into account in a socio-economic analysis of aquatic resource use. In Northeast Thailand, and particularly in Sisaket province, catching of wild fish in trap ponds contributes significantly to the income of farmers. The activity is part of the small-scale floodplain fishery and clearly influences the fish marketing system in Sisaket. A central market is set up in Sisaket town during the trap pond draining season, when a large amount of fish is available and many wholesale traders are in the area. Trap ponds are normally harvested once per year during the time of rice harvest, when many farmers owning trap ponds sell the rights to harvest the fish to “catching teams”, travelling around the area. Although most of the members in such teams claimed farming to be their major occupation, trap pond harvesting appeared to be a quite attractive cash income opportunity in comparison to other off-farm labour and agricultural labour. Catching teams are able to take opportunistic advantage of the production of fish in trap ponds, which is known to vary greatly between years. This primarily depends on the amount and timing of rains in the wet season and the number of teams involved in the activity varies accordingly, with fewer teams being active in years when the onset of rains is late. The fish yield in trap ponds also appears to depend on the location of the pond, with ponds situated in low lying land or near reservoirs being more productive. Although wild fish production from trap ponds was perceived to have declined in recent years it appears to be still an important component of the rural household economy and nutrition (AIT/AOP, 1998a).

From the analysis of seasonal landcover over the province it becomes apparent that clusters 25, 36 and 61 represent typical rainfed areas yielding one crop per year. The VI pattern of these clusters also presents some evidence of inter-annual variability in the onset of rains, with VI values increasing relatively late, indicating a late onset of rains in the years 2000 and 2002, and an earlier increase in VI, related to earlier rains, in the years 2001 and 2003. An anomaly of low VI values is noticeable around June 2001 (Julian date 2001161, corresponding to 10 June) in these and other clusters, which could indicate that heavy and persistent cloud contamination, likely to be associated with rainfall, over a 16-day period has affected the composite image, resulting in lower registered VI values for that period. Cluster 32 and 43 show the same anomaly. Cluster 43 coincides with floodplain areas (Figure 6.41). In dry years the floodplain area of the Mun river does not flood and the VI graph of cluster 43 indicates that 2003 was such a dry year. Whether or not the satellite derived seasonal agro-ecosystems classification represents an improvement over the agro-ecological zonation by AIT adopted in section 5.6 depends on how well different clusters can be related to actual differences in aquatic resource abundance in the area. The distinctive area of upland paddy in Uthumphon Phisai district, zone 4, does not appear as distinctly in the current agro-ecosystems classification (Figure 6.41) which rather suggests a wider distribution of areas similar to zone 4 over the province.

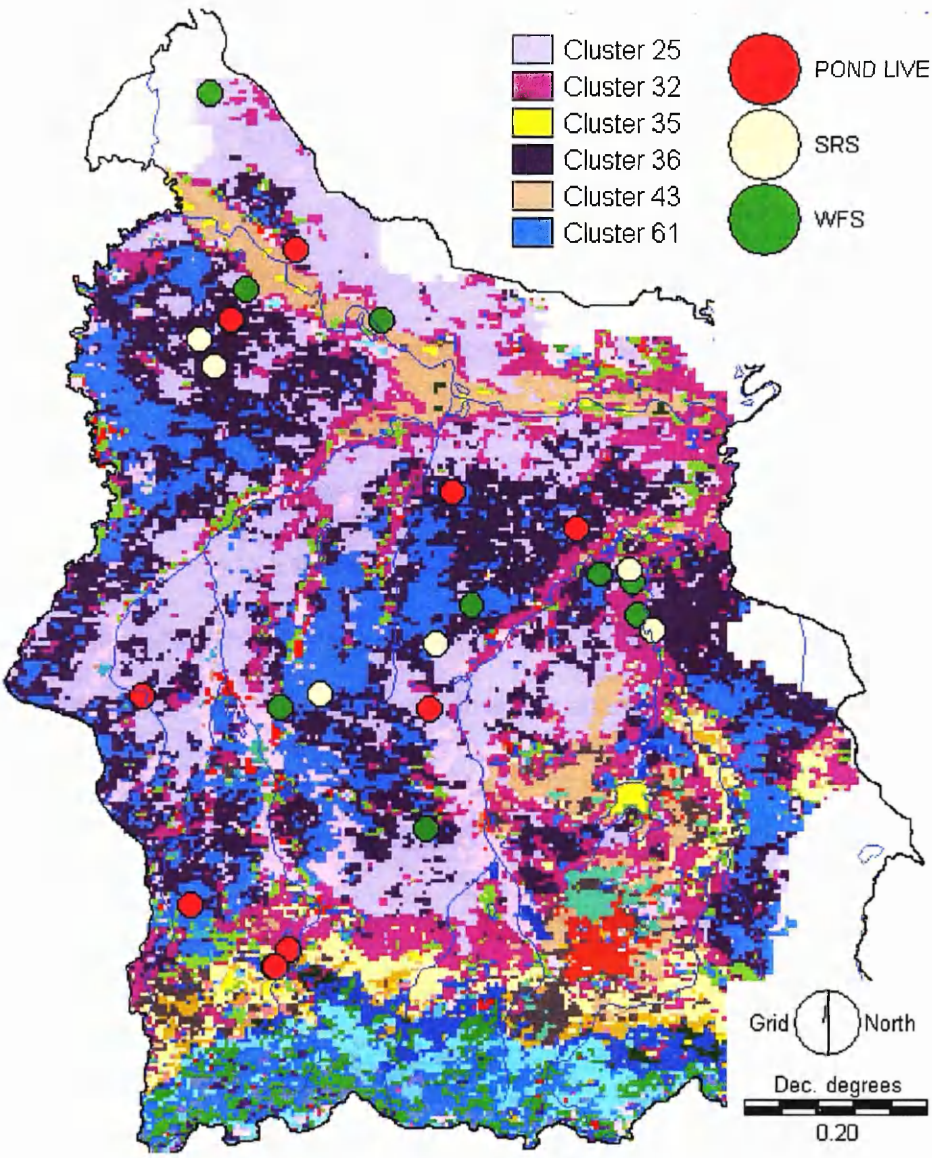


Figure 6.41 Seasonal landcover clusters for Sisaket province, derived from MODIS Enhanced Vegetation Index (EVI) composites, 500 m resolution

A field visit was undertaken in Sisaket from 11 till 13 June 2003 (Figure 6.42) in order to characterise agro-ecosystems and aquatic resource use, particularly the relation between the availability of wild fish resources in farmer managed systems and the adoption of different types of pond dike integrated agriculture aquaculture systems. Trap ponds can provide an indicator on the local availability of wild fish, whereas pond dike systems can provide clues about the local availability of agricultural inputs.

Trap pond surveys and surveys on wild fish capture among pond holding households in Sisaket (WFS) have been carried out by the AIT Aqua Outreach Program (AOP) since 1993, and the WFS survey in 1994-95 was used as a basis for selection of sites for the SRS project in Sisaket. WFS and SRS sites were visited to collect ground truth data on aquatic resource exploitation under locally varying agro-ecological conditions. The SRS project has worked extensively in agro-ecological zone 6, which is a midland area close to a stream and subject to flood. SRS project sites were visited in Nonweang village (waypoint 50) and Lao-phai village (waypoint 56). Wild fish is abundant in area 5, also a midland area close to a stream and with a high groundwater table. In Duang-yai village (waypoint 61) many catching teams are active and the commune was included as WFS survey commune in 1995. Zone 4 is a typical upper paddy zone, far from rivers and dry with a low groundwater table (waypoint 80 and 81). It is one of the least productive zones in terms of fishing and almost all the catch comes from the paddy fields. Trap pond catches constitute over 60 percent of the total paddy field catch in this area. Trap ponds are usually surrounded by trees, providing shading, and often located next to roads to benefit from rainwater run-off. Catches are also reported to be low in zone 2, a lowland area far from the Mun river but near a stream (waypoint 91). Lowland areas near the Mun river, such as zone 3 (waypoint 86) are generally more productive. The productivity in zone 9, an upland area in Phaibueng district (waypoint 76) located far away from the main rivers, was reported to be remarkably high. NRD-2C data (5.6.1) confirm that a relatively high fraction of households (nearly 19 percent) in this area is practising fishing as a source of income.

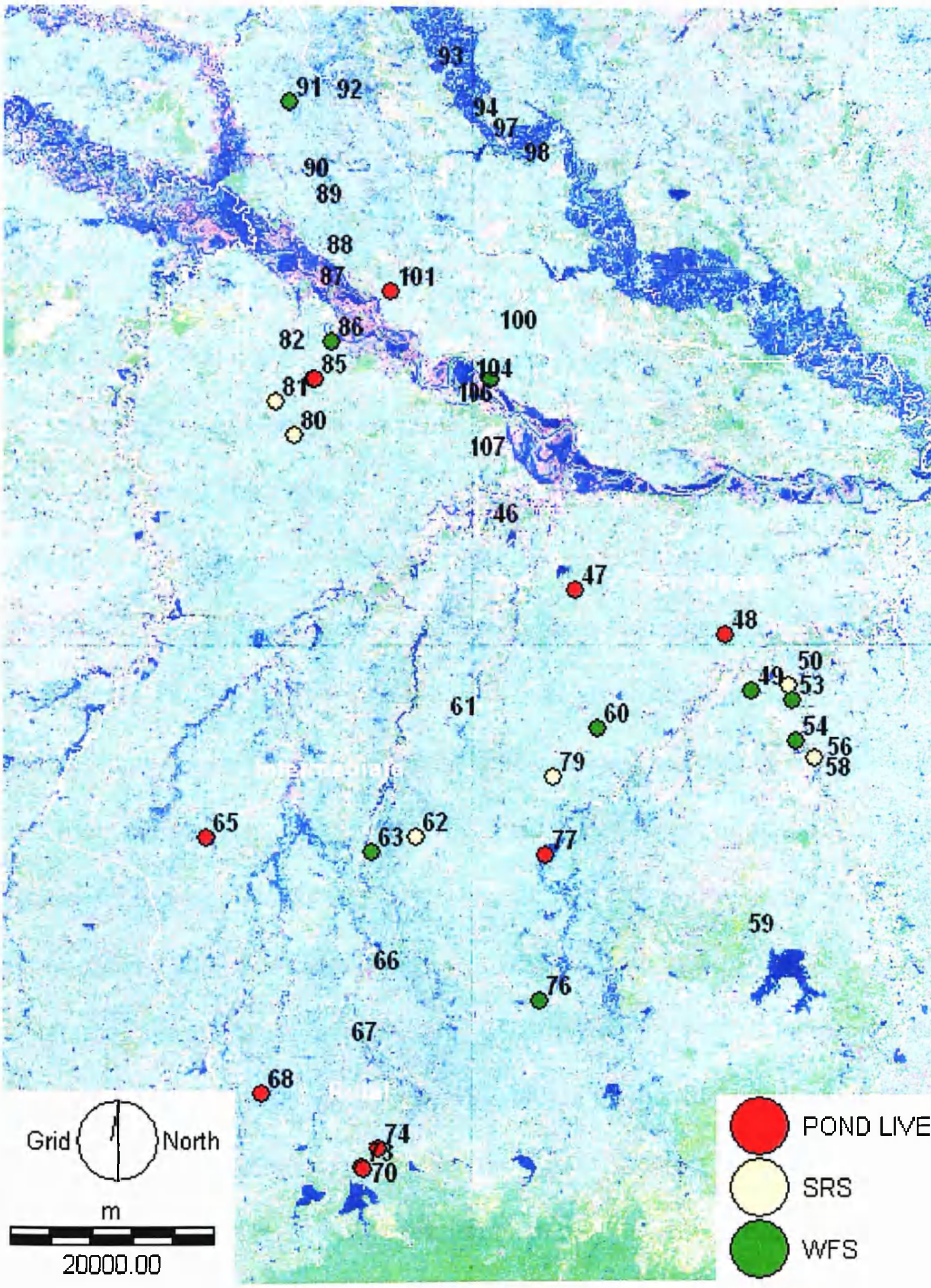


Figure 6.42 Landsat ETM+ composite image (band 5 red, band 4 green, band 2 blue) with projected GPS waypoints (numbers referred to in text) taken for ground truthing, Sisaket province (image date 04 November 2000, ground truth dates 11 - 13 June 2003).

Pond dike locations were visited to collect ground truth data on the types of pond dike systems in use, depending on local availability of agricultural inputs under varying agro-ecological conditions. A crop dominated pond dike system was visited in Nhon village (waypoint 47), which is located near Sisaket town (waypoint 46). Therefore it was classified as representative for 'peri-urban' pond dike systems by POND LIVE. Fruit and vegetables such as chilli, mango, banana and ginger were cultivated, as well as single crop rice. In Nhonpuy village, (waypoint 48), the visited pond dike system had a central Thai-style canal system, where mulberry was grown on the pond banks. The system was not used for aquaculture but only for trapping of fish. A vegetable dominated pond dike system at 'intermediate' distance from the urban area was visited in Pranku district (waypoint 65). Rural pond dike systems were visited in Phusing district in Khokjaroen village (waypoint 68), and in Sala and Nasila villages (waypoints 70-74) which are located near a large reservoir. Chilli was a common upland crop grown in the rural pond dike systems, and tilapia and silverbarb were common culture fish. Maize was the main other crop cultivated in the system in Khokjaroen, while the farmer in Nasila cultured rice and cassava, but reportedly on plots of land that were separate from the pond dike system. A fairly large orchard dominated system consisting of 4 pond dike systems on 14 rai of farmland was visited in Sam Lo Noi village (waypoint 85), Uthumphon Phisai district. The system is almost entirely managed by one female family member, remaining on-farm. This illustrates the tendency of out-migration from rural areas by younger family members, in search of better wage opportunities in urban areas, which leads to reduced availability of on-farm labour force.

