

Landscape level characterization of seasonal floodplains under community based aquaculture: illustrating a case of the Ganges and the Mekong Delta

CBFC Working Paper No. 4

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April 2010



CBFC Working Paper Series

The Community-based Fish Culture in Seasonal Floodplains and Irrigation Systems (CBFC) project is a five year research project supported by the Challenge Program on Water and Food (CPWF), with the aim of increasing productivity of seasonally occurring water bodies through aquaculture. The project has been implemented in Bangladesh, Cambodia, China, Mali and Vietnam, where technical and institutional options for community based aquaculture have been tested. The project began in 2005 and was completed in March 2010.

This working paper represents work-in-progress. It forms part of a series of documents presenting research findings from the project. The reader is advised that it has not been subjected to academic quality control, nor edited for errors of fact or interpretation.

DRAFT

1 Background and study scope

1.1 Floodplain ecosystem

Floodplains of world's major rivers systems support occupations, livelihoods, and trade for millions (King, 2008). They provide the most fertile agricultural lands in the world with alluvial deposits enriching soils, providing an ideal medium for crop production (Reij et al, 1991; Erenstein, 2006). In tropical landscapes, these rich environments provide a range of diverse livelihoods, often characterized by dry season cropping and flood season fishing. In some regions, flood waters are controlled to permit an additional cropping season (Baran et al. 2001; Winklerprins, 2002). In particular, seasonal floodplains are water bodies that annually retain water for 5-6 months largely during the wet and the post-wet season (World Fish, 2002). In terms of land use, they generally serve as a private property for rice production during the dry months and a common resource pool available to catch and grow fish and other aquatic organisms while flooded or inundated (Baran et al. 2001; Sheriff et al, 2008).

The project 'Community-based Fish Culture in Seasonal Floodplains' (henceforward the community-based fish culture project), CGIAR Challenge Program on Water and Food, aims to enhance fish production in seasonal floodplains to improve and sustain rural livelihoods in Bangladesh, Cambodia, China, Mali and Vietnam. During the dry season, these areas are predominantly used for agricultural production and boundaries between private and commonly owned land are clear. In the flood season, land boundaries in flooded areas become indistinct, and ownership reverts to open access or common ownership. Seasonal flooding creates a dramatic shift in livelihoods and resource production for households in floodplain areas. Fish production, based on open access to capture fisheries, becomes an important use of these areas under flooded conditions (Sheriff, Arthur, Barman & Hong, 2008).

Based on the premise that production from these water bodies could be enhanced by stocking locally important fish species, the community-based fish culture project seeks to develop technologies and institutional arrangements to support collective fish culture in the flood season. The development of collective approaches to fish culture with local stakeholders has met with varying degrees of success. This has led to a deeper consideration of context and its contribution to the success or failure of collective action under differing socio-ecological conditions. The current report provides a landscape level characterization of seasonal floodplains in two of these areas. We compare the Ganges seasonal floodplain agro-ecology in Bangladesh to that in the Mekong Delta of Cambodia and Vietnam. In both areas the project has been under implementation since the outset, but has met with contrasting results (Sheriff et al., 2008).

Densely populated river deltas in South and Southeast Asia are amongst the areas most vulnerable to environmental degradation and change. Such change translates directly in increased risks and vulnerabilities to communities dependent on fisheries and related natural resources. Floodplains in these river deltas provide important ecosystem services to the burgeoning population. Floodplains are fertile agricultural areas that provide food security to urban and rural households alike. During monsoon large expanses of floodplain become virtually uninhabitable but they provide valuable fisheries resources.

In much of the developed world, the floodplain dynamics have been brought under control by elaborate engineering structures, exerting our control over nature (Parker, 1995). Throughout the developing world, floodplains are still subject to the natural seasonal patterns of flood, following a regular pattern of inundation and recession (Tamuno, 2003). Diverse food production systems of seasonal tropical floodplains in Asian countries like Bangladesh, China, India, Indonesia, Malaysia, Thailand and Vietnam reflect a high degree of complexity in human and the ecosystem interactions (Little & Muir 1987). For example, Bangladesh has 2.8 million hectare of floodplains; of that, 1.5 million hectare are suitable for fish production (Rahman and Ranamukhaarachchi, 2003; Shankar. 2002). The Vietnamese Mekong Delta is responsible for nearly sixty percent of Vietnam's aquaculture (Wilder and Thanh Phuong, 2002) and their contribution to rice crop production is more than fifty percent and growing (Brocheux, 1995; Lam, 2001).

The floodplain ecosystem accounts for million hectares of rice land in South and South East Asia (Dey and Prein, 2004). Where the flood waters are deep, private land gives way to open access water resources during the flood season, opening up capture fisheries to the surrounding population as explained by Dey and Prein (2006) in case of Bangladesh and Ahmed and Tana (1996) for Cambodia. Mazid (2002) estimates that in Bangladesh, 1.4 million people are engaged in fisheries for their full time employment and 12 million on part time basis for household consumption and livelihood support.

It is anticipated that fisheries production will no longer be able to meet the needs of a growing global population (FAO, 2000). Aquaculture is seen as a potential alternative to capture fisheries as a source of both food and income (FAO, 2000). In flood plain regions, extensive water resources have the potential to support aquaculture production, augmenting supplies from capture fisheries and supporting the livelihoods of the many vulnerable people who live in these dynamic environments. For instance, it is estimated that annual fish production in Bangladesh can increase 4 to 5 times if 50% of the 1.5 million hectare of floodplains suitable for aquaculture can be brought under community management (Dey & Prein, 2006).

Remote Sensing and Geographic Information Systems (GIS) tools to map resource features using earth observation data acquired from spatial systems have become important as decision support system. Acknowledging, the landscape pattern and relief are important parameters to determine the hydrological flow and interactions that can potentially support or undermine the fish culture activity during the wet season, we illustrate the multi-scalar (ranging from basin, catchment and the community level) floodplain dynamics in the Indo-Gangentic and the Mekong, while explaining the framework.

- a) How bio-physically appropriate is the introduction of seasonal aquaculture in floodplain landscape context? Does floodplain fish culture have a clear potential for up scaling?
- b) Is the technology 'suitable' in a multiple water use context? Is it scalable and sustainable?
- c) How does the concept fit into the context of future development of floodplains, fisheries and aquaculture?

1.2 Floodplains in the Indo-Gangentic and the Mekong basin

Ganges Floodplains

As a representative of low-lying floodplains in the Indo-Gangentic basin, we explain in detail the floodplain characteristics in Bangladesh. Bangladesh is composed of an alluvial delta of ca. 144,000 km² formed by the Ganges –Padma, Meghna and Jamuna – Brahmaputra rivers and their tributaries. Bangladesh is composed of an alluvial delta of ca. 144,000 km² formed by the Ganges – Padma, Meghna and Jamuna – Brahmaputra rivers and their tributaries. Floodplain agro-ecozones occupy ca. 80 percent of the country (FAO/UNDP 1988 in Craig et al. 2004). Of these, river floodplains cover 80,500 km² or 55 percent of the country (Brammer 1997 in Craig et al. 2004). The extent, depth and duration of annual flood inundation is variable and unpredictable. In an average year ca. 26,000 km² of the floodplain is seasonally submerged, roughly from June till October. The maximum extent in recent years has been 82,000 km², but the extent of inundation in 1998 is thought to be the highest on record with 95,000 km² (66 percent of the country) inundated.

Within the floodplains, large inland depressions occur, which become inundated during the flood season and form permanent or semi-permanent waterbodies ('beels' and 'haors') that support productive fisheries. These water bodies retain water for 5-6 months during which they are suitable for growing fish and other aquatic animals that are essential for the livelihoods of millions of people. During dry months they are largely used for rice production (Haque et al. 2008). Fisheries supply ca. 80 percent of the daily animal protein intake of the population in Bangladesh (Rashid 1991 in Craig et al. 2004). Mazid (2002) estimates that 1.4 million people are engaged in fisheries for their full time employment and 12 million on part time basis for household consumption and livelihood support.

Participation in floodplain fisheries can be categorized into professional, seasonal and subsistence, but there is considerable overlap between these categories. Despite its widely recognized importance there is a general lack of data on the contribution of fishing to floodplain livelihoods, and particularly the contribution of fishing to incomes in mixed occupation households. The Bangladesh Department of Fisheries (DOF, 1990) estimated that 73 percent of rural households are involved in floodplain fisheries. The Flood Action Plan (FAP) found the participation in fishing in agricultural villages to range from 47 percent in the northwest to 73 percent in the north-central region. Huq and Huq (1985, cited in Craig et al. 2004) found in a reciprocal study that households in fishing communities were involved in farming and agricultural labour in a village well endowed with land, but trade was more important in perennially flooded areas.

The estimated total annual catch of fishes and shrimp from all inland waters in Bangladesh was ca. 600,000 t in 1996 – 1997. An increase of ca. 190,000 t in inland catches since 1989 – 1990 is mainly attributed to floodplain fisheries. According to official statistics (Ministry of Fisheries and Livestock) inland fisheries have been steadily increasing, to just over one million t in 2006-07. Fisheries from flooded land have doubled from 378,000 t to 768,000 t over that time, thus accounting for more than 75 percent of the total inland capture production (Table 1). Catches from rivers and estuaries have been stagnant or declining over the same period. National catch statistics indicate a catch per unit area (CPUA) of 60 to 130 kg ha⁻¹ per year from an estimated total floodplain area of 2.8×10^6 ha. Despite the promise that floodplains hold for maintaining fish production, the extent of floodplain fisheries is being

reduced due to hydraulic engineering interventions, reclamation and cultivation of wetlands, and use of surface water for irrigation of crops. The total area under flood control is projected to increase from 4.4×10^6 ha in 1995 to 5.7×10^6 ha in 2010. Agriculture is the major use of floodplain areas in Bangladesh and competition for use of floodplains revolves around control of flooding in the monsoon season and the use of surface water for crop irrigation in the dry season. Earthen embankments or levees form poldered areas for flood control, drainage and irrigation, and often affect fish production in these schemes negatively. A number of studies have been undertaken to assess the impacts on fish production but firm conclusions could not be drawn because of non-significant, inconsistent and often contradictory results (Craig et al. 2004).

Several floodplain fisheries enhancement projects have been undertaken in Bangladesh. The results of these projects indicate that a more systematic approach is required to develop management models and policies, and that habitat restoration may be a more appropriate way to improve resource availability or enhancing fish stocks than floodplain stocking alone. Enhancement also must serve a social reason. People involved should be entitled to a share of the benefit. This is the basic rationale of the community-based fish culture project. There are concerns that introduction of large scale stocking of carps in open water might imbalance the ecosystem and adversely impact on biodiversity of non-stocked indigenous fish (Ali 1997). In some occasions stocking with major carp has negatively affected catches of small indigenous species (SIS) and has resulted in poorer nutritional outcomes in women and children who consume SIS.

All inland fisheries resources in rivers, canals and permanent water bodies, except those from privately owned ponds and borrow pits, fall under the jurisdiction of the Government, with legal ownership held by the Ministry of Lands (MOL). During the flood season the 'jalmohal' (water estate) leasing system cannot operate because individual waterbodies are no longer demarcated by land and private access right can no longer be enforced because geographical boundaries do no longer exist. Customarily, access is open to all fishers during this period. This is of considerable social and economic importance, particularly for the landless poor. The jalmohal system has been widely criticized because it promotes over-exploitation through short term leases in the absence of appropriate incentives for conservation and lack of control mechanisms and surveillance by DOF. Since 1995 the leasing of jalmohals was abolished by the MOL altogether. Effectively all flowing rivers and sites not managed by licensing arrangements became free access, with no restrictions on fishing activities. As a consequence the system is in confusion and a complex array of management systems and arrangements now prevail. Faced with the complex and dynamic nature of the system, DOF increasingly favours co-management approaches in order to achieve national objectives for the sector. The Government is increasingly devolving management responsibility to local communities and community based management of inland fisheries is becoming more common (Craig et al. 2004).