6.2.6 Integrated farming systems in the Vietnamese Mekong Delta

The Vietnamese Mekong Delta is the most important agricultural region in Vietnam and is dominated by rice based farming systems. The Delta is a flat and low lying region which was formed through slow alluvial deposition. Hydrology and soil type are the two major factors that influence the agro-ecosystems in the Delta. The upstream discharge of the Mekong river combined with local rainfall in the rainy season cause high flood in the upstream section and the centre of the Delta, whereas the low river flow in the dry season allows saline water to intrude far into the dense river and canal network (Nhan & Duong, 2002).

The development of intensive rice farming systems during the 1990s was closely linked to government policies. Recently, a shift to diversified and integrated farming systems has been influenced by markets, in order to counteract socio-economic problems resulting from the decline in market prices of paddy. On-farm integration of orchard crops, animal production, fish and/or prawn production in ponds and rice cultivation has led to highly productive, profitable and environmentally sound farming systems, so-called VAC integrated pond systems. A typical VAC farm integrates a garden (*vuon*), pond (*ao*) and livestock (*chuong)*. The farm comprises a homestead area, livestock quarters, a fish pond for aquaculture or domestic water use, garden ditches where fish and prawn can be cultured, garden dikes for fruit trees or cash crops, and paddy fields for rice cultivation. The integration of these components varies and the relative importance of the various components within the system is strongly affected by factors such as soil conditions, the availability of water, and household capital assets such as farm size, finance and labour, technology, information and markets (Nhan & Duong, 2002).

The Mekong Delta was visited on 21 and 22 February 2003 for a comparative analysis of integrated farming systems in the freshwater alluvial zone in three representative agro-ecological contexts and geographical locations. The first, Song Phu village, located in Tanh Binh district of Vinh Long province, is representative for semi-intensive horticulture areas located far from main rivers. The topography of the area is depressed. Geographically the area can be characterised as a peri-urban. The dominant seasonal land cover clusters for the study area, 19, 62 and 67 (Figure 6.43), are characterised by wet and dry season rice cropping with a residual third crop which is reflected in the seasonal VI patterns (Figure 6.44).

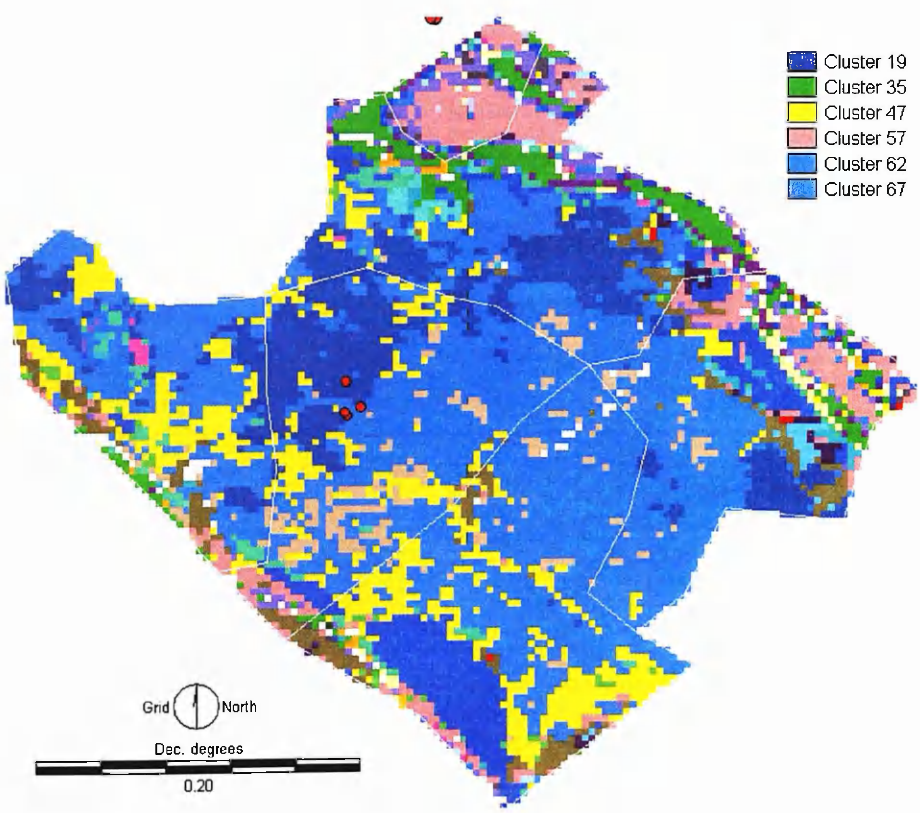


Figure 6.43 Seasonal landcover clusters for Vinh Long province, derived from MODIS Enhanced Vegetation Index (EVI) composites, 500 m resolution

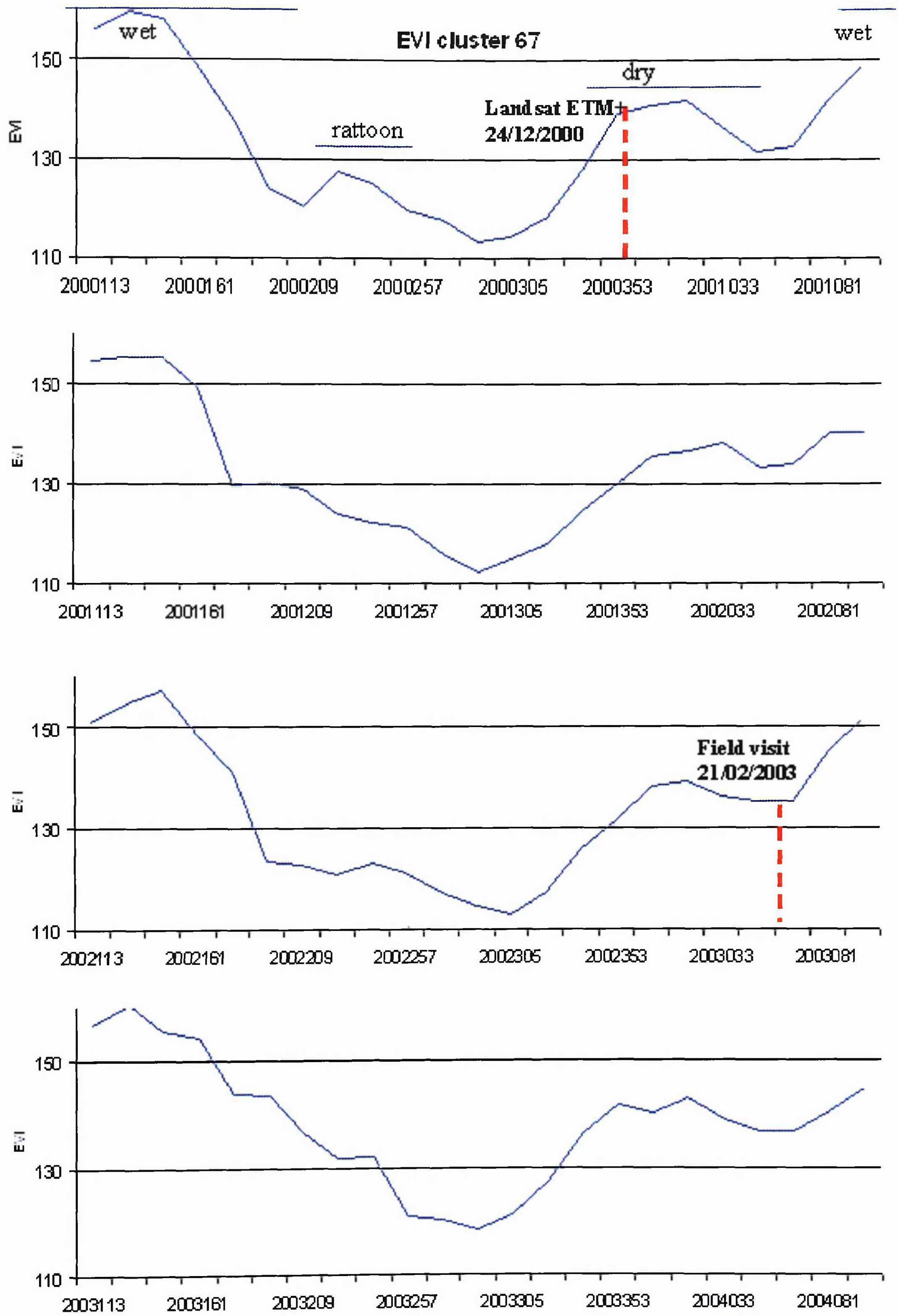


Figure 6.44 Agro-ecosystem seasonality in Vinh Long province reflecting wet and dry season rice cropping, and a residual third crop (x-axis: Julian date, y-axis: 16-day average EVI)

From the aquaculture development perspective the district is important for fingerling supply. Private hatcheries replaced a collapsed government hatchery and supply fingerlings as far as to An Giang province and Central Vietnam. Many small-scale farmers nurse fry to fingerlings which are collected by traders for wholesale to other provinces or retail within the district.

Three VAC integrated farms were visited (Figure 6.45, waypoints 27 – 31). The farm components on the first firm were rice, fish, vegetables and poultry. Rice was the most important component of the farm economy. Two pond subsystems provided fish for household consumption and additional income. They consisted of a catfish - *Colossoma* subsystem in which fish were fed with chicken manure, rice bran and broken rice, snails and crabs, and rice - fish culture subsystem with pangasius, giant gourami, kissing gourami, and common carp. The second farm had broiler chicken, a 1110 m^2 pigpen and latrine integrated with a pond culture of *Pangasius*, common carp, silver barb, Nile tilapia, silver carp and giant gourami. The fish were fed on golden snails, which were reportedly abundant in rice fields, and crabs, alternatively on semi-filled rice grains, vegetables, plant material and rice bran. Fruit and other trees grown on-farm were banana, grapefruit, coconut, bamboo, and eucalyptus. Double crop rice production amounted to 10 tons / ha / yr. According to the farmer rice required a large investment and was less profitable than fish and vegetable crops. The third farm, a larger farm sized 1.8 ha., had as the most important component 1.3 ha of rice, and another 0.4 ha consisted of grapefruit, mango, durian, and orange orchards. Pigs were the third most important component. An on-farm pond (0.1 ha) was used for extensive culture of common carp, Nile tilapia and silver barb, with pig and duck manure and semi-filled rice bran as the only inputs.

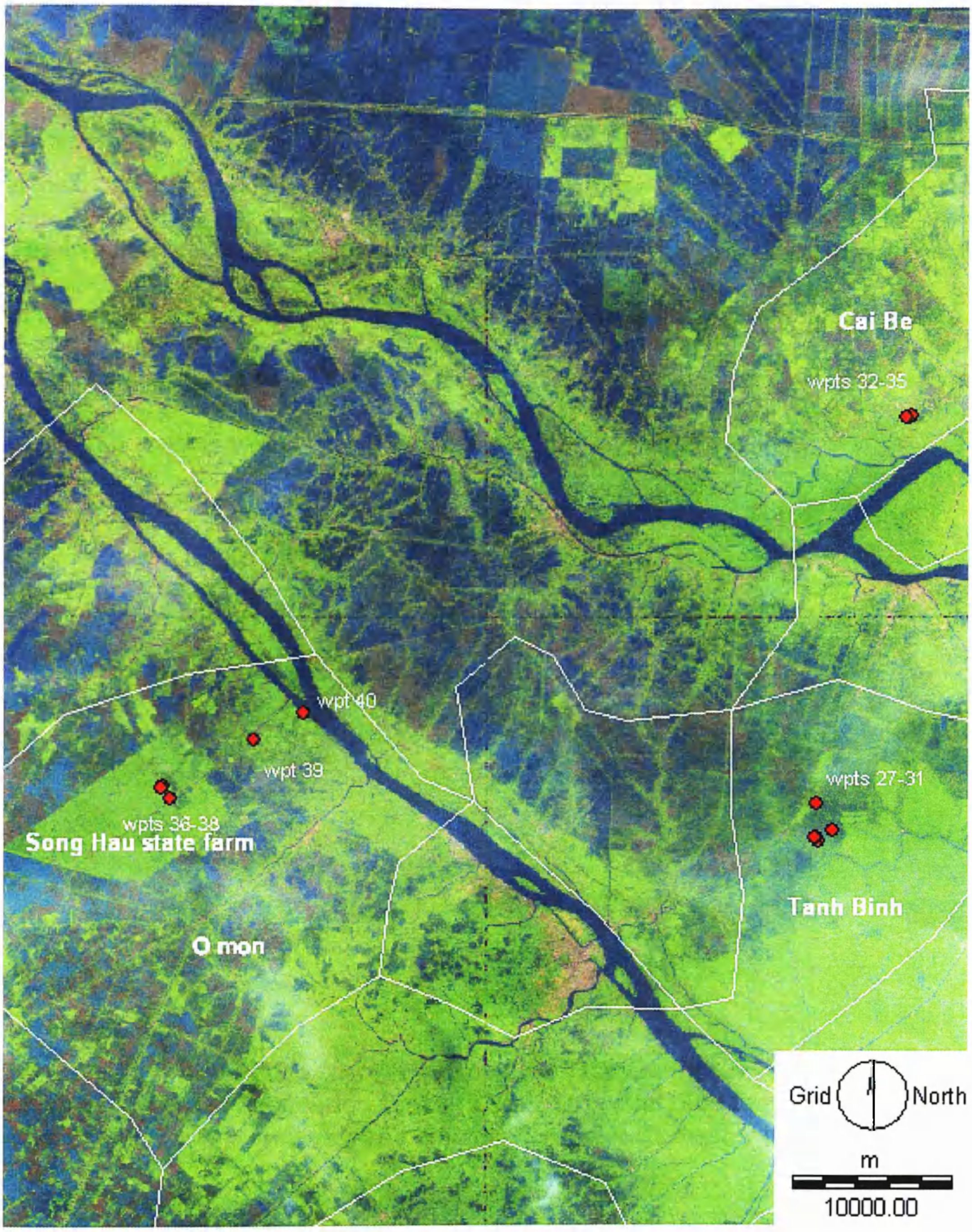


Figure 6.45 Landsat ETM+ composite image (band 5 red, band 4 green, band 2 blue) with projected GPS waypoints taken for ground truthing, Vietnamese Mekong Delta (image date 24 December 2000, ground truth dates 21 - 22 February 2003). GPS locations of VAC integrated farming systems: semi-intensive horticulture dominated, far from rivers (wpts 27-31); intensive horticulture on Mekong river bank (wpts 32-35); 7,000 ha Song Hau state farm (wpts 36-38) and flood-prone extensive/semi-intensive horticulture (wpt 39-40) adjacent to Bassac river.

The second context, Thien Tri village, located in Cai Be district of Tien Giang province (Figure 6.45, waypoints 32 – 35) is representative of intensive horticulture areas located at river banks. Geographically the village is considered as a rural area. The area is characterised by highly intensive triple crop rice cultivation, as is reflected in the seasonal VI pattern of seasonal land cover cluster 48, whereas the VI pattern of the orchard area, cluster 57 (Figure 6.46), is irregular and does not exhibit a seasonal trend. The orchard area occupies 38 percent of the total village area.

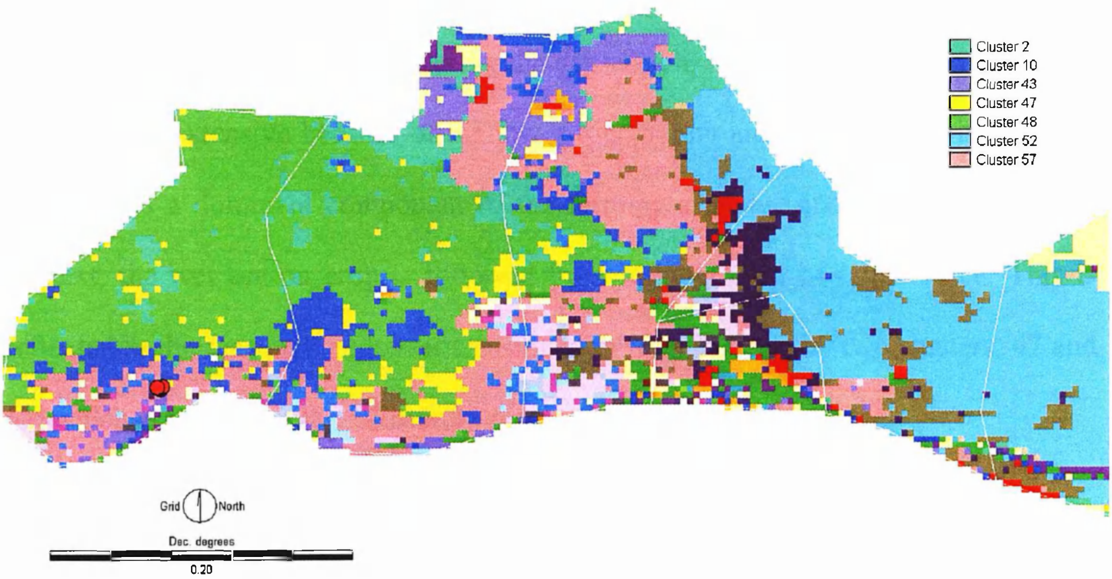


Figure 6.46 Seasonal landcover clusters for Tien Giang province, derived from MODIS Enhanced Vegetation Index (EVI) composites, 500 m resolution. Cluster 48 represents triple crop rice and cluster 57 represents orchards.

The visited farms comprise a system of orchards and ditches. Different kinds of fruit trees are intercropped to optimize ecological space and reduce market risk. A common combination is orange under a longan canopy, because orange needs less light. Aquaculture is a minor component in these farming systems as ditches are too narrow and shallow (< 70 cm in depth), and shaded by the fruit tree canopy. The ratio of the ditch to bed is 2:8. The fruit orchards provide the main source of income. Watermelon is a popular dry season crop in the area.

The third context, Thoi Long village, is located in O mon district of Can Tho province (Figure 6.45, waypoints 39 and 40). The village is considered as a peri-urban area where extensive and semi-intensive horticulture is practiced. It is representative of the upstream area adjacent to the Bassac river. The soil is fertile but the hydrology has important implications for horticulture. Flood depth is high in the wet season, whereas water shortages are experienced during the dry season. Horticulture areas further from the river are extensive because of the lower topography and less fertile soils. Double crop rice is a dominant component of the farming systems, and similar to the first context, the wet season crop is followed by a residual crop of rattoon rice. This is reflected in the seasonal landcover classification (Figure 6.47) by two clusters, 47 and 62, which are very similar. Cluster 35 represents the Bassac river area.

The village is located in the vicinity of Song Hau state farm, which covers an area of 7,000 ha of which 5,670 ha is double crop rice. The farm is clearly distinguishable on both the Landsat ETM+ imagery (Figure 6.45, waypoints 36 – 38) and the seasonal land cover classification (Figure 6.47). Farm production is integrated and can be characterised as a triple R VAC system (R-rice R-vegetable R-forest V-orchard A-pond C-livestock). Fish culture is an important component and can be differentiated into intensive (100 – 200 t / ha / 6 months, on industrial concentrated feeds) and semi-intensive *Pangasius* monoculture, aquaculture cum animal pen systems (ca 20 tons / ha /yr) and rice-fish production systems (300 – 400 kg /ha, sometimes up to 1 ton / ha).

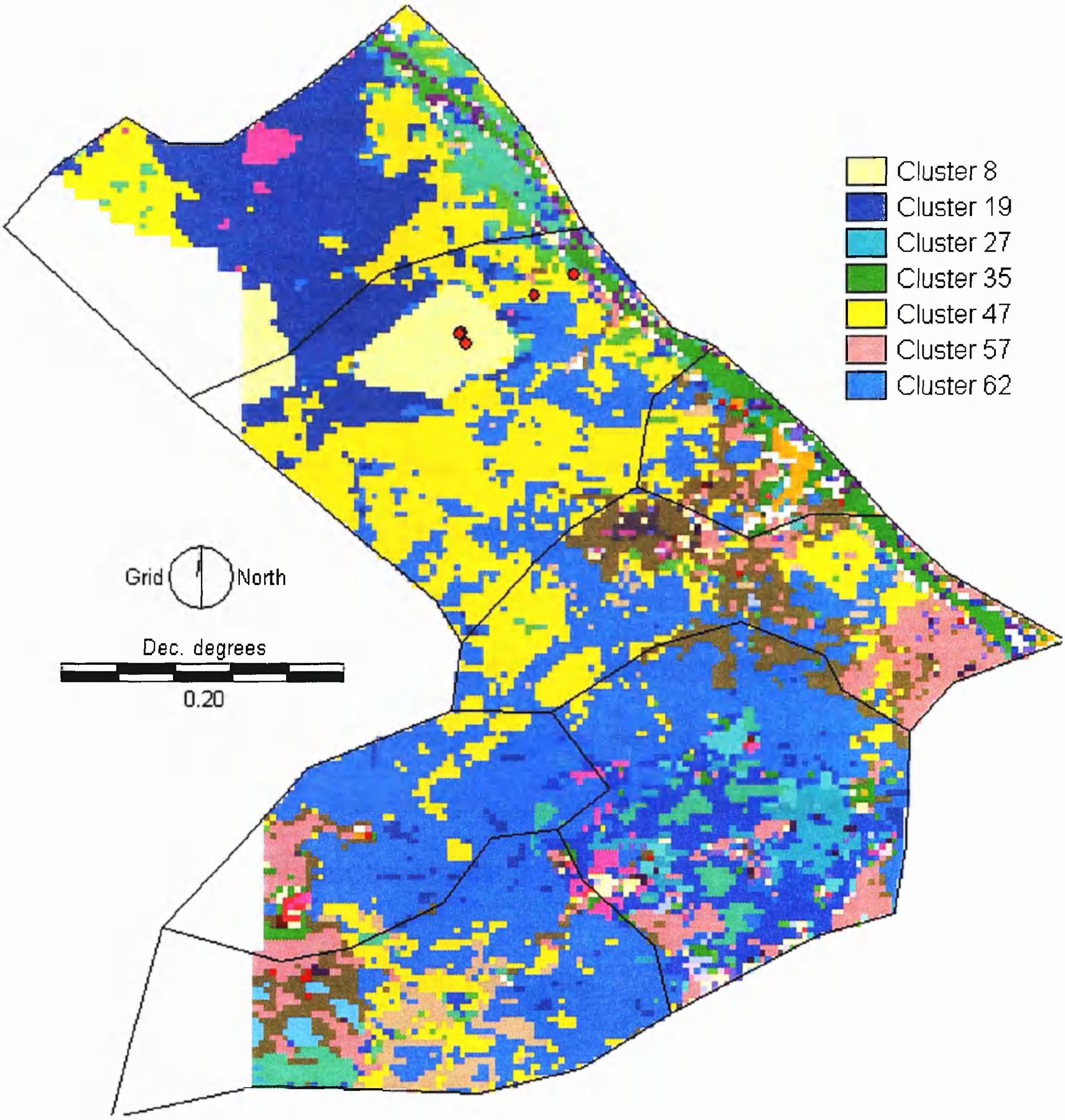


Figure 6.47 Seasonal landcover clusters for Can Tho province, derived from MODIS Enhanced Vegetation Index (EVI) composites, 500 m resolution. Cluster 8 represents double crop rice at Song Hau state farm, marked by the waypoints (red dots) in the centre.

The study area in the Vietnamese Mekong Delta is characterised by a range of integrated farming systems (VACR) which have in common that the homestead is usually connected with ponds, orchards and rice fields. In the three visited contexts, the systems are located along main rivers or canals and main roads in order to take advantage of higher topography, fertile soil and availability of water resources.

Horticulture is an important component of the systems, and tends to be intensive where it is located on riverbanks and fertile soil, or semi-intensive in upstream areas adjacent to the Bassac river where the hydrology becomes a limiting factor. In areas further from the rivers, where topography and soil fertility tend to be lower, horticulture tends to be extensive. Rice is the dominant farm component in terms of area. Animal husbandry and horticulture are mostly practiced for income generation, but market prices for pigs and fruits are unstable. Poultry and ducks are generally destined for home consumption. In terms of area, aquaculture is a minor component in VAC farming systems, particularly in those where horticulture is intensive. Fish production is mainly for home consumption in the latter but farmers reportedly prefer fishes caught from the wild during the flood season over cultured fish. More commercially oriented medium to high input fish farming is linked to commercial pig husbandry, and is mainly practised by better off farmers.

6.3 Agro-ecosystems and local resources

Rural livelihoods across the study area depend heavily on rice based farming systems, characterised by both wet and dry season rice production. Wet season rice production depends entirely on rainfall. The area and production of dry season rice depends on rainfall during the previous wet season and annual flooding of the Mekong River system, which determines the level of water availability in reservoirs and residual soil moisture content (FAO, 2000). Flood recession rice is grown as flood waters recede in the early dry season. The soils on which these farming systems are based are predominantly acid acrisols, characterised by a general paucity of plant nutrients, aluminium toxicity, strong phosphorus sorption and high susceptibility to erosion.

Acrisols are generally not very productive and are mainly used for subsistence farming. Acrisols under a protective forest cover have porous surface soils, which degrade and form a hard surface crust if the forest is cleared, allowing insufficient penetration of water during rain showers. As a result of the drive to put more land area under rice cultivation, forests have been cleared almost throughout Prey Veng province and also over large areas in Svay Rieng and Takeo. Many acrisols in low lying areas show signs of periodic water saturation. Acrisols are only suitable for rain fed and irrigated crop production after liming and full fertilisation (FAO, 2001). Annual flooding of the Mekong helps to enhance soil fertility by deposition of nutrient laden silt. Alluvial soils along elevated river banks are more fertile and in the Vietnamese Mekong Delta they support a range of integrated farming systems in which horticulture is an important component. These systems are generally practiced by better off farmers, whereas farming households that practice low input horticulture on less fertile soils further from the river tend to be less well off. Similarly, WFP poverty analysis suggests that households in riverine zones in Cambodia are less vulnerable to poverty and food security than households in rainfed lowland areas located further from rivers.

In terms of pond construction, acrisols pose only moderate constraints. Pond farms located on the predominantly acid acrisols in the study area would require liming, but the texture of the topsoil is fine to medium, which is suitable for ponds (Kapetsky, 1993; Aguilar-Manjarrez & Nath, 1998). The drainage capacity of these soils is generally imperfect to poor. Locally and periodically this can pose severe limitations to pond aquaculture in frequently flood affected areas, but also it could facilitate pond water retention into the dry season.

7 Discussion

7.1 General discussion

In this study, poverty characteristics for selected Cambodian provinces were analysed in relation to population- and agro-ecological indicators derived from satellite data, and field information on farming systems and aquatic resource use. The results confirm that agro-ecosystems seasonality and annual variations in rainfall are important indicators of the dynamics of aquatic resource use in the target area. Ricefield fisheries yields vary seasonally and geographically according to local conditions. There are clear indications that seasonal and inter-annual variations of wild fish resources may influence the decision of rural farming households on whether or not to adopt aquaculture. The methodology developed in this study for analysis of socio-economic indicators in relation to agro-ecosystems use provides a useful framework for poverty targeted aquatic resource development strategies.