Community based aquaculture (CBA) could help mitigate the declining volume of inland capture fisheries production. About half of the 2.8×10^6 ha floodplain area in Bangladesh is suitable for community based fish culture. According to Dey and Prein (2005) annual fish production could increase by 450,000 t, with estimated value of US\$340 million, if CBA would be adopted in only half of the suitable floodplain area. This would assume an increase

in average yield by ca. 320 kg ha⁻¹ and would benefit an estimated 6.7 million people, 2.7 million of whom are either landless or functionally landless. Enhancements in floodplain fish productivity through community-based fish culture have been targeted under a 5-year interdisciplinary action research project with the overall aim to improve and sustain rural livelihoods, supported by the Challenge Program on Water and Food (Sheriff et al. 2008). The project is carried out in three floodplains within the Indo-Gangetic River Basin. Results after two harvest periods are encouraging, with total fish production in seasonal floodplains under intervention ranging between 215 kg and 658 kg ha⁻¹, averaging a production of 409 kg ha⁻¹ over a culture period of 5-6 months.



Picture1 : Indo-Gangetic floodplain in the Brahmaputra catchment: Mymensingh, Bangladesh (January, 2009)

Mekong Floodplains

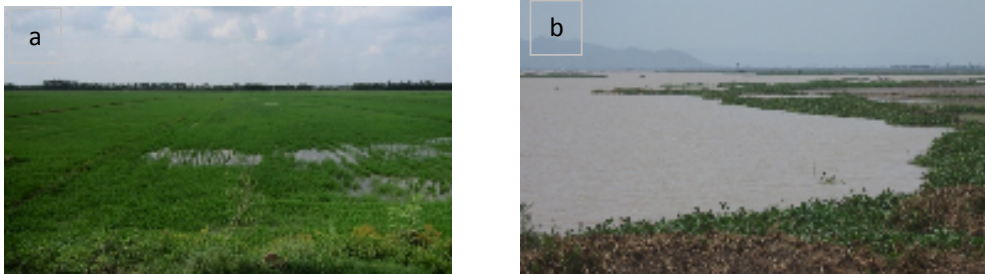
The floodplains of the lower Mekong basin (LMB) in Cambodia and Vietnam are significant part of the Mekong wetland ecosystem. The ecosystem is primarily driven by the monsoon floods of the Mekong River, the large floodplain, rich biodiversity, and high annual sediment and nutrient fluxes from river render the area highly productive both for crop and fish culture. The fishery in the Lower Mekong Basin is among the biggest and most productive inland fisheries in the world, and LMB floodplains produce some four times as much fish per square kilometre as the North Sea, hence regarded among the most productive areas globally (Jensen, 2000). Livelihoods, food security, income and nutrition of the people living in and around the floodplains, majorly in Cambodia, are depend strongly on the floodplain resource use for crop culture and capture fisheries (Kummu et al., 2006).

Vast seasonal floodplains, created by annual flooding, characterize the lowland agro-ecosystems in the Mekong Delta in Vietnam and a large part of the Cambodian lowland area. Floodplains in the Lower Mekong Basin (LMB) cover some 70,000 km² (van Zalinge et. al., 2004). These floodplains fulfil important ecosystem services. Amongst the most important of these are water storage, flood conveyance (Fujii *et al.*, 2003) and food provisioning from agriculture and fisheries. Despite the benefits derived from floodplains, people dependent on these systems are amongst the poorest and most vulnerable in the LMB, particularly in Cambodia. Natural disasters caused by floods and drought are direct threats to food security and transitory food insecurity occurs frequently. Seasonal floodplains in the Mekong Basin are highly productive in terms of fish and other aquatic organisms. They provide an indispensable source of protein for local people (Sverdrup-Jensen, 2002). Consumption of fisheries products is very high. Estimates range from 13.5 to 40 kg fish per person per year, and up to 75.6 kg in provinces bordering the Tonle Sap in Cambodia. According to MRC (2004) the Mekong counts approximately 1,500 freshwater fish species.

In Cambodia alone 477 freshwater fish species have been recorded (Baran, 2005). Most fish populations in the Mekong basin follow the yearly inundation patterns and migrate from the mainstream and tributaries to colonize inundated areas where they spawn and feed. Large areas of natural floodplains are accessible to fish for foraging, offering a diversity of trophic niches and shelters (Junk, 1976). Commercially important species can broadly be categorised into two groups: *black fish*, species that undertake limited lateral migrations and are able to survive in swamps and plains year round, and *white fish*, species that mostly undertake significant lateral and longitudinal migrations (Welcomme, 1985; Fernando, 1993). As the competition for the basin water resources are becoming stronger in the region, the use of water resources for competing economic activities has brought unplanned threat to the fish sector. Considering this impact, an in-depth understanding of the ecosystem functions seems essential for integrated water resources management and for sustainable basin resource management, and national and regional policy making process.

The annual inland fisheries catch of Cambodia is conservatively estimated at about 400,000 tonnes. Three categories of inland fisheries are distinguished; large scale fishing, also known as fishing lots, medium scale fishing in open areas in rivers and lakes, and small-scale or family fishing for subsistence. Family fishing and rice field fisheries were not included in official catch statistics up till 1998 but they account for up to two-thirds of the yearly inland fisheries production (Table 2). Fish yields in Cambodian floodplains are estimated at 139 to 230 kg/ha/year. This amount is higher than in any other tropical floodplains. According to Baran (2005) this can be explained by three interconnected factors: high biodiversity, accessibility of the floodplains and a very high exploitation rate, at 20 kg per capita per year. Fast-growing species with a short life span, mostly Cyprinids, are now dominant. This is probably the result of the high exploitation rates maintained over decades. Unlike in many of its neighbouring countries, rice fields in Cambodia still produce a considerable amount of aquatic products such as fish, shrimps, frogs, crabs and snails (Gregory *et al.*, 1996). During the rainy season, most rice fields are flooded and the aquatic medium is connected with the wider aquatic environment. Rice fields offer a temporary and seasonal habitat to fish and other aquatic organisms. The duration of this phase varies greatly from site to site and from year to year depending on the average annual rainfall (Figure1).

The ecology of rice fields is dominated by rapid physical, chemical and biological changes, and organisms which survive and thrive in this environment have wide tolerance limits for these rapid changes. Fish species that colonize rice fields are predominantly marsh-dwelling and air breathing species (Fernando, 1993). Estimates of rice field fisheries production from studies in Svay Rieng province, South-eastern Cambodia, range from a minimum of 25 kg.ha⁻¹.yr⁻¹ (Guttman, 1999) up to 125 kg.ha⁻¹.yr⁻¹ (Gregory *et al.*, 1996). Rice field fisheries contributed 45,000 to 110,000 tonnes to annual fish production in the years 1994-97 (Ahmed *et al.*, 1998; Diep *et al.*, 1998, cited in Sopha *et al.*, 2004). Guttman (1999) found that the value of fish caught in rice fields in Svay Rieng reaches 37 to 42 percent of that of rice production. Gregory *et al.* (1996) concluded that the value of fish and other aquatic products collected in rice fields in three villages in Svay Rieng's Svay Theap district exceeded that of rice. Despite its importance, rice field fisheries are generally overlooked in development planning (Hortle *et al.*, 2008).



Picture 2: Land water use pattern in the Lower Mekong basin: Rice plantation post wet season in Thap Muoi district of Vietnam 9 (a); the Kirivong reservoir in Takeo province, Cambodia (b)

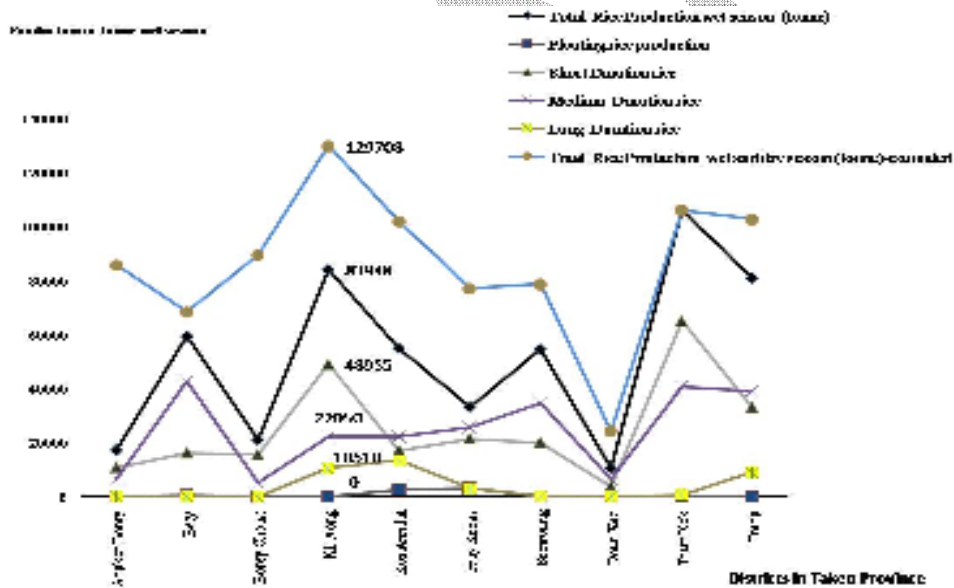


Figure 1: The national level rice production profile for Lower Mekong Basin (Vietnam). The wet season rice production dominates the total rice production in the Kirivong (study area) region

Area of Interest

This study compares seasonal and hydrological cycles of floodplains in Bangladesh and Mekong Delta under project intervention and its implications for the contribution of community based aquaculture (CBA) production vis-à-vis alternative and sometimes competing livelihoods. Fish stocking has been carried out at each of the project sites in the region under the guidance of national partners with expertise in local aquaculture systems. Locally preferred species have been stocked in polyculture systems, with stocking densities and proportions varying from year to year as the culture systems have evolved. Enclosure designs have similarly been locally adapted and modified.

In Bangladesh we present a landscape level analysis of patterns of water- and land use in two seasonal floodplains, 'Beel Mail' in Mohanpur sub-district ('upazila') in Rajshahi district, and 'Kalmina Beel' in Fulbaria upazila, Mymensingh district. We also estimate the total area in Bangladesh under similar floodplains and population living in and around such floodplain areas in order to assess the potential for up- and outscaling the CBA approach. On the basis of the area estimate we evaluate the potential increase in floodplain fish production. In the Mekong Delta we compare the relatively unmodified seasonal floodplains in southern Takeo province Cambodia, with the highly modified, irrigated rice dominated floodplains in the Vietnamese Mekong Delta (VMD).

In Cambodia we focus on Krapum Chhuk, an impoverished commune in southern Takeo province near the border with Vietnam's An Giang province. The commune is heavily dependent on floodplain rice production. Except from a low production deepwater rice crop, wet season rice production is not anymore an option since a nearby flood protection scheme across the Vietnamese border has been in operation.

1.3 Context of Community based aquaculture (CBA) in Seasonal floodplains

It is anticipated that fisheries production will no longer be able to meet the needs of a growing global population (FAO, 2000). Aquaculture is seen as a potential alternative to capture fisheries as a source of both food and income (FAO, 2000). In flood plain regions, extensive water resources have the potential to support aquaculture production, augmenting supplies from capture fisheries and supporting the livelihoods of the many vulnerable people who live in these dynamic environments. For instance, it is estimated that annual fish production in Bangladesh can increase 4 to 5 times if 50% of the 1.5 million hectare of floodplains suitable for aquaculture can be brought under community management (Dey & Prein, 2006).

In 2005, the WorldFish Center initiated a project with an overall aim of enhancing fish production in seasonal floodplains to improve and sustain rural livelihoods. The project has sought to develop technologies and institutional arrangements to support collective fish culture in the flood season appropriate to a variety of environmental and socio-cultural settings represented by Bangladesh, Cambodia, Vietnam, China, and Mali (Sheriff et al, 2008). As the initial start up cost for an aquaculture system can be prohibitive for individual poor households, a community-based approach was selected to allow poorer households to participate in, and benefit from, aquaculture production. This section of the project explores seasonal and hydrological cycles in floodplains under the intervention and its implications for the contribution of community based aquaculture (CBA) production vis-à-vis alternative and sometimes competing livelihoods.