7.1.1 Rural poverty and vulnerability in rice-based agro-ecosystems

Rural poverty and vulnerability to floods and droughts affects households in many different contexts and in particular depending on different farming systems, but there are also major similarities. Firstly, most households are heavily dependent on agricultural income sources, and secondly, wet season rice fields annually flood but flooding generally does not occur inside the village settlement area. Some general recommendations such as growing short duration crop varieties, which minimises the risk associated with long season crops, can be made for reducing the risks to agricultural production from natural disasters. Other recommendations such as matching varieties to conditions are more site and farming system specific (CARE International, 2001). In general farming system diversification should be encouraged in order to increase the nutritional value of daily diets and reduce the risks associated with the production of one particular crop, but the available options will vary according to local conditions. Livelihoods under apparently similar conditions and in close proximity to each other may well require different approaches towards poverty reduction and risk mitigation. In this multidisciplinary context, holistic, systems based approaches to rural aquaculture development are best placed to fulfil its potential contribution to improving the livelihoods of the rural poor (Edwards, Little, & Demaine, 2002).

7.1.2 Poverty and aquatic resource use in rice based agro-ecosystems

Recommendations for targeting aquaculture development geographically on poor areas have to take existing water and aquatic resource availability and use into account. Bunra and Gregory (1995) recommend that aquatic resource development in areas where wild fish stocks were abundant in the past but are now depleted should aim at restoring natural ricefield fisheries rather than promoting aquaculture to fill the gap between declining production from fisheries and increasing demand. The understanding of ricefield fisheries has improved recently but this has not led to readily identifiable ways to improve or maintain the resource, and doubts are cast on the feasibility to do so (Edwards *et al.*, 2002). Small-scale aquaculture, however, could complement catches of wild fish, and help households in areas with poorer water resources to improve food security (Gregory & Guttman, 2002). Rural farming households in such areas often are vulnerable to transient food insecurity, which is likely to be aggravated further with the increasing frequency of shock events such as droughts and floods, as a result of increased climate variability. Continuing dependence on declining wild fish supplies alone under such circumstances can be a high risk strategy. Rather than to focus on either aquaculture or fisheries, aquatic resource development should be incorporated in a holistic approach aiming at risk mitigation through diversification of farming systems. Mitigation of the impacts of flood and drought on aquatic resource production should take traditional coping strategies regarding aquatic resource seasonality into consideration. Construction of a pond can provide a focal point for such a strategy by providing a source of water. In that context farmers can take opportunistic advantage of on-farm ponds for stocking wild or cultured fish, and growing short duration crops on the pond banks and around the homestead.

In the geographical area targeted in this study, the rainfed rice based agro-ecosystems in lowlands and floodplains in Southeast Asia, rice field fisheries continue to be important. Gregory & Guttman (2002) call for the development of approaches that take the importance of rice field fisheries into account, as well as methods which serve to identify the contexts in which aquaculture is an option. Appraisal at the project design stage should include careful economic analysis of the true value of the existing system that considers the 'hidden' value of fish and other aquatic resources that often disproportionately benefit the poor (Edwards *et al.*, 2002).

7.1.3 Targeting of poverty in the study area

There are various possible ways to reach the poor and for the efficient allocation of resources it is essential to consider whether or not the poor should be explicitly targeted in order to make poverty alleviation effective. An approach that targets communities with significant numbers of poor households is more efficient from a project management perspective than targeting individual poor households at a level at which the costs of targeting outweigh the benefits. Such an approach also benefits more poor people than would otherwise be reached, even when many beneficiaries are not among the poorest groups (Islam & Mardall, 2002). This research argues that an appropriate targeting framework for aquaculture development can be based on existing poverty counts and identifies agro-ecological contexts that are of relevance to aquatic resource development for the benefit of the rural poor. Rural poverty is widespread in Cambodia, but according to various studies (MoP, WFP and UNDP, 2001; CARE, 2001) rural rice farming households in lowland areas, particularly those that are both flood- and drought prone, form the most vulnerable group. Poverty maps reveal high levels of rural poverty in upland areas in western Takeo and northern Svay Rieng provinces, but the highest number of poor people live in the lowland area of Prey Veng province. These people are also highly vulnerable to flood related disasters. The poorest commune in Svay Rieng province, Tras in Romeas Haek district, is located in the upland area where aquatic resources are likely to be scarce. The commune is classified as chronically insecure by WFP. There are also pockets of poverty in the flood prone south of the province, which were targeted by WFP's flood emergency food assistance programme in 2001. Tnort commune was amongst these. In Takeo province, the highest numbers of poor people are found in upland areas in the north and northeast of the province, particularly in Tramkok district, but the poverty incidence is also high in the southwest of the province, which is characterised by flood prone lowland.

Poverty characteristics in the three provinces appeared to be broadly similar. Poor people own very little or no land and principally sell labour to augment their income. They are vulnerable to transient food security, sometimes for up to six months, during the months prior to rice harvest. Poverty characteristics as classified in a wealth ranking exercise by CARE in Prey Veng were similar to those defined during PRA workshops held by the SRS project in Svay Rieng and Takeo. Very poor households survive on a "hand-to-mouth" subsistence basis. They own little or no land, sell labour and buy food each day, and often have to borrow money in advance of labour to buy food. Less poor households have enough rice land to support food needs for most of the year, but they have to borrow food for 1 to 2 months.

The majority of the poor in Southeast Cambodia are small-scale farmers who own little land and depend heavily on rice production. Seasonal labour migration is commonplace. Many rural families throughout Cambodia sell labour as agricultural workers, construction workers and factory workers. Labour in Prey Veng is predominantly related to rice production (CARE, 2001). Within that poverty context, the benefits to be derived from aquaculture development could be in the form of on-farm labour provision to the poor when beneficiaries are not directly among the poorest groups. Fish farming in common water bodies may provide an opportunity for landless people and poor fishers to farm fish (Edwards, 2000). Poor farmers who own some land could diversify out of rice production by integrating a small pond, livestock and short duration crops near the homestead, thus reducing the dependence on rice. Such a household strategy could reduce the risk of transient food security and the need to sell assets as a coping strategy. Seasonal labour migration and selling labour is still an option, while household members remaining on-farm can relatively easily manage the system, especially when little off-farm inputs are required.

7.2 Conclusion

7.2.1 Aquaculture and aquatic resources development perspective

The abundance of wild aquatic animals varies between different agro-ecosystems and within systems, both seasonally and inter-annually. Earlier studies suggest that the demand for aquaculture in the study area is inversely related to the abundance of wild fish stocks, with the demand probably being higher in upland areas which are located far from the main floodplains, and generally are fish deficit. In lowland areas with viable ricefield fisheries the demand appears to be lower. Trap pond productivity appears to be a reliable indicator for wild fish abundance in Svay Rieng province but there are signs that trap ponds in Sisaket have been excavated in response to declining wild fish yields (AIT/AOP, 1998b).

In Sisaket, ponds are in use for a range of purposes. Aquaculture is always secondary to crop production (POND LIVE, 2003). Pond water is also used for livestock and domestic use. Because of its multipurpose characteristics and its resource efficiency the pond dike system might be a viable alternative to other forms of aquatic resource use. In drought prone and fish deficit areas such as in the uplands in Takeo and northern Svay Rieng provinces they can provide a water reserve for emergency irrigation, and be used to stock fish.

Fish was also found to be a minor component in integrated farming systems in the Vietnamese Mekong Delta, except in those where medium to high input fish farming is linked to commercial pig husbandry, mainly practised by better off farmers. Low topography and annual flooding in the Vietnamese Mekong Delta make it necessary for farmers to elevate the land, and ponds and garden ditches are created in the process. In flood prone areas of Prey Veng province a similar strategy could be followed in order to diversify farming systems and to mitigate flood impacts. It would increase the area of 'upland' for settlement and growing crops. The need for farming systems diversification through pond based systems in areas that are both flood and drought prone is probably even more acute. In such areas these systems are likely to have the highest poverty reducing potential.

7.2.2 Systems perspective

This study has highlighted the relationship between agro-ecosystems seasonality, rural poverty and vulnerability. The rice-based agro-ecosystems in the study area are of fundamental importance to rural households. Poor rural livelihoods depend almost entirely on paddy production and the collection of wild aquatic animals in these systems. The production of both rice and aquatic animals varies seasonally, and transient food insecurity is commonplace amongst poor rural households. Frequently occurring shocks such as floods and drought exacerbate rural poverty, but the vulnerability of rural households to such shocks varies spatially and temporally. Agro-ecosystems in the study area are predominantly rice based, but productivity varies according to local conditions.

The demarcation of different functional agro-ecosystems is often not clear, unless sharp natural boundaries are present. A hard classifier was developed, which appeared to be capable of separating functionally different agro-ecosystems from each other. The results confirm that in Sisaket, Northeast Thailand, as well as in Cambodian upland areas, rain fed single crop systems dominate. In the Cambodian lowland area, double crop rainfed and flood recession rice dominates, but the classification, supported by ground truth, revealed local presence of single crops in areas that are both flood- and drought prone, especially in the south-eastern provinces of Cambodia. In the Vietnamese Mekong Delta, double and triple crop rice systems dominate.

One strategy to reduce the vulnerability of rural households is through agricultural diversification. This strategy is promoted in the Vietnamese Mekong Delta, where a range of integrated farming systems is established. The level of integration of the individual farm components is strongly affected by soil conditions, availability of water resources, technology, household assets such as farm size, financial capital and labour, and access to markets and information. Integrated farming is also being adopted in Sisaket province, Northeast Thailand. The relative importance of the individual farm components varies with geographical location and the availability of inputs. In Southeast Cambodia, farming systems diversification through adoption of pond dike systems, adapted to the local agro-ecological context, has considerable potential to help reduce rural poverty and food insecurity.

7.2.3 General conclusion

Development of pond based integrated agriculture aquaculture systems has a high potential for the reduction of rural poverty and vulnerability in the lower Mekong region. Its use for aquaculture is generally of secondary importance, but can still be of relevance to household fish consumption. If well managed, the system allows the farmer to take opportunistic advantage of local resources, through diversified production and reuse of farm wastes and by-products. Its development should be targeted locally, according to the prevailing agro-ecosystems dynamics. A GIS provides a useful and cost effective tool to analyse systems dynamics and linked to a sufficiently detailed socio-economic dataset it offers a powerful decision support system for targeting aquaculture within a wider rural development context. The methodology developed in this study serves to identify the agro-ecological and socio-economic contexts in which the needs for pro-poor aquatic resources development can be assessed in a neutral way with no particular bias towards fisheries or aquaculture, and offers the option to move away from a sectoral approach in favour of a more holistic view towards rural development.

7.3 Recommendations

7.3.1 Research focus for aquaculture development

Further research on poverty oriented aquaculture development should take place at the systems level as the options to use local resources for integrated agriculture aquaculture vary geographically between agro-ecosytems, seasonally within agro-ecosystems and inter-annually with climate. Disaggregated poverty maps offer a useful tool to target poor areas but provide only a starting point to investigate the relationship between agro-ecosystems dynamics and the use of locally available aquatic resources. A detailed socio-economic analysis of the relationship between aquatic resource use and poverty and vulnerability, disaggregated according to agro-ecosystems functions rather than administrative boundaries, can provide a useful framework for targeting aquaculture development on poor areas within a wider rural development context. The outcome can be presented as an alternative poverty map that represents the functional relationship between poverty and natural resources spatially (Figure 7.1), rather than use administrative boundaries which only to a limited extent coincide with socio-economic and functional agro-ecosystems boundaries.

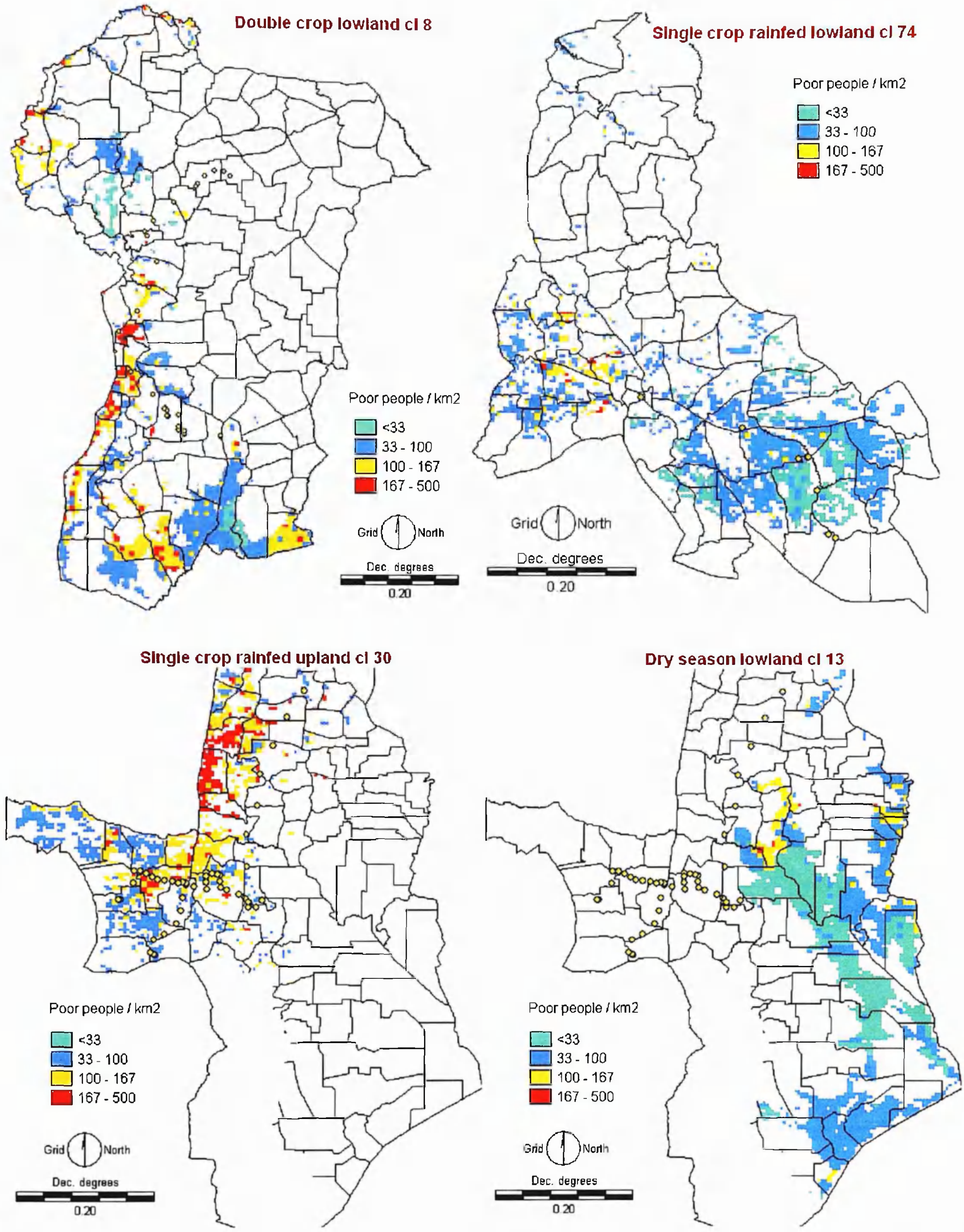


Figure 7.1 Population density of poor in rice based agro-ecosystems: a) double crop rainfed / flood recession, Prey Veng province, b) single crop rainfed lowland, Svay Rieng, c) single crop rainfed upland, Takeo, and d) dry season lowland in areas deeply flooded during the wet season, Takeo