The study compares seasonal and hydrological cycles of floodplains in Bangladesh and Mekong Delta under project intervention and its implications for the contribution of community based aquaculture (CBA) production vis-à-vis alternative and sometimes competing livelihoods. In Bangladesh we present a landscape level analysis of patterns of water- and land use in two seasonal floodplains, 'Beel Mail' in Mohanpur sub-district ('upazila') in Rajshahi district, and 'Kalmina Beel' in Fulbaria upazila, Mymensingh district. We also estimate the total area in Bangladesh under similar floodplains and population living in and around such floodplain areas in order to assess the potential for up- and outscaling the CBA approach. On the basis of the area estimate we evaluate the potential increase in floodplain fish production. In the Mekong Delta we compare the relatively unmodified seasonal floodplains in southern Takeo province Cambodia, with the highly modified, irrigated rice dominated floodplains in the Vietnamese Mekong Delta (VMD). In Cambodia we focus on Krapum Chhuk, an impoverished commune in southern Takeo province near the border with Vietnam's An Giang province. The commune is heavily dependent on floodplain rice production. Except from a low production deepwater rice crop, wet season rice production is not anymore an option since a nearby flood protection scheme across the Vietnamese border has been in operation.

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and would benefit an estimated 6.7 million people, 2.7 million of whom are either landless or functionally landless. Enhancements in floodplain fish productivity through community-based fish culture have been targeted under a 5-year interdisciplinary action research project in five countries with the overall aim to improve and sustain rural livelihoods, supported by the Challenge Program on Water and Food (Sheriff et al. 2008). The project is carried out in three floodplains within the Indo-Gangetic River Basin; .. sites in the Mekong Basin spreading out in Cambodia and Vietnam (Figure1). Results after two harvest periods from Bangladesh are encouraging, with total fish production in seasonal floodplains under intervention ranging between 215 kg and 658 kg ha⁻¹, averaging a production of 409 kg ha⁻¹ over a culture period of 5-6 months.

We present a landscape multi-level analysis of patterns of water- and land use in two seasonal floodplains of the **Indo-Gangetic basin**; ‘Beel Mail’ in Mohanpur sub-district (‘upazila’) in Rajshahi district, and ‘Kalmina Beel’ in Fulbaria upazila, Mymensingh district and two floodplain sites from the Mekong viz., Pum Ed in Prey Ampok Commune, Kirivong district -Takeo Province in Cambodia and other floodplain in Trung Xuan Commune, Thap Muoi District -Vietnam. Additionally, for Bangladesh, we also estimate the total area under similar floodplains and population living in and around such floodplain areas in order to assess the potential for up- and out scaling the CBA approach. On the basis of the area estimate, the potential increase in floodplain fish production is evaluated.

Data and Methodology

Floodplain Seasonality Analysis at national level

A regional scale spatio-temporal analysis was undertaken to describe seasonal patterns and trends in land cover and related changes in floodplain resource use over a nine and half year period from 18 February 2000 (DOY 049) to 11 August 2009 (DOY 209). We used the methodology developed by van Brakel & Ross (submitted) to identify floodplain seasonality by deriving spatio-temporal changes in vegetation index (VI) from time series of MODIS satellite imagery. MODIS imagery is capable of revealing cyclical as well as inter-annual climate dynamics and its effects, such as seasonal and long-term vegetation change. 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). This study uses a time series of 218 enhanced vegetation index (EVI) composite images of 16 days each, at 500 m resolution (MOD13A1 Vegetation Index product, Version 005) to analyse the seasonal dynamics of floodplain ecosystems in Bangladesh. The EVI provides improved vegetation monitoring through a de-coupling of the canopy background signal and a reduction in atmospheric influences. This is an important advantage over using the standard Normalized Difference Vegetation Index which is attenuated by higher levels of atmospheric contamination (aerosols and water vapour) associated with humid rice production areas in tropical and subtropical regions.

An unsupervised pixel classification method was applied by combining two well established image processing routines; Principal Components Analysis (PCA) and an iterative self-organising cluster routine. Long sequence time series PCA provides a comprehensive indicator of change events in time series of spatial environmental data (Eastman & Fulk, 1993). The application involves the following steps (refer Figure 2).

- 1) A time series of EVI composites is subjected to PCA,
- 2) The resulting Principal Component images are used as input layers or 'bands' in the cluster routine,
- 3) For each spatial cluster in the image output a Boolean mask is created and,
- 4) The mask overlaid (multiplied) with the original time series,
- 5) Result is a VI time series for that cluster only.

Seven EVI principal component images resulting from the PCA and capturing most of the spatial and temporal variability in EVI over the study area were used as inputs into a self-organising cluster analysis. The principal component images in this analysis can be considered equivalent to bands of a multi-spectral image. Each image represents a different portion of spectral variability in the original image data set. The routine is used to uncover clusters of pixels that share a set of spectral reflectance characteristics unique to that cluster. The number of clusters to be uncovered through this procedure is determined by the user. In this case the number of clusters to be uncovered was initially set to 76 (including a background cluster), the maximum that could be processed with the available IDRISI 15.0 Andes Edition software. Each cluster in the output consists of a set of pixels sharing a unique combination of characteristics that in theory distinguishes a particular ecosystem unit in terms of the environmental variable under study.

Temporal variations in 16-day EVI means, and deviation from the mean, were calculated for each cluster. The result, a time series of EVI average 16-day values for that particular cluster, was used to infer the seasonal characteristics for the cluster over the entire 9.5 year period. Change analysis of cluster-specific time series reveals whether seasonal or long-term (inter-annual) changes occur within the system (Barbu and Zhu, 2004). The PRIMER 6 statistical package (© PRIMER-E Ltd.) was used to test the clusters in each time series for resemblance. Similarity coefficients between pixel clusters were computed, and the dissimilarity between each cluster was plotted as simple Euclidean distance in a 2-dimensional ordination space

The PRIMER 6 statistical package (© PRIMER-E Ltd.) was used to analyze similarity of the clusters resulting from the PCA. A non-metric Multi-Dimensional Scaling (MDS) analysis was performed to test the clusters in each time series for resemblance. Similarity coefficients between pixel clusters were computed, and the dissimilarity between each cluster was plotted as simple Euclidean distance in a 2-dimensional ordination space. Higher resemblance in patterns of EVI characteristic between systems is graphically expressed in the MDS configuration plot as lower Euclidean distance between the clusters representing these systems (**Error! Reference source not found.**). Clusters that resembled each other highly (Euclidean distance < 1.0) were considered as belonging to the same agro-ecosystem.

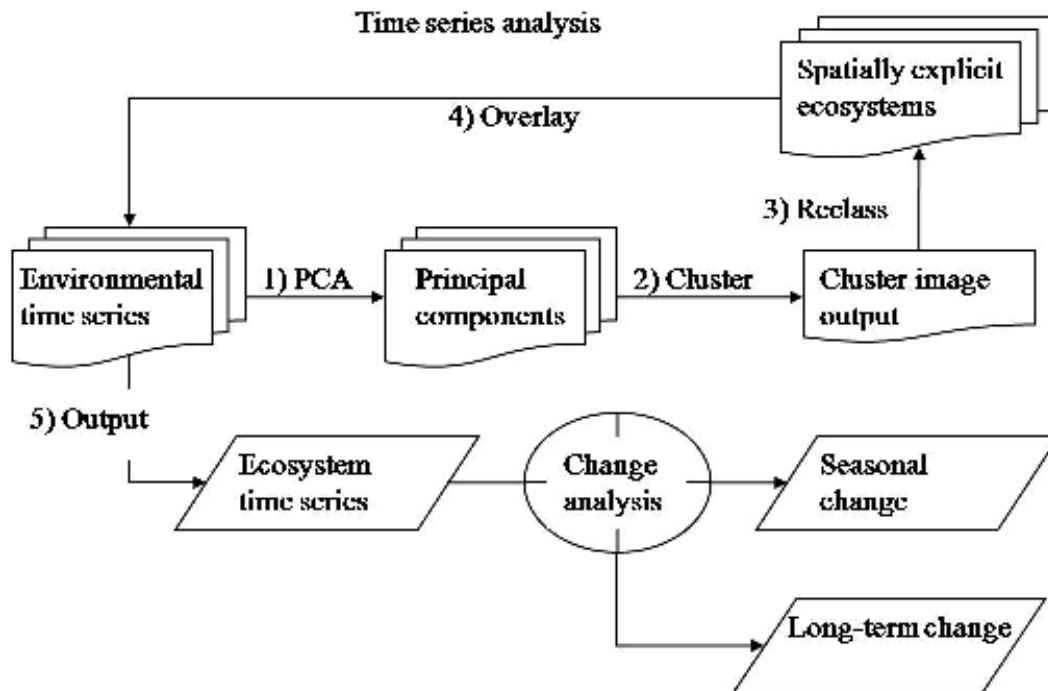


Figure 2: Diagram for change analysis in time series of spatial environmental data (adapted from van Brakel & Ross, 2009)

Floodplain Seasonality Analysis at landscape level

Spatial Classification

To capture the seasonal complexness of the floodplain ecosystem, the spatial classification applies geospatial tools to characterize present land–water pattern and track temporal trends. The boundary for floodplain was defined using the basin boundary. To assess the biophysical characteristics, multi-temporal earth observation data reflecting wet and dry season floodplain landscape was subjected for classification for two sites in Ganges Basin and two in Mekong (details of the data in Table ..). All these datasets were geometrically corrected and projected to 1:50,000 with UTM projection (WGS 84 datum). Ancillary data for example stream network, road map, information on hydrological parameters are used as reference data to compliment different stages of the geospatial analysis. The GCP's were collected with the help of False colour composite (FCC) hard copy print, survey sheets of the region and Global Positioning System (GARMIN-GPS). The ground control points (GCPs) collected during the site reconnaissance are used to derive signature value for each floodplain land use category identified on ground and spectral range (interpretation key) for each category. A schematic representation of the methodology is depicted in Figure

Freely available Landsat Enhanced Thematic Mapper data (Global Land Cover Facility-<http://glcf.umiacs.umd.edu>) both for wet and dry season are classified on 'WINDOWS' based computer program 'ERDAS IMAGINE 9.3' image processing software using

unsupervised 'cluster based approach' classification method and 'Maximum Likelihood' algorithm. The data was subjected for unsupervised classification method, the approach facilitated to capture applicable information from the earth observation data based on the spectral properties. Classification accuracy for unsupervised classification method falls between 70 to 85 for all sites. In terms of natural vegetation, the floodplain ecosystem is comparatively less heterogeneous when compared to forest or riparian zones. Majority of floodplain ecosystems in the Asian region are exploited for crop (rice) cultivation for the entire year, depending on inundation levels.

The digital classification approach takes account of the contextual image information and the process repetitiveness is prognosticated. With this advantage of multiple spatial iterations, closely related floodplain land cover categories could be separated and delineated, employing the image interpretation elements such as tone, texture, colour, pattern and association (described in Table ...). The accuracy of the classification methods was calculated based on the Kappa statistics (Monserud and Leemans, 1992). The floodplain classes were defined based on the local knowledge and anecdotal records, so as to understand the 'relationship' and 'fit' with the locally accepted floodplain management system. The geospatial analysis was validated using the secondary data collected during ground survey and the information derived from secondary socio-economic data. The socioeconomic data needed for the classification process was collected at multiple administrative level for each site to supplement the biophysical characterisation process.

Change Detection Analysis

This component examines the temporal dynamics in the floodplain wetland complex. The floodplain cover/use thematic layer derived from the classification phase serve as the 'input layer' to capture the transitions in the floodplain ecosystem based on the change module (algorithms) in ERDAS. The input layers were subjected for the change analysis process to classify temporal states in the floodplain complex and to explain the impact of annual and temporal spatial variations. This component of the spatial analysis was also validated by using relevant socioeconomic observations and data derived form from focal group discussions, employment sector structure and pattern, ecosystem services and benefits seasonal profiling and data synthesis from household survey. Classification results from historical images (.....) are validated based on geographical locations of some important features, like settlements, water channels etc on available survey sheets.

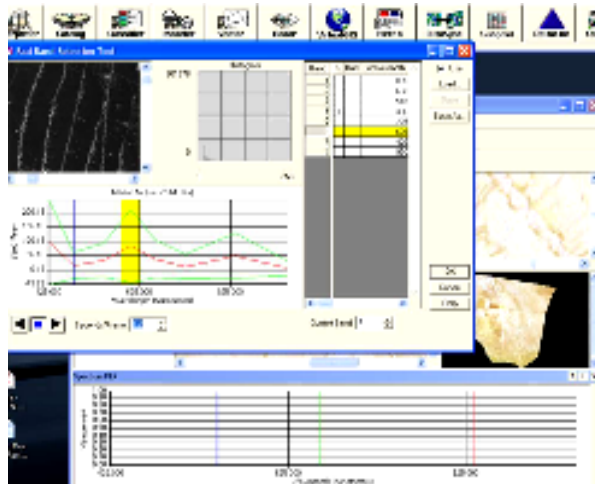


Figure: Overview of spectral (pixel) pattern while spatially classifying floodplain landscape in ERDAS Imagine

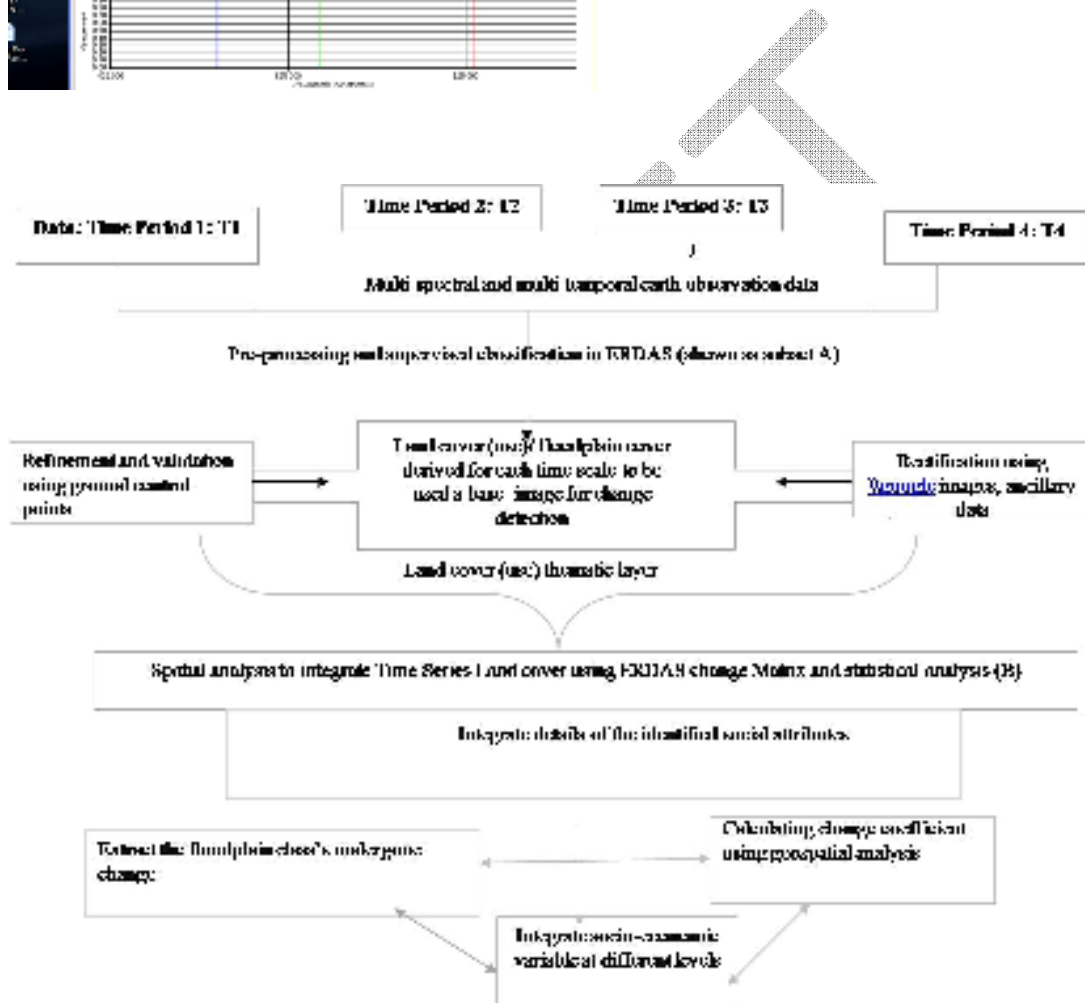


Figure: Methodology for floodplain classification, change analysis and spatial modelling

Table 1 Multi-spectral and multi-temporal earth observation (A) data used for the spatial analysis; (B) interpretation key for mapping the land cover /use in flood characterisation for all sites

Section A: Data characteristics					
Satellite-sensor	Path-row	Date of acquisition	Spatial resolution (m)	No of bands	
Main Data					
Landsat-MSS					
Landsat TM					
Landsat ETM					
Reference data					
Landsat ETM					
Photo-interpretation element					
Land Cover Class	Tone	Texture	Shape	Pattern	Description
Aquatic vegetation	Dark red and light pink	Smooth	Varying	Smooth	Densely packed vegetation
Aquaculture	Dark blue	Fine	Regular	Scattered	Closed water tanks with clear bunds
Marshy land	Dark brown	Coarse	Irregular	Rough	Vegetation in water logged areas
Open land	Light grey	Coarse	Irregular	Smooth	Land with scattered vegetation
Agriculture	Light green	Smooth	Varying	Smooth	Crops with current fallow lands
Water body	Dark or light blue	Smooth	Irregular	Scattered	Canals, ponds and tanks
Settlement	Whitish grey	Coarse	Regular	Rough	Many houses grouped into one

Results and Discussion

Seasonality Analysis for Bangladesh: National scale

The floodplain seasonality based on MODIS-time series is described using cluster analysis. Higher resemblance in patterns of EVI characteristic between systems is graphically expressed in the MDS configuration plot as lower Euclidean distance between the clusters representing these systems as shown in **Error! Reference source not found.** Clusters that resembled each other highly (Euclidean distance < 1.0) were considered as belonging to the same agro-ecosystem. Clusters 'cl15' and 'cl49' (**Error! Reference source not found.**, green ellipse) are discerned as being highly dissimilar from all other clusters. These clusters have low (0 – 0.1) EVI values throughout the time series, which is characteristic for water and 'no vegetation' (**Error! Reference source not found.**).

In the case of Bangladesh, clusters cl15 and cl49 (**Error! Reference source not found.**, green ellipse) are discerned as being highly dissimilar from all other clusters. These clusters have low (0 – 0.1) EVI values throughout the time series, which is characteristic for water and 'no vegetation' (Figure 3a). Cluster 15 appears to represent inland water, notably the mainstream area of the Brahmaputra – Jamuna river system (

a). Cluster 49 demarcates tidal areas along the coast. Clusters cl5 and cl56 (**Error! Reference source not found.**, grey ellipse) are also highly dissimilar from other clusters. These clusters are characterized by high seasonal variations in EVI, representative for seasonal floodplain systems (Figure 3). Spatially, these floodplains are predominantly located in the north-eastern part of Bangladesh (

b) in the largest single inland depression in the country, known as the 'Haor basin'. This basin covers an area of ca. 8,000 km². There are about 47 major haors in the basin and seasonal flooding is very deep (Ali 1990 in Rahman & Chowdhury 1998). Several of these natural depressions are also present in the southern part of the north-west region in the Atrai basin (Rahman & Chowdhury 1998). The largest beel of the country, Chalan beel is also located in this area. The area coverage of cl5 and cl56 taken together is ca. 861,150 ha.

In the case of the Mekong Delta, two groups of seasonal floodplains can be distinguished at Euclidean distance 2.1 (**Error! Reference source not found.**b). One of these represents the highly modified seasonal floodplains and irrigated crop agro-ecosystems of the Vietnamese Mekong Delta (Figure a). Clusters representing these floodplains are characterized by two or three peaks annually in EVI for double and triple crop systems respectively. The other group represents broadly the flood recession agro-ecosystems that dominate the Cambodian parts of the Mekong Delta (CMD) and Tonle Sap floodplains (Figure b). Clusters representing the latter generally are characterized by seasonal variations in EVI, with only one pronounced peak in EVI annually, representative for single crop rainfed, or two peaks representative for an early wet season and a flood recession crop respectively.

Comparison of the EVI seasonality profiles between Bangladesh (bd) and lower Mekong (lm) demonstrates that EVI profiles for open water are similar, as expected. Perennial water

clusters bd15, bd49 and lm50 are all located within Euclidean distance < 0.97 . The highest similarity of EVI profiles that represent seasonal floodplains in Bangladesh and lower Mekong respectively, is found between clusters bd5, bd56 and lm39, lm69 (**Error! Reference source not found.**c). Despite the apparent similarity, profiles of seasonal floodplains in Bangladesh (bd5) and lower Mekong (lm69) are considerably different. Seasonal floodplains in Bangladesh are characterized by a longer period of low EVI values, indicative for long inundation, in comparison to lower Mekong. EVI values in seasonal floodplains in Bangladesh increase to considerably higher values after flood recession than in ‘comparable’ seasonal floodplains in the lower Mekong (Figure). This increase coincides with the ‘boro’ rice cultivation period which takes place from November to May (Singh, 2002), and the high EVI values bear resemblance to those of modified seasonal floodplains in the VMD. The profile of EVI in the lower Mekong floodplain cluster (lm69) is indicative for a longer but less pronounced vegetation cycle.

Cluster 49 demarcates tidal areas along the coast. Clusters c15 and c156 (**Error! Reference source not found.**, grey ellipse) are also highly dissimilar from other clusters. These clusters are characterized by high seasonal variations in EVI, representative for seasonal floodplain systems (Figure 3). Cluster 15 appears to represent inland water, notably the mainstream area of the Brahmaputra – Jamuna river system (

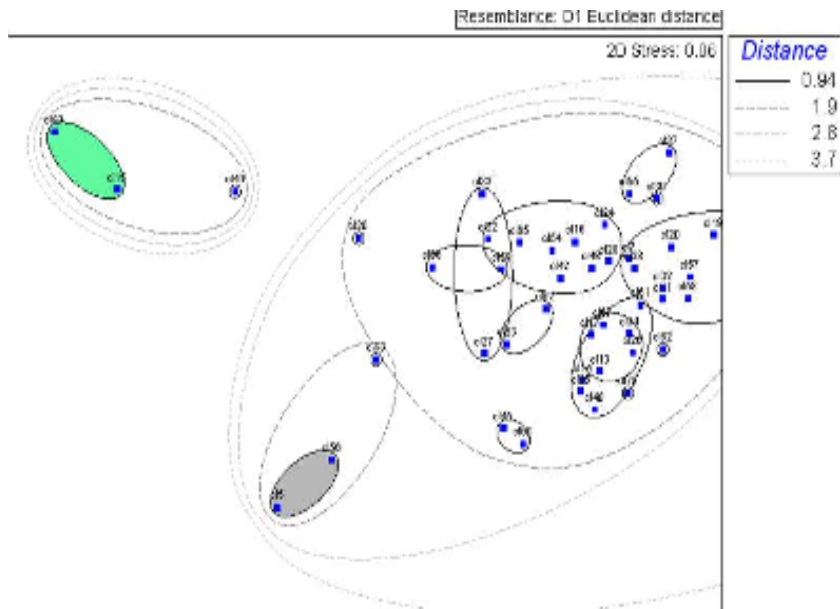
a). Spatially, these floodplains are predominantly located in the north-eastern part of Bangladesh (

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Figure 3: Cluster 5 demonstrates strong seasonal variations in EVI, characteristic for seasonal floodplains (red triangles indicate Landsat imagery available for that specific time period).