7.3.2 A programme perspective for aquaculture development

Aquatic resource exploitation is an integral part of farmer managed systems and is closely related to the seasonal dynamics of agro-ecosystems in inland areas of Cambodia, Northeast Thailand and the Vietnamese part of the Mekong Delta. Catches from inland ricefield fisheries fluctuate markedly over years, reflecting fluctuating climate conditions. From a programme perspective, poverty targeted aquaculture and aquatic resources development in Southeast Asia's rice based ecosystems could usefully be incorporated in DFID's current research programmes on climate change and its impacts on poverty. Pond based systems can help poor people to cope with the consequences of more frequent droughts and floods and under such circumstances can be part of a disaster risk mitigation strategy, especially in the Cambodian lowland area. The improved resource use efficiency of pond based systems also justifies its incorporation in research programmes on sustainable agriculture and natural resources management.

The GIS application developed in this study does not only offer an appropriate tool to assess the relation between seasonal agro-ecosystems dynamics and rural poverty, but can also use longer time series of spatial data in order to assess longer term climate change events at various scales, and its impacts on poverty. Such data are becoming increasingly available in the public domain, which greatly enhances the cost-effectiveness of GIS as a research and decision support tool. This study has demonstrated its application in a holistic approach to poverty targeted aquatic resources development and presents a strategic framework for its use in future poverty targeted interdisciplinary research on climate and natural resources.

References

ADB. (2004). *Development of technology and extension for small-scale fish farms in Northeastern Thailand.* Special Evaluation Study on Small-Scale Freshwater Rural Aquaculture Development for Poverty Reduction. [Electronic version] (Case study 8). http://www.adb.org/Documents/Reports/Evaluation/sst-reg-2004-07/.

Aguilar-Manjarrez, J. & Nath, S.S. (1998). A strategic reassessment of fish farming potential in Africa. Rome: FAO. CIFA Technical Paper 32

AIT/AOP. (1998a). Survey of Fish Catching Teams in Sisaket Province, Thailand (Results From the 1993-94 Survey. Bangkok, Thailand: Aqua Outreach Program.

AIT/AOP. (1998b). Survey of Trap Pond Owners in Sisaket and Roi Et Provinces, Thailand (Results From the 1993-94 Survey). Bangkok, Thailand: Aqua Outreach Program.

Beckman, M. (2001). Extension, Poverty and Vulnerability in Vietnam. Country Study for the Neuchâtel Initiative. [Electronic version] http://www.odi.org.uk/publications/working.html.

Bunra, S., & Gregory, R. (1995). Trap Pond Mapping as a Survey Tool for Aquaculture Development Planning. *Seminar on Aquaculture in South and South Eastern Cambodia* AIT.

CARE International. (2001). Risk Mitigation and Disaster Management Among Rural Communities In Cambodia.

CARE International. (2002). Flood Impact on Women & Girls in Cambodia.

CGIAR Challenge Program on Water & Food. (2002a). The Contribution of Aquatic Ecosystems and Fisheries to Food Security and Livelihoods: A Research Agenda. [Electronic version] (Challenge Program on Water and Food Background Paper 3). http://www.waterforfood.org/pdf/Background%20paper%20theme%203.pdf.

CGIAR Challenge Program on Water & Food. (2002b). Full Proposal Challenge Program On Water and Food. [Electronic version] http://www.waterforfood.org/docPresent/DownloadCP_Fullproposal.asp.

CGIAR Challenge Program on Water & Food. (2002c). Integrating Research in Water, Food and Environment. [Electronic version] (Challenge Program on Water and Food Background Paper 4). http://www.waterforfood.org/pdf/Background%20paper%20theme%204.pdf.

CGIAR Challenge Program on Water & Food. (n.d.) *Benchmark basins: Mekong river basin: Main issues* [Web Page]. URL http://www.waterforfood.org/BB_Mekong_River_Basin.asp [2006, February 8].

Chea, S., Cramb, R. A., & Fukai, S. (2004). The economics of rice double-cropping with supplementary irrigation in the rainfed lowlands of Cambodia: a survey in two provinces. *Research on Water in Agricultural Production in Asia for the 21st Century*, 32-44. ACIAR Proceedings. Canberra: ACIAR.

Chenoweth, J. L., Malano, H. M., & Bird, J. F. (2001). Integrated River Basin Management in the Multi-jurisdictional River Basins: The Case of the Mekong River Basin. *Water Resources Development, 17*(3), 365-377.

Community Development Information Centre (2003). *NRD-2C.* [CD-ROM]. Bangkok, Thailand.

Cornell International Institute for Food and Agricultural Development (CIIFAD). (1999). Alternatives to Conventional Modern Agriculture for Meeting World Needs in the Next Century. *Evaluation of New Paradigms and Old Practices* .

Cosgrove, W. J., & Rijsberman, F. R. (2000). *World water vision: making water everybody's business* (108p.). London: Earthscan.

Council for Social Development. (2002). Cambodia: National Poverty Reduction Strategy. [Electronic version] http://siteresources.worldbank.org/INTCAMBODIA/Data%20and%20Reference/20182374/Cambodia_PRSP.pdf.

Cox, A., Farrington, J., & Gilling, J. (1998). Reaching the Poor? Developing a Poverty Screen for Agricultural Research Proposals. [Electronic version] London: Chameleon Press Ltd. http://www.odi.org.uk/publications/working.html.

Csaki, C. (2001). Reaching the rural poor. *Development Policy Review, 19*(4), 563-573.

Dapice, D. O. (2003). Viet Nam's Economy: Success Story or Weird Dualism? A SWOT Amalysis. [Electronic version] Ha Noi, Vietnam: http://www.undp.org.vn/undp/docs/2003/dual/index.htm.

Davis, B. (2003). Choosing a Method for Poverty Mapping. [Electronic version] Retrieved from FAO Corporate Document Repository http://www.fao.org/documents/show_cdr.asp?url_file=/DOCREP/005/Y4597E/Y4597E05.htm.

Deichmann, U., & Eklundh, L. (1991). Global Digital Datasets for Land Degradation Studies: A GIS Approach. Nairobi: Global Environment Monitoring System (GEMS), United Nations Environment Programme.

Demaine, H., Innes-Taylor, N., Turongruang, D., Edwards, P., Little, D. C., & Pant. J. (1999). Small-Scale Aquaculture in Northeast Thailand: a Case Study from Udon Thani. Bangkok, Thailand: Asian Institute of Technology.

Demaine, H. (2002). Review of the AIT Aqua Outreach experience in data collection within the Southeast Asia region. *Expert Consultation on Land and Water Use in Aquaculture*.

DEWA/GRID-Europe. (1998) *Data: Atmosphere* [Web Page]. URL http://www.grid.unep.ch/data/summary.php?dataid=GNV15&category=atmosphere&dataurl=http://www.grid.unep.ch/data/download/gnv15.tar.Z&browsen = [2006, February 16].

DFID. (2004). Official Development Assistance to Agriculture. [Electronic version] (working paper 9). http://dfid-agriculture-consultation.nri.org/summaries/wp9.pdf.

DFID/AFGRP. (2002a). Participatory Rural Appraisal in Angtasom. [Electronic version] http://www.dfid.stir.ac.uk/Afgrp/projects/r7917/pcareports.htm.

DFID/AFGRP. (2002b). Participatory Rural Appraisal in Prey Tadoc. [Electronic version] http://www.dfid.stir.ac.uk/Afgrp/projects/r7917/pcareports.htm.

DFID/AFGRP. (2002c). Participatory Rural Appraisal in Svay Cheak. [Electronic version] http://www.dfid.stir.ac.uk/Afgrp/projects/r7917/pcareports.htm.

DFID/AFGRP. (2002d). Participatory Rural Appraisal in Thom Village. [Electronic version] http://www.dfid.stir.ac.uk/Afgrp/projects/r7917/pcareports.htm.

DFID-SEA Aquatic Resources Management Programme. (2000). An Analysis of Poverty and Aquatic Resources Use Focusing Especially on the Livelihoods of the Poor in Cambodia. [Electronic version] (Report No. PRAR/00/01). Bangkok: DFID-SEA ARMP.http://www.streaminitiative.org/Library/Livelihoods/livelihoods.html.

Didan, K., & Yin, Y. (2002). Theoretical Basis for the Enhanced Vegetation Index. [Electronic version] http://tbrs.arizona.edu/cdrom/VI_Intro/EVI_Theo.html.

Diner, D. J., Asner, G. P., Davies, R., Knyazikhin, Y., Muller, J.-P., Nolin, A. W., Pinty, B., Schaaf, C. B., & Stroeve, J. (1999). New Directions in Earth Observing: Scientific Applications of Multiangle Remote Sensing. *Bulletin of the American Meteorological Society, 80*(11), 2209-2228.

Dobson, J. E., Bright, E. A., Coleman, P. R., Durfee, R. C., & Worley, B. A. (2000). LandScan: A Global Population Database for Estimating Populations at Risk. *Photogrammetric Engineering and Remote Sensing, 66*(7), 849-858.

Eastman, R. J. (1999). Guide to GIS and Image Processing. Worchester, MA: Clark Labs.

Eastman, J. R., & Fulk, M. (1993). Long Sequence Time-Series Evaluation Using Standardized Principal Components. *Photogrammetric Engineering and Remote Sensing, 59*(8), 1307-1312.

EDCDAAC. (2005) *MODIS Reprojection Tool Overview* [Web Page]. URL http://edcdaac.usgs.gov/landdaac/tools/modis/about.asp [2006, February 16].

Edwards, P. (2000). Aquaculture, poverty impacts and livelihoods. *Natural Resource Perspectives,* (56), 4.

Edwards, P., & Allan G.L. (2004). *Feeds and feeding for inland aquaculture in Mekong region countries.* ACIAR Technical Reports No. 56. Canberra.

Edwards, P., & Demaine, H. (1998). Rural Aquaculture: Overview and Framework for Country Reviews. [Electronic version] Bangkok, Thailand: Regional Office for Asia and the Pacific, Food and Agriculture Organization of the United Nations. Retrieved from FAO Corporate Document Repository http://www.fao.org/documents/show_cdr.asp?url_file=/DOCREP/003/X6941E /X6941E00.HTM.

Edwards, P., Demaine, H., Innes-Taylor, N., & Turongruang, D. (1996). Sustainable Aquaculture for Small-scale Farmers: Need for a Balanced Model. *25*(1), 19-26.

Edwards, P., Little, D. C., & Demaine, H. (2002). Issues in Rural Aquaculture. *Rural Aquaculture*, 323-340. CABI *Publishing.*

Edwards, P., Little, D. C., & Yakupitiyage, A. (1997). A comparison of traditional and modified inland artisanal aquaculture systems. *Aquaculture Research, 28*, 777-788.

Edwards, P., Pullin, R. S. V., & Gartner, J. A. (1988). Research and Education for the Development of Integrated Crop-Livestock-Fish Farming Systems in the Tropics. Manila, Philippines: International Center for Living Aquatic Resources Management (ICLARM).

Eidenshink, J.C. & Faundeen, J.L. (1994). The 1km AVHRR global land data set: first stages in implementation. *International Journal of Remote Sensing, 15*(17), 3443-3462.

Elbers, C., Lanjouw, J. O., & Lanjouw, P. (2003). Micro-Level Estimation of Poverty and Inequality. *Econometrica, 71*(1), 355-364.

EOSDIS. (2004) *An Overview of EOSDIS* [Web Page]. URL http://spsosun.gsfc.nasa.gov/eosinfo/EOSDIS_Site/Overview.html [2006, February 15].

FAO. (2000). Special Report FAO/WFP Crop and Food Supply Assessment Mission to Cambodia. [Electronic version] Retrieved from FAO Corporate Document Repository http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/004/x9237e/x9237e00.htm.