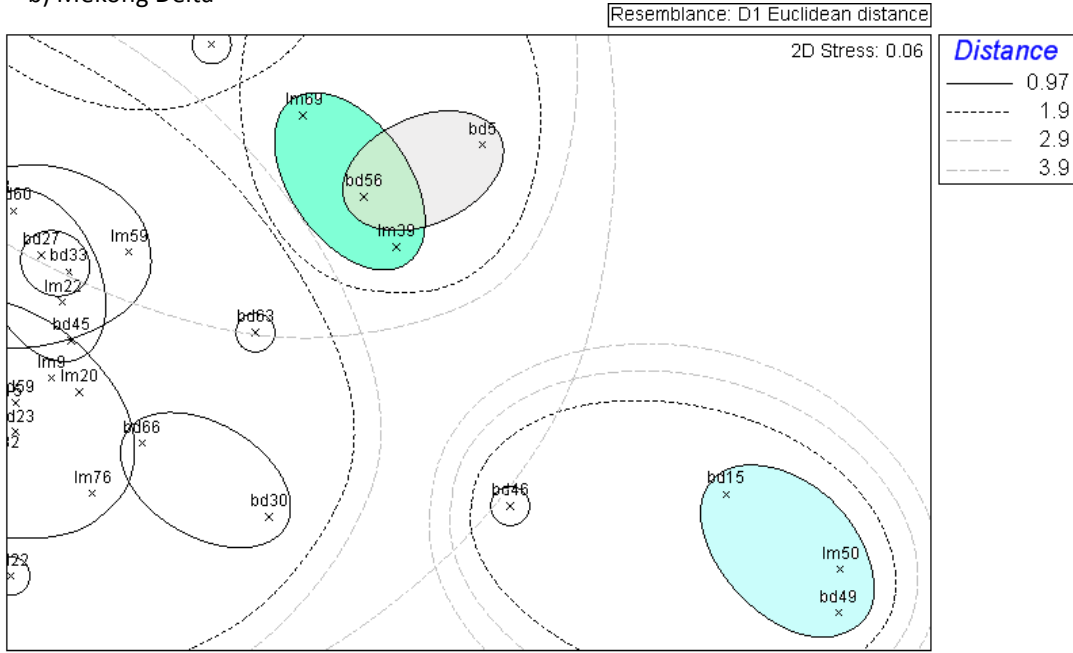
a) Bangladesh





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b) Mekong Delta



c) Comparison Bangladesh viz. Mekong Delta

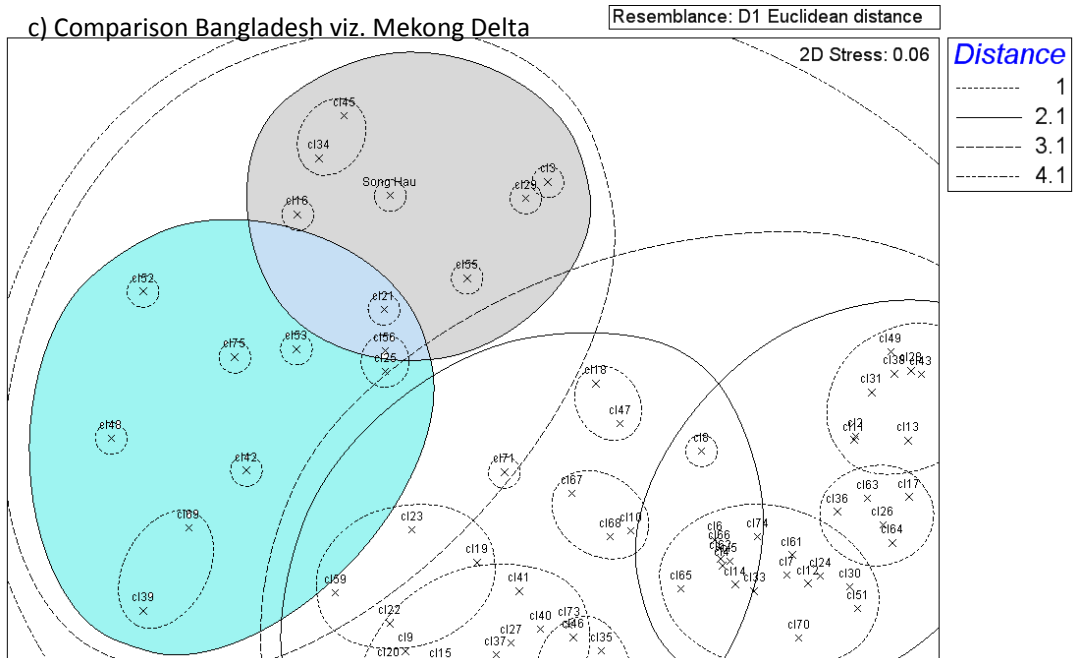


Figure: MDS configuration of relative similarity between 76 clusters derived from analysis of the EVI time series from 18 February 2000 to 11 August 2009 (218 images). a) Bangladesh: Cluster cl5 and cl16 (grey ellipse) represent seasonal floodplain systems, cl15 and cl49 (green ellipse) represent perennial water systems. b) lower Mekong: Flood recession agro-ecosystems (blue circle) and irrigated crop agro-ecosystems (grey circle) are readily distinguished in the analysis. c) Similarity between clusters representing permanent water (bd15, bd49, Im50) and seasonal floodplains in Bangladesh (bd5, bd56) and lower Mekong (Im39, Im69).

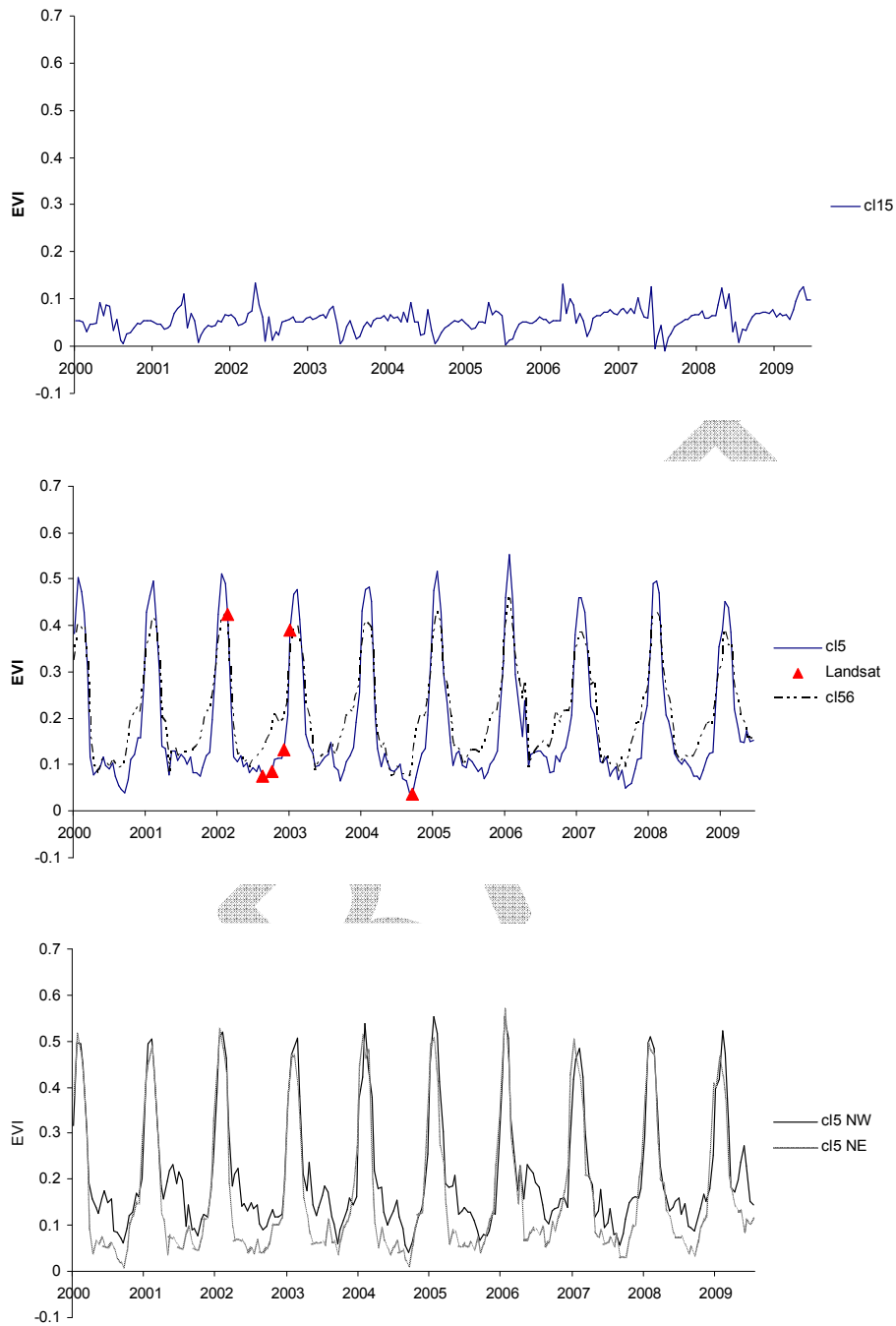


Figure 4 Bangladesh: a) Cluster c15 is characteristic for permanent waterbodies (low EVI); b) Cluster c15 characteristic for seasonal floodplains (red triangles: Landsat imagery available for that specific time period); c) c15 seasonal floodplains in the northeast (NE, Haor basin) characterized by lower EVI indicative for longer and deeper inundation during the flood season than those in the northwest (NW, Rajshahi)

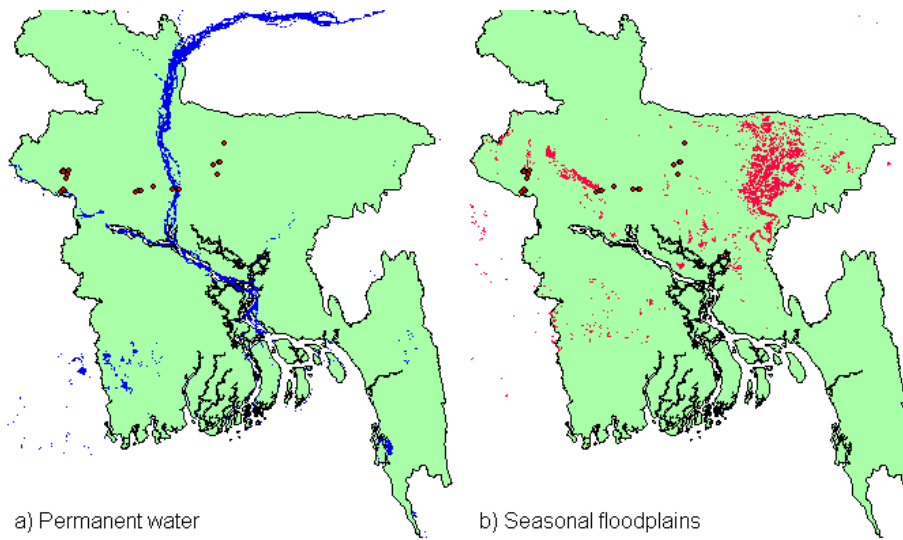


Figure: Spatial distribution of a) permanent water and b) seasonal floodplains in Bangladesh (red dots are GPS waypoints from a field visit during 24 - 29 January 2009)