FAO. (2002). The State of World Fisheries and Aquaculture. [Electronic version] Retrieved from FAO Corporate Document Repository http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/005/y7300e/y7300e00.htm.

FAO. (2003). Review of the State of World Fishery Resources: Inland Fisheries. [Electronic version] (Report No. FIRI/C942). Rome, Italy

FAO, & WFP. (1999). FAO/WFP Crop and Food Supply Assessment Mission to Cambodia. [Electronic version] Retrieved from FAO Corporate Document Repository http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/004/x1319e/x1319e00.htm.

Friend, R. F., & Funge-Smith , S. J. (2002). Focusing Small-Scale Aquaculture and Aquatic Resource Management on Poverty Alleviation. [Electronic version] Bangkok, Thailand: FAO//NACA. http://www.streaminitiative.org/Library/Strategies/strategies.html.

Fujii, T. (2003). Commune-Level Estimation of Poverty Measures and Its Application in Cambodia. [Electronic version] University of California, Berkeley: http://siteresources.worldbank.org/INTPGI/Resources/342674-1092157888460/Fujji.Commune-LevelCambodia.pdf.

Giri, C., Defourny, P., & Shrestha, S. (2003). Land Cover Characterization and Mapping of Continental Southeast Asia Using Multi-Resolution Satellite Sensor Data. *International Journal of Remote Sensing, 24*(21), 4181-4196.

Glewwe, P., Gragnolati, M., & Zaman, H. (2000). Who Gained From Vietnam's Boom in the 1990's? An Analysis of Poverty and Inequality Trends. [Electronic version] (Working Paper No. 2275). http://econ.worldbank.org/view.php?type=5&id=1029.

Global Spatial Data Infrastructure (GSDI). (2004). Developing Spatial Data Infrastructures: The SDI Cookbook. [Electronic version] http://www.gsdi.org/docs2004/Cookbook/cookbookV2.0.pdf.

Gregory, R., & Guttman, H. (2002). The ricefield catch and rural food security. *Rural Aquaculture* pp. 1-13. Wallingford, UK: CABI Publishing.

Guttman, H., & Kunty, R. (1997). *Survey of Fish Marketing in Svay Rieng Province, Cambodia.* [Electronic version] Retrieved 23 February 2006 from http://www.aqua-information.ait.ac.th/aarmpage/documents/outreach/workingpapers/WP-C-6.htm.

Hansen, M. C., DeFries, R. S., Townshend, J. R. G., Carroll, M., Dimiceli, C., & Sohlberg, R. A. (2003). Global Percent Tree Cover at a Spatial Resolution of 500 Meters: First Results of the MODIS Vegetation Continuous Fields Algorithm. *Earth Interactions, 7*(10), 14 p.

Hazell, P., & Haggblade, S. (1993). Farm-Nonfarm Growth Linkages and the Welfare of the Poor. M. Lipton, & J. v. d. Gaag. *Including the Poor.*

Hoddinott, J. (1999). Targeting: Principles and Practice. [Electronic version] http://www.ifpri.org/themes/mp18/techguid/tg09.pdf.

Hook, J., Novak, S., & Johnston, R. (2003). *Social Atlas of the Lower Mekong Basin.* (2003). [CD-ROM]. Phnom Penh: Mekong River Commission.

Huete, A., Justice, C., & van Leeuwen, W. (1999). MODIS Vegetation Index (MOD 13) Algorithm Theoretical Basis Document. [Electronic version]

IFAD. (2001). Rural Poverty Report 2001 - The Challenge of Ending Rural Poverty. [Electronic version] New York: Oxford University Press. Retrieved 23 February 2006 from http://www.ifad.org/poverty/index.htm.

IFAD. (2002). Regional Assessment of Rural Poverty in Asia and the Pacific. [Electronic version] Rome: Palombi. Retrieved 23 February 2006 from http://www.ifad.org/poverty/region/pi/index.htm.

Islam, M., & Mardall, N. (2002). The Effectiveness of a Model Fisheries Village Approach to Aquaculture Extension in Northwest Bangladesh. *Rural Aquaculture*, 301-306. CABI *Publishing.*

Johnston, R. J. (1978). *Multivariate statistical analysis in geography: a primer on the general linear method* (p. 280). London : Longman.

Justice, C. O., Vermote, E., Townshend, J. R. G. , Defries, R., Roy, D. P., Hall, D. K., Salomonson, V. V., Privette, J. L., Riggs, G., Strahler, A., Lucht, W., Myneni, R. B., Knyazikhin, Y., Running, S. W., Nemani, R. R., Wan, Z., Huete, A. R., van Leeuwen, W., Wolfe, R. E., Giglio, L., Muller, J.-P., Lewis, P., & Barnsley, M. J. (1998). The Moderate Resolution Imaging Spectroradiometer (MODIS): Land Remote Sensing for Global Change Research. *IEEE Transactions on Geoscience and Remote Sensing, 36*(4), 1228-1249.

Kaojarern, S. (1986). *Exploration of Application of the National Rural Development Village Data System for Rural-Regional Development Planning at Local-Level: A Case Study of Nakhon Ratchasima Province, Northeast Thailand.* Unpublished MSc Thesis, Asian Institute of Technology, Bangkok, Thailand.

Kapetsky, J. M. (1993). A Strategic Assessment of Warm Water Fish Farming Potential in Africa. [Electronic version] Rome: FAO. CIFA Technical Paper 27.http://www.fao.org/documents/show_cdr.asp?url_file=/DOCREP/005/V4740E/V4740E00.HTM.

Khay, D., & Hortle, K. G. (2005). Monitoring sales of fish and other aquatic animals at retail markets in Phnom Penh, Cambodia. *MRC Conference Series: 6th Technical Symposium on Mekong Fisheries* MRC.

Kite, G., & Droogers, P. (2000). Integrated Basin Modeling. [Electronic version] Colombo, Sri Lanka: International Water Management Institute.http://www.iwmi.cgiar.org/pubs/rrindex.htm.

Lesaca, R. M. (1983). Rivers of southeast Asia: their regime, utilization and regulation. *Hydrology of humid tropical regions* International Association of Hydrological Sciences.

Little, D. C., Surintaraseree, P., & Innes-Taylor, N. (1996). Fish culture in rainfed rice fields of northeast Thailand. *Aquaculture, 140*(4), 295-321.

Loveland, T. R., Zhu, Z. L., Ohlen, D. O., Brown, J. F., Reed, B. C., & Yang, L. M. (1999). An Analysis of the Igbp Global Land-Cover Characterization Process. *Photogrammetric Engineering and Remote Sensing, 65*(9), 1021-1032.

Maurer, J. (2001) *Overview of NASA's Terra Satellite: Introduction* [Web Page]. URL http://cires.colorado.edu/~maurerj/terra.htm [2006, February 15].

McCormack, G. (2000). Water Margins: Development and Sustainability in China. [Electronic version] http://www.mekong.es.usyd.edu.au/publications/wp_index.htm.

McNally, R., & Tognetti, S. (2002). Tackling Poverty and Promoting Sustainable Development: Key Lessons for Integrated River Basin Management. [Electronic version] WWF-UK.http://www.panda.org/news_facts/publications/freshwater/index.cfm.

Meusch, E. (2002). Notes on Effective Targeting of Poor People. *Regional Consultation on focusing small-scale aquaculture and aquatic resources management on poverty alleviation.*

Ministry of Planning, R. G. o. C. & United Nations World Food Programme. (2002). Estimation of Poverty Rates at Commune-Level in Cambodia Using the Small-Area Estimation Techniques to Obtain Reliable Estimates. [CD-ROM] Phnom Penh: WFP Cambodia

Ministry of Planning, R. G. o. C., United Nations World Food Programme, & United Nations Development Program. (2001). Identifying Poor Areas in Cambodia Combining Census and Socio-Economic Survey Data to Trace the Spatial Dimensions of Poverty. [Electronic version] Cambodia: http://www.wfp.org/operations/vam/country_experience/cambodia_vam/index.asp?section=5&sub_section=4.

Minot, N. (2000). Generating Disaggregated Poverty Maps: An Application to Vietnam. *World Development, 28*(2), 319-331.

Minot, N., & Baulch, B. (2002). The Spatial Distribution of Poverty in Vietnam and the Potential for Targeting. [Electronic version] IFPRI.http://www.ifpri.org/divs/mtid/dp/papers/mssdp42.pdf.

Molle, F. (2003). Development Trajectories of River Basins: A Conceptual Framework. [Electronic version] Colombo, Sri Lanka: International Water Management Institute.http://www.iwmi.cgiar.org/pubs/rrindex.htm.

Molle, F. (n.d.). *River Basin Development: a framework for case studies.* Retrieved 23 February 2006 from http://www.mrea-jo.org/Documents/basin-studies-meth.pdf.

MRC. (2004 March). The present low flows in the Lower Mekong Basin. *Mekong River Commission: Press Releases.*

MRC. (2006) *The Mekong Programme: Basin Development Plan* [Web Page]. URL http://www.mrcmekong.org/programmes/bdp.htm [2006, February 8].

NACA, & FAO. (2000). Report of the Conference on Aquaculture in the Third Millenium. *Conference on Aquaculture in the Third Millenium*, 120 p. NACA, Bangkok and FAO, Rome.

Naret, K., Viryak, S., & Griffiths, D. (2003). Fish Price Monitoring in Kandal, Prey Veng and Takeo Provinces of Cambodia. [Electronic version] MRC Fisheries Programme (FP). Retrieved from: http://www.mekonginfo.org/mrc_en/doclib.nsf/dddacc89bda83d0f85256fae002a9051/b9ec48aebefbcf5d47256de3002717f7?OpenDocument.

NASA. (1997). MTPE/EOS Data Products Handbook. [Electronic version] http://eospso.gsfc.nasa.gov/ftp_docs/DPH.pdf.

NASA. (1998). *Landsat 7 Science Data Users Handbook.* Retrieved 15 February 2006 from http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_htmls/chapter3/chapter3.html.

NASA. (2003) *MODIS land team: validation* [Web Page]. URL http://landval.gsfc.nasa.gov/ProductStatus.php?ProductID=MOD13 [2006, February 15].

Nath, S. S., Bolte, J. P., Ross, L. G., & Aguilar-Manjarrez, J. (2000). Applications of geographical information systems (GIS) for spatial decision support in aquaculture. *Aquacultural Engineering, 23*, 233-278.

Nelson, A. (2001). Analysing data across geographic scales in Honduras: detecting levels of organisation within systems. *Agriculture, Ecosystems and Environment, 85*, 107-131.

NESDIS. (n.d.) *Satellites* [Web Page]. URL http://www.nesdis.noaa.gov/satellites.html [2006, February 15].

Nhan, D. K., & Duong, L. T. (2002). Farming System Development and Crops-Animal-Aquaculture (VACR) Integrated Farming Systems in the Mekong Delta of Vietnam. Vietnam: Mekong Delta Farming Systems R & D Institute, Can Tho University.

NOAA. (n.d.) *Polar Operational Environmental Satellite* [Web Page]. URL http://www.oso.noaa.gov/poes/index.htm [2006, February 15].

NSIDC. (n.d.) *Introduction to HDF-EOS* [Web Page]. URL http://nsidc.org/data/hdfeos/intro.html [2006, February 16].

Openshaw, S. (1984). The modifiable areal unit problem. (p. 40). Norwich: Geo Books.

Oxfam. (2001). Rice for the Poor and Trade Liberalization in Vietnam. [Electronic version] Hanoi, Vietnam: http://www.maketradefair.com/en/assets/english/VietnamRiceResearch2001Final.pdf.

Pant, J., Demaine, H., & Edwards, P. (2004). Assessment of the aquaculture subsystem in integrated agriculture-aquaculture systems in Northeast Thailand. *Aquaculture Research, 35*, 289-298.

Pantulu, V. R. (1986). The Mekong River system. Bryan R. Davies and Keith F. Walker *The Ecology of River Systems* Vol. Monographiae Biologicae volume 60pp. 695-719. Dordrecht: Dr. W. Junk Publishers.

Phillips, M. J. (2002). *Fresh water aquaculture in the Lower Mekong Basin.* (Report No. MRC Technical Paper No. 7). Phnom Penh: Mekong River Commission.http://www.mrcmekong.org/download/free_download/Technical_paper7.pdf.

Plate, E. J., & Thanongdeth, I. (n.d.). *Early warning system for the Mekong river.* Retrieved 23 February 2006 from http://www.na.unep.net/flood/MEKONG_R.pdf.

POND LIVE. (2003). State-of-the-System Report: Thailand. [Electronic version] Sisaket College of Agriculture and Technology and Asian Institute of Technology.

Poverty Task Force. (2003). Mekong Delta Participatory Poverty Assessment. [Electronic version] Retrieved 08 February 2006 from http://www.undp.org.vn/undp/docs/2003/ppa/mekongppae.pdf.

Poverty Working Group. (2000). Attacking Poverty. Joint Report of the Govenment-Donor-NGO Working Group, *Consultative Group Meeting for Vietnam.*

Ravallion, M., & Sen, B. (1994). How Land-Based Targeting Affects Rural Poverty. [Electronic version] World Bank.

Raytheon Systems Company. (2003). HDF-EOS Data Format Converter (HEG) Users Guide. [Electronic version] Upper Marlboro, Maryland

Rodriguez, A. (1999). Rapid Assessment National Anti-Poverty Programme Kingdom of Thailand. [Electronic version]

Scepan, J. (1999). Thematic Validation of High-Resolution Global Land-Cover Data Sets. *Photogrammetric Engineering and Remote Sensing, 65*(9), 1051-1060.