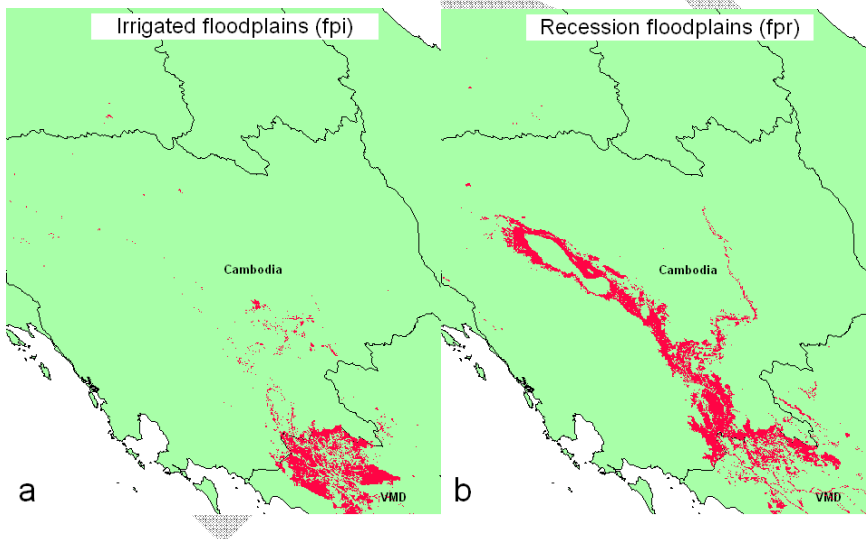


Figure a) irrigated floodplain agro-ecosystems dominating the upper and middle VMD; b) seasonal floodplains and flood recession agro-ecosystems dominating the Cambodian floodplains

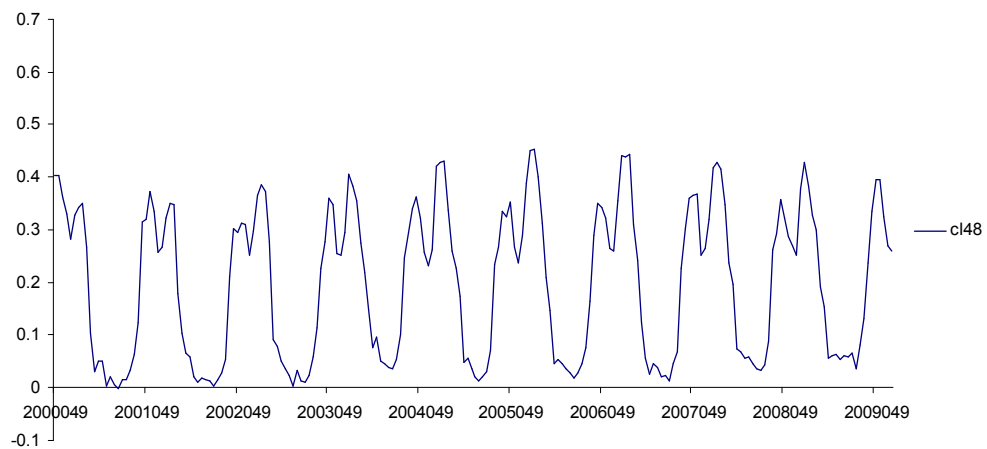
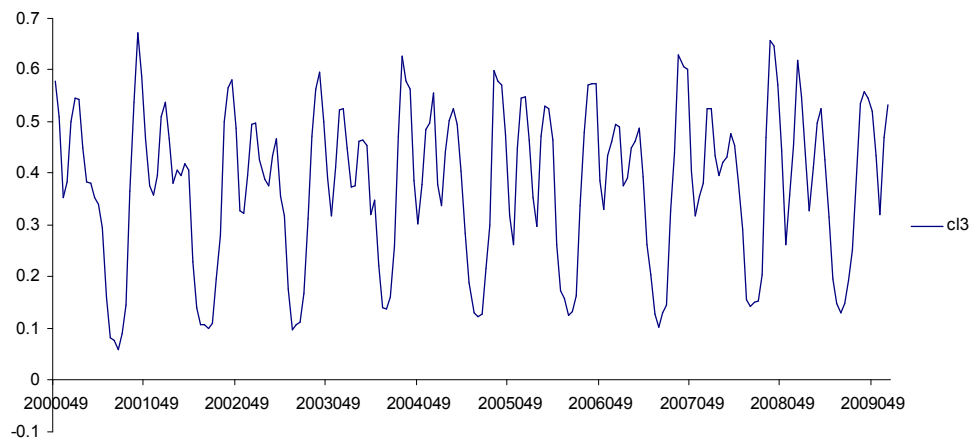
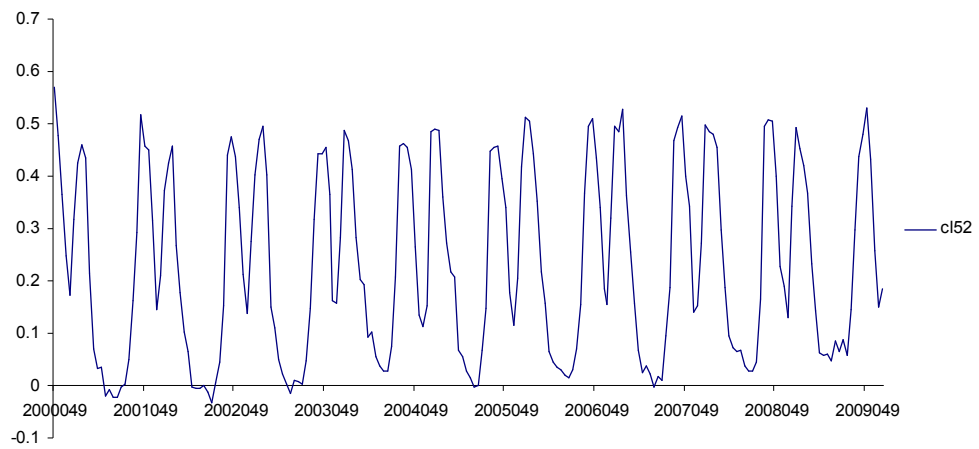


Figure: a) double crop long term inundated (> 4 months yr^{-1}) agro-ecosystem representative for upper VMD; b) triple crop short term inundated (< 3.5 months yr^{-1}) agro-ecosystem representative for middle VMD; c) double crop early wet season / flood recession agro-ecosystem representative for CMD

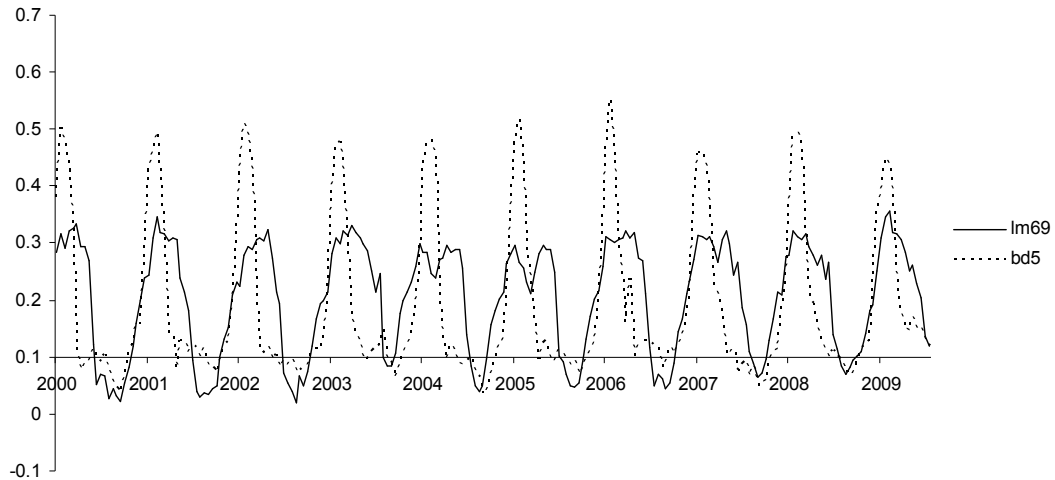


Figure: Similarity between inland seasonal floodplains in Bangladesh (bd5) and 'most similar' seasonal floodplain agro-ecosystem representative for CMD and Tonle Sap (Im69)

EVI values are seasonally low (around 0) when floodplains are inundated. At 500 m resolution the likelihood is high that a pixel contains a mixture of flooded and non-flooded vegetation unless the area is covered by a large permanent open water body such as the Tonle Sap great lake. The likelihood that EVI deviates from 0 over seasonally and partly inundated areas is therefore also high. As an indicator of the likelihood of seasonal flooding the following criterion was adopted for identifying a 'flood pixel'. If the EVI of any pixel (one pixel equals 500 x 500 m) is equal or less than one standard deviation above the average 16-day EVI over areas identified as perennial water ('permanent flooding') for that period, the pixel is identified as a 'flood pixel'.

$$EVI_{flood} \leq \overline{EVI}_{pf} + 1s$$

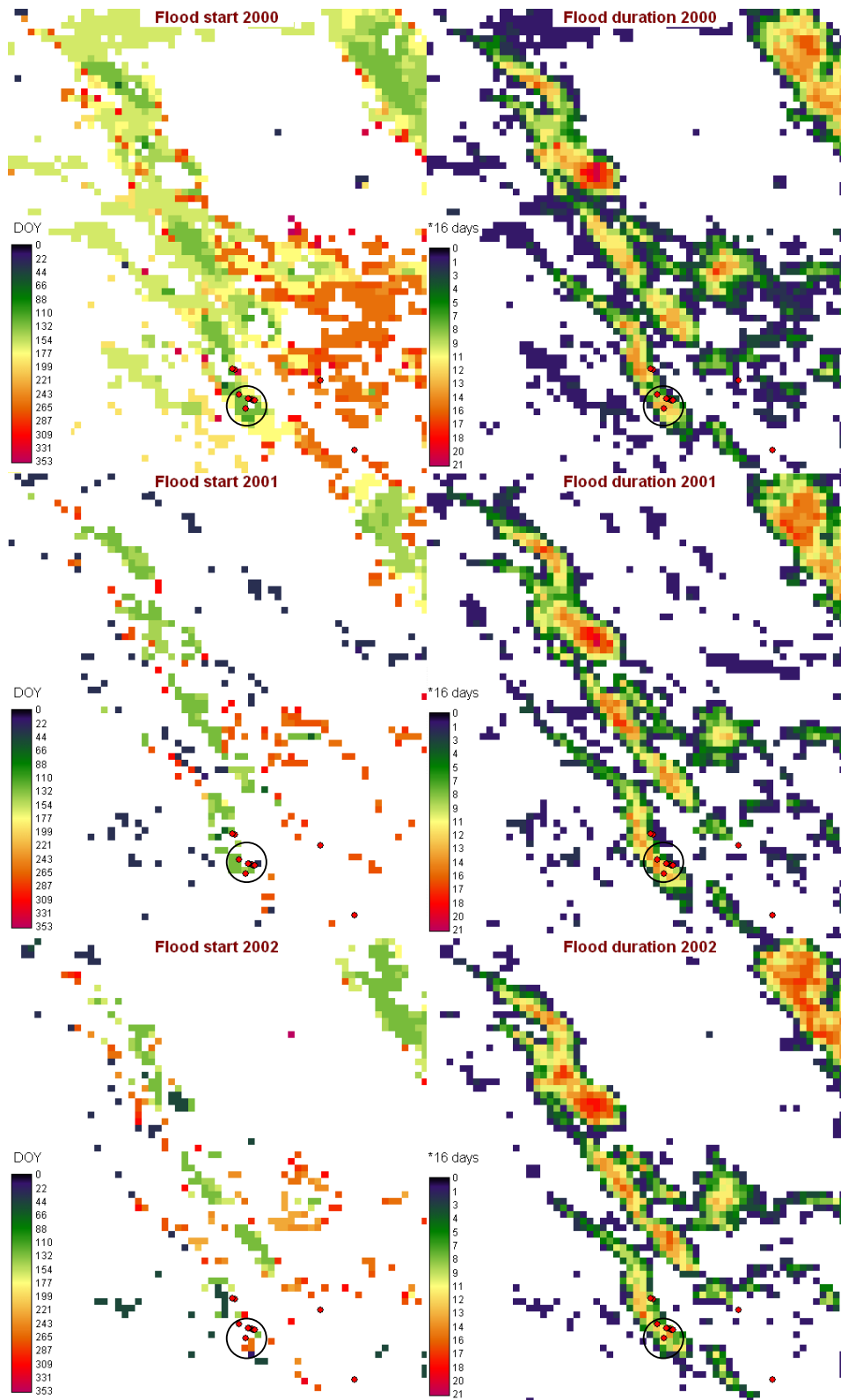
where 'pf' = permanent flood and s = standard deviate

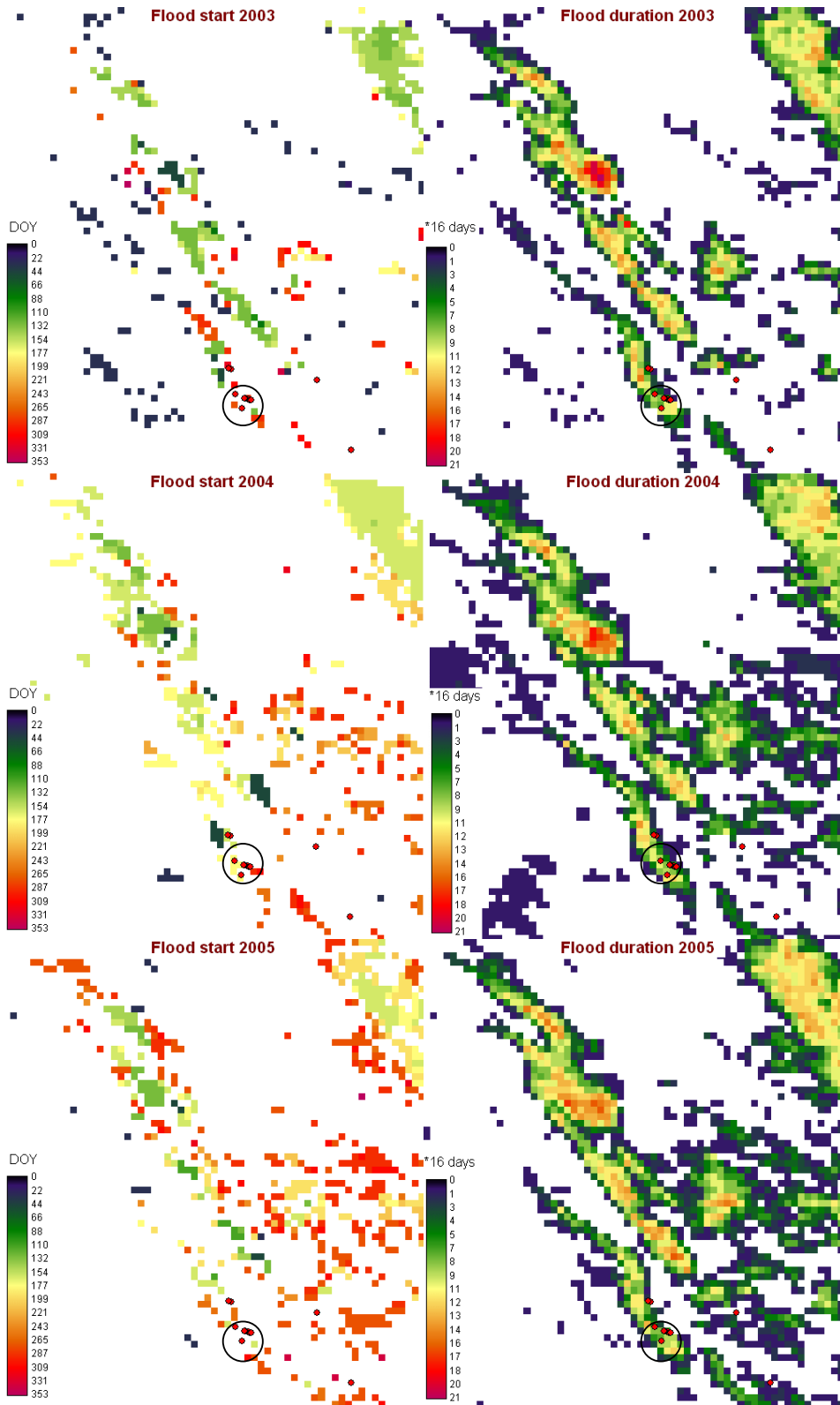
The start date of flooding was determined to be the Date Of Year (DOY) at the start of the 16-day interval in which a pixel was first determined to be a 'flood pixel' within a given year (Figure 5: Flood start).

An overlay of 16-day images of flooded areas ('flood pixels') was performed in order to estimate the duration of seasonal flooding over each year in the time series.

$$\sum_{n=flood}^{n=23} EVI_{flood}$$

Where $n = 23$, the number of EVI images in a year, and $n = 'flood'$ the number of 16-day intervals within that year that a pixel is identified as a 'flood' pixel (Figure 5: Flood duration, max = 23).





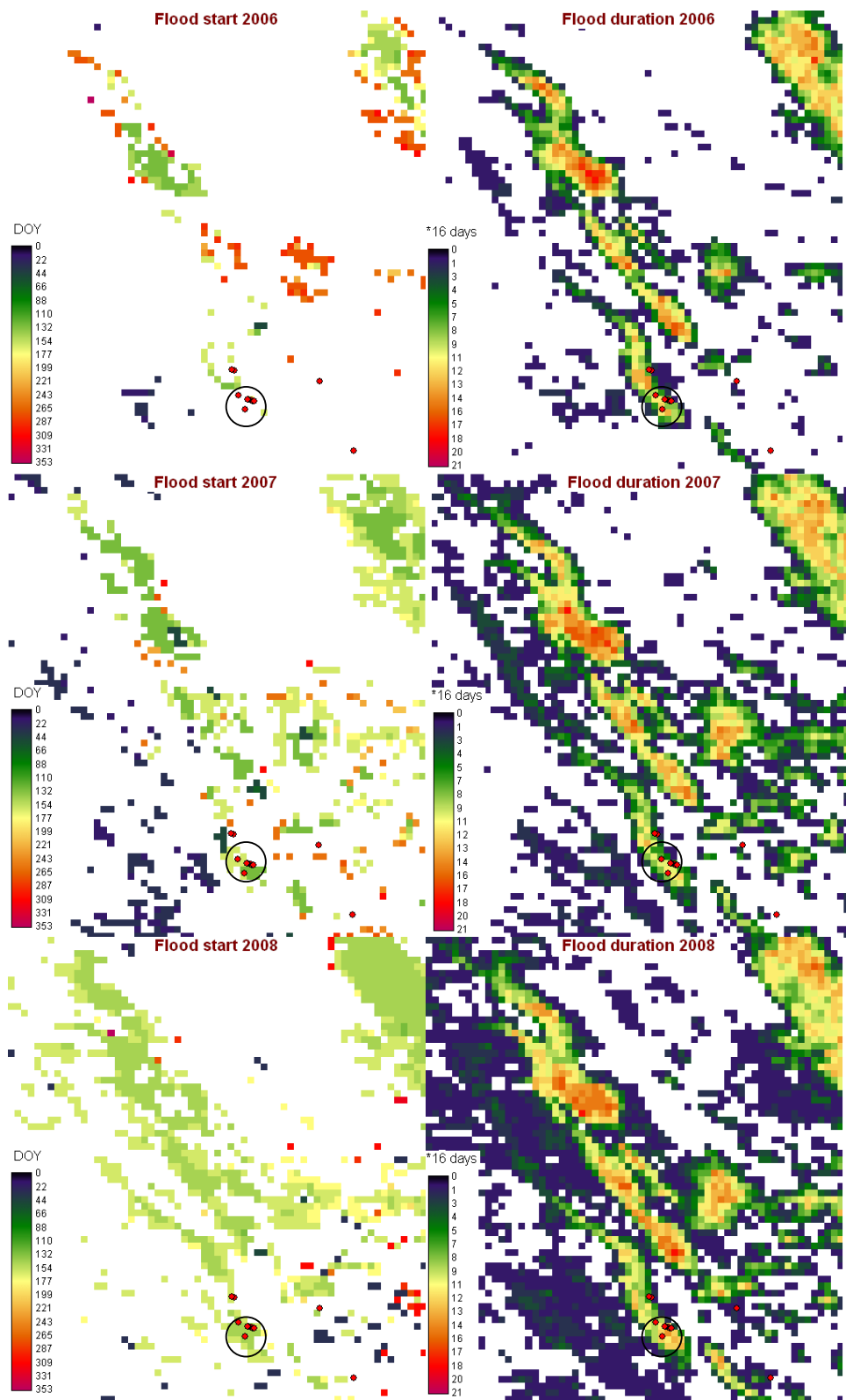


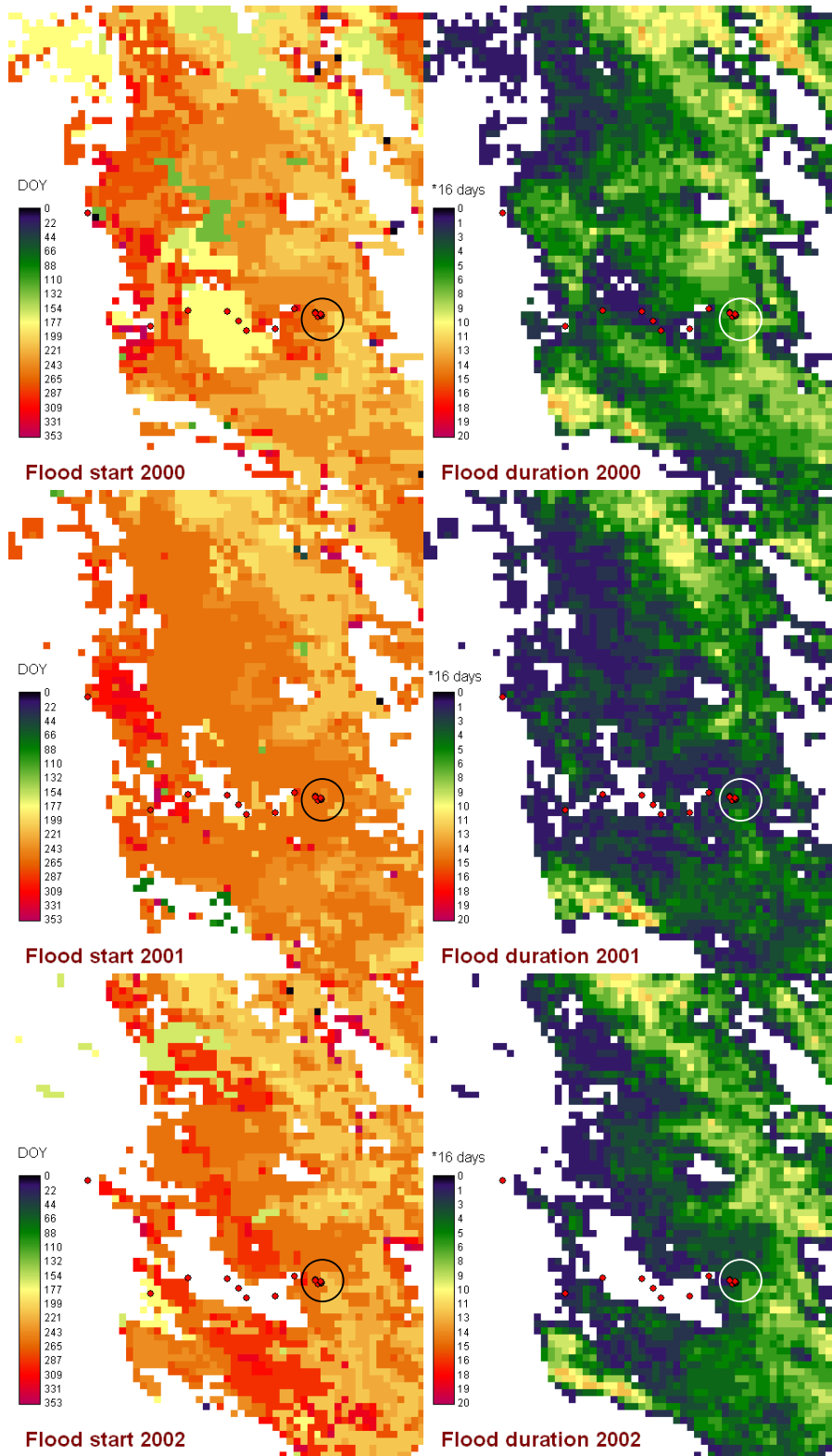
Figure 5: Flood start dates (DOY = Day Of Year) and flood duration expressed in number of 16-day intervals in floodplains in the Northwest of Bangladesh (Rajshahi District); red dots are GPS waypoints from the field visit to Beel Mail (encircled), 24 - 25 January 2009