Siamwalla, A., & Sobchokchai, O. (1998). Responding to the Thai Economic Crisis. *High-Level Consultative Meeting "Policy Response to the Economic Crisis and Social Impact in Thailand".*

Sokal, R. R., & Rohlf, F. J. (1995). *Biometry* 3 ed., (p. 887). New York: W.H. Freeman.

Steinwand, D. R. (1994) *Mapping Raster Imagery to the Interrupted Goode Homolosine Projection* [Web Page]. URL http://edcsns17.cr.usgs.gov/1KM/goodesarticle.html [2006, February 16].

Steinwand, D. R., Hutchinson, J. A., & Snyder, J. P. (1995). Map projections for global and continental data sets and an analysis of pixel distortion caused by reprojection. *Photogrammetric Engineering and Remote Sensing, 61*(12), pp 1487-1497.

Sverdrup-Jensen, S. (2002). Fisheries in the Lower Mekong Basin: Status and Perspectives. [Electronic version] Phnom Penh: http://www.mrcmekong.org/download/free_download/Technical_paper6.pdf.

Tana, T. S. (1993). *Fish Supply and Demand in Rural Svay Rieng.* Unpublished MSc Thesis, Asian Institute of Technology, Bangkok, Thailand.

Thiam, A. K., & Eastman, J. R. (1999). Vegetation Indices. *Guide to GIS and Image Processing Volume 2* pp. 107-122. Worcester, MA: Clark Labs.

Turk, C. (2001). Linking Particiaptory Poverty Assessments to Policy and Policymaking: an Experience From Vietnam. [Electronic version] Hanoi: http://econ.worldbank.org/view.php?type=5&id=1356.

UNDP. (1997). Human Development to Eradicate Poverty. [Electronic version] http://hdr.undp.org/reports/global/1997/en/.

UNDP. (2001). Doi Moi and Human Development in Viet Nam. [Electronic version] Hanoi, Vietnam: The Political Publishing House. http://www.undp.org.vn//undp/docs/2001/vnnhdr2001/index.htm.

UNDP. (2003a). Millennium Development Goals: A Compact Among Nations to End Human Poverty. [Electronic version] New York: Oxford University Press. http://hdr.undp.org/reports/global/2003/.

UNDP. (2003b). Thailand Human development Report 2003 on Community Empowerment and Human Development. [Electronic version] Bangkok, Thailand. http://www.undp.or.th/publications/index.html.

UNDP. (2005) *Basic Facts about Viet Nam* [Web Page]. URL http://www.undp.org.vn/undp/fact/base.htm [2006, February 11].

United Nations Resident Coordinator System in Cambodia. (2003) *Cambodia: Society and Economy* [Web Page]. URL http://www.un.org.kh/rcsystem/ [2006, February 8].

USGS. (2005) *Earth Resources Observation & Science (EROS): Global Landcover Characterization background* [Web Page]. URL http://edcsns17.cr.usgs.gov/glcc/background.html [2006, February 16].

USGS. (n.d.) *HYDRO1k Documentation* [Web Page]. URL http://edc.usgs.gov/products/elevation/gtopo30/hydro/readme.html#DrainageBasinBoundaries [2006, February 16].

U.S. Geological Survey (USGS), University of Nebraska-Lincoln (UNL), & European Commission's joint Research Centre (JRC). (1997). *Global Land Cover Characterization*. [On-line].

Verdin, K. L. (Work performed under U.S. Geological Survey contract 1434-CR-97-CN-40274). (1997) *A System for Topologically Coding Global Drainage Basins and Stream Networks* [Web Page]. URL http://edcdaac.usgs.gov/gtopo30/hydro/P311.html [2002, December 11].

Verdin, K. L., & Jenson, S. K. (1996). Development of Continental Scale DEMs and extraction of Hydrographic Features. *Proceedings, Third International Conference/Workshop on Integrating GIS and Environmental Modelling*.

Volker, A. (1983). Rivers of southeast Asia: their regime, utilization and regulation. *Hydrology of humid tropical regions.* International Association of Hydrological Sciences.

WFP. (1996). Project Cambodia 5483 (Exp.3). [Electronic version] Rome: http://www.wfp.org/eb/docs/1996/5483.03~1.pdf.

World Bank. (1998). Vietnam-Mekong Delta Water Resources Project . [Electronic version] http://www-wds.worldbank.org/servlet/WDS_IBank_Servlet?pcont=details&eid=000094946_99031911045189.

World Bank. (2002). Implementing Reforms for Faster Growth and Poverty Reduction. [Electronic version]

World Bank. (2003a). *DEPweb: Glossary*. [Web Page] http://www.worldbank.org/depweb/english/modules/glossary.html

World Bank. (2003b October). *Thailand Economic Monitor* [Electronic version]

World Bank. (2004 April). *Thailand Economic Monitor* [Electronic version]

World Bank. (2005). Poverty Manual. [Electronic version] http://web.worldbank.org/WBSITE/EXTERNAL/WBI/WBIPROGRAMS/PGLP/0,,contentMDK:20284296~menuPK:461269~pagePK:64156158~piPK:64152884~theSitePK:461246,00.html.

World Bank. (n.d.) *Cambodia: Country Brief: Current Challenges* [Web Page]. http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/EASTASIAPACIFICEXT/CAMBODIAEXTN/0,,contentMDK:20174714~pagePK:1497618~piPK:217854~theSitePK:293856,00.html [2006, February 8].

World Commission on Dams. (2000). Dams and Development. A New Framework for Decision-Making. [Electronic version] Earthscan Publications Ltd. http://www.dams.org/report/contents.htm.

Appendix I

Table I 1 On-line resources for spatial data used in this study

Host	URL	Product
EOSDIS	http://redhook.gsfc.nasa.gov/%7Eimswww/pub/imswelcome/plain.html	MOD13A1 MOD13A2
NESDIS	http://www.class.noaa.gov/nsaa/products/welcome;jsessionid=29F435C2EB9DD962C35D4E878111E09E	AVHRR
GLCN	http://esip.umiacs.umd.edu/index.shtml	Landsat TM/ETM+ SRTM
USGS	http://edcsns17.cr.usgs.gov/glcc/	GLCC V2 GTOPO30 HYDRO1k
DEWA/GRID-Europe	http://www.grid.unep.ch/data/data.php?category=atmosphere	GNV14 GNV15 GNV183
ORNL	http://www.ornl.gov/sci/landscan/	LandScan
UNEP/GRID–Sioux Falls	http://www.na.unep.net/datasets/datalist.php3	SE Asia admin. bnd
Penn State University	http://www.maproom.psu.edu/dcw/	DCW

Appendix II

Table II 1 Land use / land cover area and monthly mean NDVI

Id.	Land use	Area (km^2)	NDVI	Apr-92	May-92	Jun-92	Jul-92	Aug-92	Sep-92	Oct-92	Nov-92	Dec-92	Jan-93	Feb-93	Mar-93
15	Fragmented Monsoon Tropical Broadleaf Forest	340	Mean	143	148	130	125	112	125	141	151	158	152	150	143
			± sd	10.9	9.8	15.8	15.2	9.2	13.9	14.8	11.2	8.8	9.0	7.3	10.8
16	Evergreen Broadleaf Forest with Shrubland	5067	Mean	141	150	134	151	118	147	138	152	156	149	144	141
			± sd	9.4	7.7	13.7	12.4	12.2	13.9	13.8	10.5	7.6	9.1	8.5	11.8
17	Evergreen Broadleaf Forest with Grassland	2605	Mean	136	144	129	134	136	141	145	153	157	151	148	145
			± sd	9.6	8.9	13.7	13.4	11.7	13.3	13.8	8.6	6.0	7.7	9.3	9.5
18	Broadleaf Evergreen Monsoon Forest	4876	Mean	143	151	140	152	137	129	155	158	160	155	149	146
			± sd	8.7	6.9	13.9	11.0	13.9	12.7	8.1	5.9	4.9	7.7	8.3	7.7
19	Tropical Evergreen Rainforest	8316	Mean	141	148	147	153	151	158	157	155	162	158	152	149
			± sd	7.4	6.6	12.6	9.5	8.9	8.9	7.3	5.5	3.5	6.2	8.0	6.9
32	Tropical Fruit Plantations	200	Mean	136	150	149	148	128	147	148	149	139	131	128	133
			± sd	6.6	6.0	8.7	14.2	12.8	14.3	8.4	10.5	10.7	8.1	10.0	9.5
36	Disturbed Deciduous Monsoon Forest	7190	Mean	129	139	138	153	147	154	152	155	157	147	135	133
			± sd	7.9	8.6	12.7	9.1	10.7	10.4	10.1	7.0	4.9	7.6	9.5	9.5
38	Montane Deciduous Monsoon Forest	1887	Mean	144	151	141	131	124	149	157	159	161	154	147	145
			± sd	7.4	6.7	13.6	17.0	11.2	11.5	8.0	5.8	4.8	7.7	9.2	7.5
67	Mixed Pine and Broadleaf Forest	7410	Mean	125	143	152	157	152	154	154	153	151	130	120	120
			± sd	6.3	6.2	7.9	6.9	8.4	11.1	8.0	6.2	5.3	9.2	6.8	7.1
68	Fragmented and Degraded, Open Forest	3305	Mean	131	147	147	148	139	140	158	158	155	124	122	129
			± sd	7.2	6.9	11.4	12.9	11.4	15.1	5.2	3.8	5.4	10.7	9.0	7.3
71	Evergreen Broadleaf and Needleleaf Forest	1890	Mean	139	147	146	126	149	151	155	158	160	152	143	142
			± sd	7.4	6.7	11.4	14.6	9.8	12.4	8.7	6.0	5.1	8.0	10.4	9.3
79	Temperate Broadleaf Shrubland	3743	Mean	129	135	136	142	141	140	139	144	148	140	135	134
			± sd	7.0	7.5	9.2	10.0	9.4	10.4	11.0	10.4	6.3	7.4	7.8	7.6

Id.	Land use	Area (km^2)	NDVI	Apr-92	May-92	Jun-92	Jul-92	Aug-92	Sep-92	Oct-92	Nov-92	Dec-92	Jan-93	Feb-93	Mar-93
102	Sparsely Vegetated Shrubland/Grassland	674	Mean	112	115	113	122	114	114	122	129	124	116	115	114
			± sd	4.5	5.7	5.9	8.6	8.0	7.4	9.2	7.2	5.5	5.4	5.5	5.2
108	Pine/Bamboo and Oak Woodland with Cropland (Grains)	205	Mean	115	118	137	144	134	130	146	150	131	124	121	119
			± sd	5.4	5.9	7.4	7.5	11.1	10.4	8.3	7.2	6.3	6.2	4.2	5.1
109	Deciduous Woodland / Shrubland with Agriculture	2816	Mean	123	130	125	125	143	150	149	154	150	133	122	123
			± sd	7.4	10.4	11.7	14.2	10.2	11.0	8.1	6.4	6.2	8.2	8.4	7.8
131	Grassland with Cropland	260	Mean	116	129	125	130	121	119	137	141	127	115	116	116
			± sd	5.9	8.2	8.0	9.7	9.0	8.2	10.3	9.3	6.3	7.1	6.8	6.6
149	Cropland (Small Grains) with Grassland	108	Mean	126	131	123	131	116	107	115	121	125	118	127	124
			± sd	9.5	8.0	7.7	11.4	12.3	7.9	13.6	15.3	13.6	10.9	12.2	10.7
153	Cropland (Rice)	4058	Mean	111	112	111	117	115	126	130	136	128	116	113	112
			± sd	3.3	4.4	5.6	7.5	9.4	8.5	8.4	5.5	6.0	5.6	4.6	4.0
158	Cropland (Rice)	333	Mean	116	120	120	132	127	124	120	129	129	120	119	118
			± sd	5.4	7.8	8.6	8.2	7.7	9.5	10.4	9.2	6.9	7.9	7.0	6.3
159	Cropland (Winter Wheat)	3748	Mean	122	126	120	130	116	115	117	125	130	128	134	129
			± sd	7.4	8.7	9.2	10.8	10.2	10.9	11.9	11.9	8.7	9.2	9.7	8.2
161	Cropland (Rice, Cotton)	26546	Mean	114	117	117	122	113	128	139	143	132	121	117	116
			± sd	4.3	5.7	7.1	8.5	8.1	11.8	9.1	6.4	6.1	6.1	4.9	4.5
178	Irrigated Cropland (Rice, Wheat)	1008	Mean	130	142	134	140	111	105	108	109	121	120	151	143
			± sd	8.2	9.9	11.8	13.1	11.3	6.8	11.3	11.4	10.9	7.9	11.6	8.8
179	Cropland (Rice)	14991	Mean	116	121	121	130	131	141	141	145	137	124	118	118
			± sd	5.2	7.3	9.6	9.9	9.3	9.7	8.2	7.4	6.4	6.4	6.6	5.8
181	Cropland (Rice)	116	Mean	118	123	128	142	142	146	136	144	134	118	115	119
			± sd	5.3	7.5	7.5	7.6	6.9	9.7	8.2	8.7	6.4	7.3	5.9	5.7
182	Irrigated Cropland (Double Crop Rice)	923	Mean	119	130	138	143	122	137	141	143	134	121	119	120
			± sd	5.3	7.5	7.6	8.8	10.0	12.2	8.4	8.2	7.8	7.3	6.0	6.0
183	Cropland (Rice)	6050	Mean	126	134	126	133	117	124	136	144	146	137	135	129
			± sd	9.4	11.0	12.1	13.2	9.5	10.8	13.6	9.9	9.1	9.4	9.8	8.9

Id.	Land use	Area (km^2)	NDVI	Apr-92	May-92	Jun-92	Jul-92	Aug-92	Sep-92	Oct-92	Nov-92	Dec-92	Jan-93	Feb-93	Mar-93
184	Cropland (Rice, Wheat)	239	Mean	125	122	107	125	127	135	140	136	138	130	147	142
			± sd	5.8	8.4	6.5	8.1	7.1	7.4	8.4	8.4	8.2	10.5	7.0	6.1
192	Irrigated Crops (Rice)	2012	Mean	131	138	134	124	123	144	148	152	139	123	123	128
			± sd	8.1	10.5	12.1	15.1	10.8	14.7	8.2	7.4	9.2	8.9	11.2	8.9
195	Irrigated Cropland (Rice, Wheat)	4697	Mean	126	132	131	140	129	126	132	137	137	131	130	129
			± sd	7.5	8.1	8.5	8.2	10.2	10.2	11.7	9.3	7.1	8.3	8.2	8.0
196	Irrigated Crops (Rice)	9741	Mean	131	144	134	136	115	116	114	121	148	150	151	136
			± sd	10.4	9.7	15.6	12.4	8.5	11.1	11.5	13.8	12.0	9.3	8.3	8.8
199	Double Crop Rice, Wheat with Deciduous Woodland	12146	Mean	122	140	136	150	136	137	150	152	147	129	121	121
			± sd	6.7	8.7	11.8	9.6	11.8	15.2	8.4	6.9	7.5	9.6	7.1	6.7
201	Cropland (Rice) with Woodlands	11102	Mean	126	138	146	146	118	149	148	153	152	136	127	124
			± sd	9.3	10.9	13.2	13.2	10.1	11.5	9.5	7.7	7.0	9.8	9.3	8.8
207	Cropland/Open Woodland	3940	Mean	140	146	142	144	132	126	135	143	149	145	141	143
			± sd	8.4	7.7	10.1	11.3	12.3	11.6	13.8	10.8	9.0	9.4	8.3	10.4
223	Cropland/Grassland Mosaic	102	Mean	118	127	128	140	133	119	133	138	126	117	117	122
			± sd	4.2	6.1	7.3	6.9	6.0	8.0	10.5	8.1	8.2	6.2	4.7	6.9
240	Cropland/Shrubland Mosaic	8848	Mean	122	129	135	152	146	149	149	151	147	130	120	122
			± sd	6.5	7.6	10.9	8.2	9.3	11.4	8.7	7.6	6.8	9.3	7.9	6.6
244	Fragmented Forest/Shifting Agriculture	804	Mean	135	146	147	152	138	127	121	120	147	149	151	146
			± sd	10.4	7.8	8.7	8.1	13.7	15.1	15.0	11.9	12.3	7.9	7.7	8.3
245	Grassland/Woodland/Cropland Mosaic	8950	Mean	136	146	147	155	146	147	151	151	156	146	139	138
			± sd	7.1	7.3	10.5	8.0	10.2	12.7	9.4	9.1	5.3	8.1	9.6	8.8
252	Inland Water	6344													

Table II 2 Cluster analysis, monthly mean NDVI

Id.	NDVI	Apr-92	May-92	Jun-92	Jul-92	Aug-92	Sep-92	Oct-92	Nov-92	Dec-92	Jan-93	Feb-93	Mar-93
	Mean	121.9	122.5	122.2	132.8	124.2	127.2	134.9	140.4	137.6	128.6	127.3	125.9
cl1	sd	5.6	6.9	8.1	10.0	9.7	10.4	11.5	8.1	8.8	8.9	7.9	8.1
	Mean	123.2	138.9	135.4	148.2	145.0	134.8	142.0	145.8	147.6	137.6	130.6	129.0
cl2	sd	7.1	9.2	7.4	10.2	8.9	15.3	13.1	10.8	9.7	11.5	10.5	9.7
	Mean	126.7	138.6	149.6	150.8	150.1	150.9	153.7	154.0	150.0	129.7	119.8	121.5
cl3	sd	5.3	7.9	6.7	12.1	8.1	12.1	7.4	5.9	6.7	10.4	7.0	7.0
	Mean	116.6	121.8	127.9	135.2	131.9	139.5	141.6	145.2	138.0	125.7	119.5	119.3
cl4	sd	3.7	4.9	6.5	10.9	7.9	11.0	8.7	7.6	7.5	6.9	5.3	4.7
	Mean	112.2	115.5	114.4	121.3	114.1	122.0	133.3	138.5	130.7	118.7	115.5	114.7
cl5	sd	2.3	3.3	3.7	6.4	7.9	8.8	9.2	5.8	5.3	4.3	3.2	3.1
	Mean	135.6	136.1	121.8	133.1	115.5	126.7	130.2	139.5	147.8	140.9	143.6	137.1
cl6	sd	8.1	13.2	10.4	14.6	8.1	12.2	14.5	11.1	10.8	12.9	8.5	9.8
	Mean	123.8	126.7	118.7	133.9	131.5	143.0	145.2	151.0	143.1	128.2	121.2	122.6
cl7	sd	7.0	8.2	7.5	14.5	10.8	12.0	9.0	6.9	8.7	9.7	7.8	7.6
	Mean	123.5	145.2	143.3	150.7	125.5	138.2	148.5	152.5	151.1	134.8	127.1	124.8
cl8	sd	7.6	6.8	7.9	11.7	9.4	16.2	10.8	7.2	7.9	11.8	10.6	9.1
	Mean	133.7	134.0	144.7	146.8	149.6	143.4	148.0	148.7	152.5	144.3	138.9	137.3
cl9	sd	5.9	6.6	8.2	10.9	8.0	13.5	10.9	8.9	8.0	9.7	9.6	9.5
	Mean	138.9	144.5	119.6	147.1	146.1	143.2	145.9	150.7	156.2	150.8	146.6	145.5
cl10	sd	7.4	8.5	8.1	13.7	10.5	16.3	15.2	10.8	8.4	11.6	9.3	8.6
	Mean	126.3	135.5	143.8	147.7	136.0	141.9	148.1	149.5	149.6	139.7	133.4	131.5
cl11	sd	5.3	5.9	6.3	10.9	11.2	14.4	9.6	7.9	9.7	11.5	10.5	10.3
	Mean	116.2	117.0	124.6	121.7	113.8	136.3	144.1	146.8	130.5	124.4	118.9	117.9
cl12	sd	3.1	3.8	6.1	9.4	6.7	9.2	6.2	5.1	5.8	4.5	4.1	3.2
	Mean	116.9	122.1	116.4									
cl13	sd	14.9	18.6	17.7									
	Mean	127.9	137.0	137.7	138.4	114.8	118.3	120.4	128.2	144.3	143.7	144.1	133.6
cl14	sd	8.5	10.3	8.3	11.3	5.9	9.8	12.1	10.9	12.2	10.8	9.0	9.3

Id.	NDVI	Apr-92	May-92	Jun-92	Jul-92	Aug-92	Sep-92	Oct-92	Nov-92	Dec-92	Jan-93	Feb-93	Mar-93
cl15	Mean	126.5	140.7	146.1	150.3	114.7	147.7	150.2	152.8	151.8	137.5	128.1	124.3
	sd	7.7	8.8	6.7	12.1	6.8	12.8	8.2	7.0	7.9	12.7	12.2	11.3
	Mean	137.7	150.6	152.3	149.9	141.4	139.8	151.5	153.9	156.1	146.5	140.0	139.1
cl16	sd	3.7	3.9	5.3	12.2	9.1	16.0	9.8	7.9	6.4	9.7	10.3	8.9
	Mean	118.1	129.6	124.1	143.8	146.9	147.2	146.9	151.6	143.5	124.4	116.5	119.4
cl17	sd	5.4	9.0	8.7	13.5	7.8	11.7	9.3	7.1	7.7	8.6	5.6	6.1
	Mean	109.1	110.5	107.9	115.1	107.4	120.4	134.2	139.1	129.3	114.8	113.3	112.1
cl18	sd	1.7	2.4	2.8	5.8	5.3	7.8	8.4	5.3	6.1	5.3	3.1	3.2
	Mean	135.8	144.2	129.7	142.2	117.3	149.6	145.2	157.1	154.6	143.3	134.9	133.1
cl19	sd	7.0	8.9	7.8	17.5	8.8	10.0	14.9	6.7	8.3	11.5	12.0	11.3
	Mean	145.6	150.8	142.9	148.4	147.8	148.5	154.4	157.1	160.7	155.1	149.6	148.1
cl20	sd	5.0	5.3	8.5	13.2	8.1	14.7	9.1	5.8	4.6	7.7	7.4	6.7
	Mean	148.4	143.9	112.4	130.3	111.8	129.2	134.8	142.5	155.4	147.5	145.2	140.0
cl21	sd	5.6	10.8	6.7	17.0	8.7	16.8	17.0	14.7	9.6	13.3	9.8	11.8
	Mean	115.4	126.1	119.5	130.5	111.8	129.2	137.3	143.3	137.2	124.5	120.5	118.7
cl22	sd	4.4	5.8	6.3	11.6	6.0	12.7	10.6	7.8	8.0	8.5	6.5	5.5
	Mean	146.1	145.7	152.3	140.9	123.8	140.0	151.9	154.0	158.0	153.0	148.8	145.9
cl23	sd	5.6	9.3	5.9	16.6	10.7	15.8	11.2	8.7	7.5	8.6	6.8	7.3
	Mean	120.1	151.6	144.5	146.1	110.2	107.6	105.3	110.1	137.5	151.1	156.3	136.9
cl24	sd	6.2	5.3	9.5	10.2	5.8	8.3	7.4	13.9	16.1	8.3	9.7	10.7
	Mean	119.5	143.8	152.3	157.5	152.4	151.0	154.0	152.4	150.6	129.6	119.2	120.1
cl25	sd	4.7	6.2	5.9	7.1	7.4	14.5	7.8	6.0	5.8	9.2	6.0	6.6
	Mean	126.8	148.8	124.1	150.8	142.0	139.7	147.7	153.5	151.8	136.7	128.6	129.3
cl26	sd	7.0	5.7	8.1	11.8	9.3	16.7	12.2	7.8	8.5	12.9	11.5	9.9
	Mean	124.9	133.5	124.6		106.3							
cl27	sd	11.0	13.8	15.8		7.5							
	Mean	111.9	113.1	109.9	124.2	129.1	139.4	143.0	147.4	137.7	119.3	113.0	114.0
cl28	sd	2.7	3.0	3.9	10.3	9.6	9.2	7.8	5.3	7.0	6.2	5.1	5.3
	Mean	137.9	142.8	141.7	145.0	140.8	122.9	121.6	127.6	148.8	148.4	145.6	144.7
cl29	sd	9.1	10.5	10.8	11.9	9.0	13.5	13.3	12.8	11.9	9.2	7.1	10.9

Id.	NDVI	Apr-92	May-92	Jun-92	Jul-92	Aug-92	Sep-92	Oct-92	Nov-92	Dec-92	Jan-93	Feb-93	Mar-93
	Mean	139.8	148.5	158.1	153.4	151.8	156.4	156.7	153.6	162.7	157.8	152.2	148.4
cl30	sd	6.5	4.3	3.4	9.9	8.0	10.3	8.2	5.9	3.3	5.9	7.2	6.7
	Mean	148.6	150.4	139.7	126.6	126.5	144.9	151.8	156.4	156.2	149.5	143.1	144.2
cl31	sd	4.2	4.9	8.4	17.7	12.6	13.7	11.6	8.6	10.6	11.2	11.7	11.0
	Mean	136.7	146.8	118.5	135.9	137.3	152.2	152.1	156.3	153.1	135.3	125.0	128.2
cl32	sd	7.7	6.8	8.6	19.6	11.3	11.8	10.7	6.2	8.8	12.1	10.5	9.8
	Mean	125.1	146.5	151.1	143.6	110.6	108.9	106.1	109.0	140.2	153.3	160.1	140.5
cl33	sd	5.8	7.5	7.1	10.1	5.0	8.5	7.2	9.8	14.4	7.7	5.1	7.7
	Mean	123.4	150.4	132.3	153.1	119.9	154.1	152.8	157.7	154.3	127.2	120.6	121.1
cl34	sd	6.1	6.7	8.7	12.4	10.5	10.6	7.7	6.0	6.1	10.9	7.8	7.1
	Mean	125.5	150.4	114.5	148.0	114.1	144.7	146.8	155.3	154.9	135.8	130.6	126.2
cl35	sd	7.6	6.6	6.7	14.3	7.7	15.6	9.6	8.2	7.4	12.8	11.4	10.4
	Mean	119.2	141.6	116.8	137.9	118.3	116.2	117.7	126.8	144.0	142.5	145.3	131.0
cl36	sd	8.6	8.6	9.2	13.3	11.9	14.6	16.1	17.6	12.9	10.5	10.5	9.7
	Mean	123.0	126.2	119.9	130.1	116.5	113.5	117.2	124.6	133.3	134.0	136.2	130.7
cl37	sd	9.0	10.2	8.6	14.0	11.3	13.5	14.1	13.8	14.8	13.5	13.5	11.7
	Mean	146.9	156.7	110.6	139.4	104.0	143.4	140.4	151.2	160.0	148.9	144.1	132.5
cl38	sd	6.5	4.8	5.1	19.9	3.4	16.9	11.8	11.3	7.0	10.0	7.9	12.4
	Mean	137.8	131.8	140.3	131.1	127.0	144.8	148.9	153.5	148.4	136.6	131.3	132.4
cl39	sd	8.1	8.4	8.8	16.4	15.3	13.6	9.2	7.7	10.5	13.2	14.1	12.5
	Mean	148.3	158.2	148.6	137.7	112.1	124.2	123.2	129.2	155.4	153.3	146.5	143.6
cl40	sd	6.2	5.2	5.2	15.9	9.7	15.1	15.8	14.1	14.8	10.9	7.8	12.9