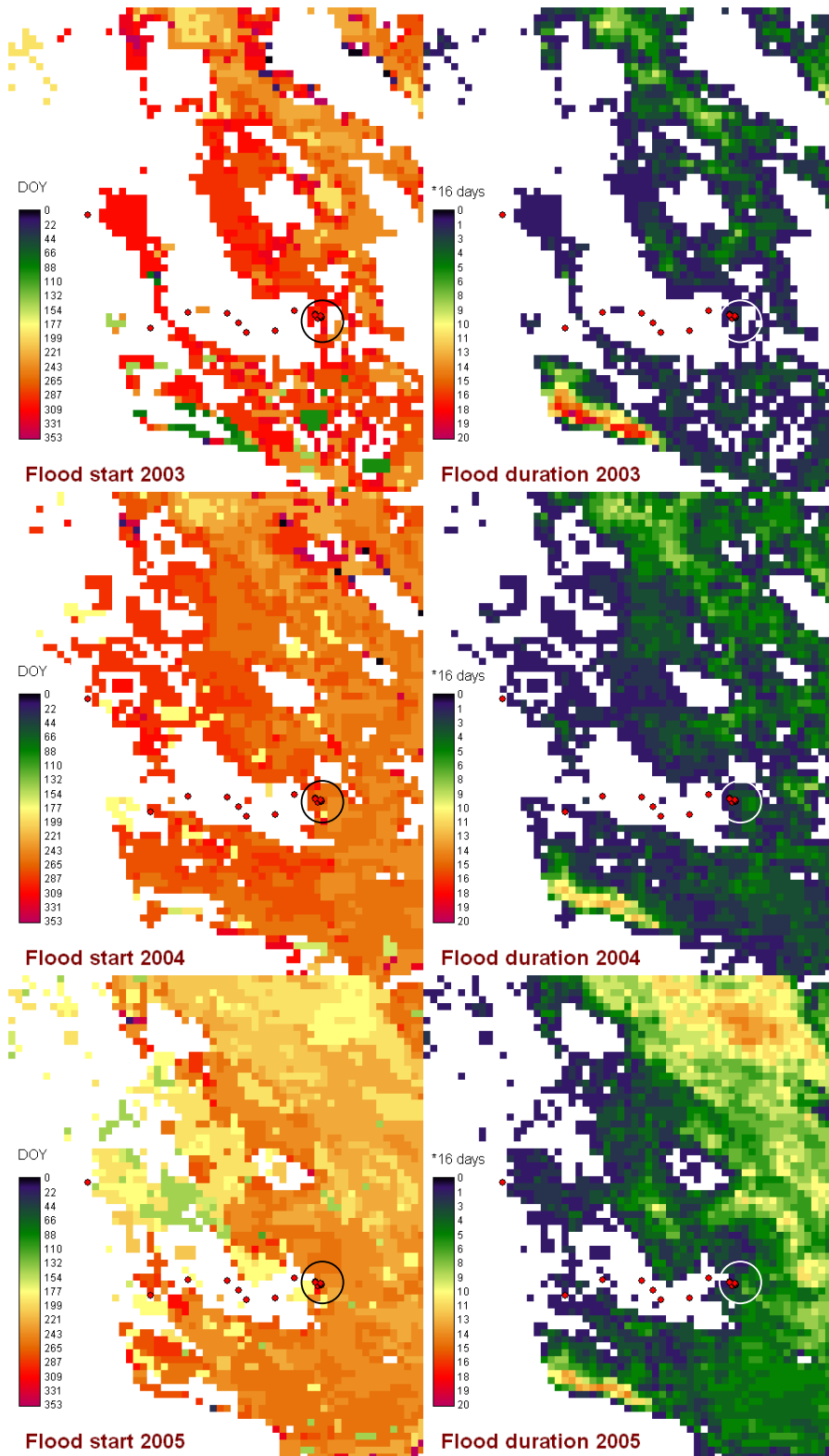
The approximate start and duration of seasonal floodplain inundation was estimated over a nine year period from 18 February 2000 (DOY 049) to 17 February 2009 (DOY 048). From Figure 5 it is clear that large areas of floodplain, including Beel Mail, are seasonally inundated for at least 6 months per year, up to almost permanently. Flood duration could be more reliably estimated than the flood start date. A 'start date' is difficult to determine for semi-permanently flooded areas and areas where flooding takes place repeatedly over a year during shorter time intervals. Flooding in Beel Mail starts around DOY 132, corresponding to early-mid May in the years 2000, 2001, 2007 and 2008. The analysis gives no clear indication for start date of flooding in the years 2002 till 2006.

The results of the analysis for flood duration over entire Bangladesh indicate that the area of long-term flooding (4 to 7 months) was higher than 10,000 km² in 2000, 2007 and 2008, and close to 10,000 km² in 2004. The area of short-term flooding (16 days till 3.5 months) was highest (near or over 40,000 km²) in 2002, 2007 and 2008. However, no clear trend is apparent over years. This is consistent with the observation of Craig et al. (2004) that the extent of annual flooding in Bangladesh is variable and unpredictable. Seasonal floodplains in the Mekong are generally inundated for a shorter period than those in Bangladesh, due to the extreme variations in wet and dry season flows of the Mekong. The inter-annual variability in flooding within the relatively short time span from 2000 till 2008 is evident, and confirmed by MRC flood observations. The year 2000 was a particularly devastating flood year in the Mekong Delta. The years 2001 and 2002 were also severe flood years. The years 2003-04 were drier.

The year 2005 was an exceptional flood year for the central area of Lao PDR and parts of Northeast Thailand. High water levels were also recorded in the Mekong Delta in 2005 (MRC, 2006). The years 2006-07 were below average flood years, with an exceptionally late start of the flood season throughout the LMB in 2007 (MRC, 2007; 2008a). The year 2008 was a strong La Niña year, which is associated with a more intense Southwest monsoon over Southeast Asia, but flood levels were average in the Mekong Delta (MRC, 2008b). Figure 6 shows flood start and duration for the project location in Krapum Chhuk commune, southern Takeo province. The larger flood extent in the years 2000 till 2002 relative to 2003 and 2004 is evident, and the onset of flooding is clearly earlier in the year 2000.

The extent of flooding is particularly low in 2003. The larger extent and early onset of flooding in 2005 is also noticeable. The late onset of flooding in 2007 is also apparent in the project location. The flood extent in 2008 does not differ much from 2006 and 2007, but flood onset is relatively early and flood duration is relatively longer for 2008. The project location, Chrouy Poun village, is located at the periphery of the seasonally flooded area. Locally, the inundation is attributed to the flood control structures that have been constructed across the border in neighbouring An Giang province, Vietnam, as a consequence of which flood waters back up at the Cambodian side of the border. Flooding is predominantly 'short-term', lasting for 2 – 3 months per year, with localized areas of longer inundation that could serve as fish refuge areas during the dry season.





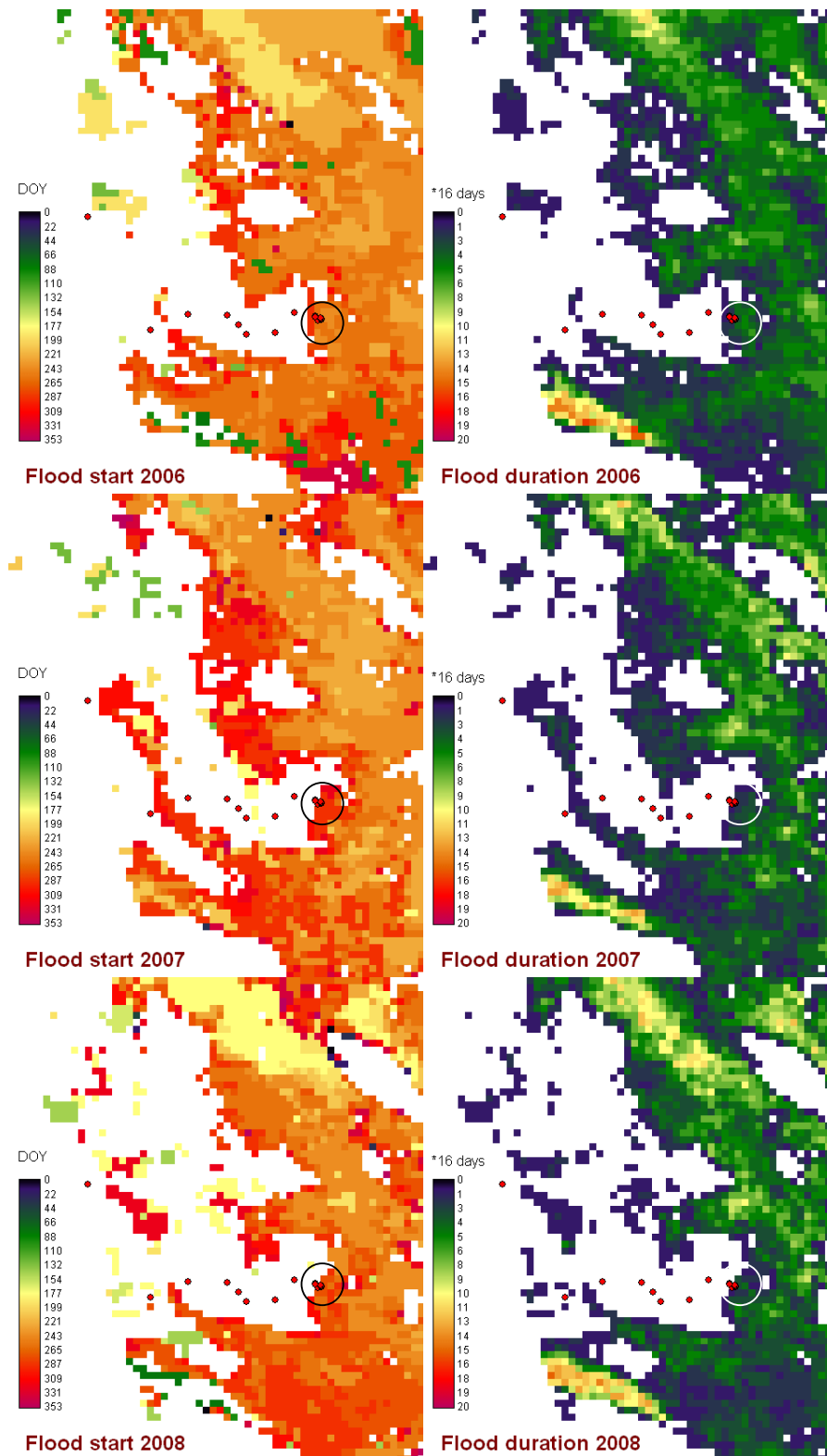


Figure 6: Flood start dates (DOY = Day Of Year) and flood duration expressed in number of 16-day intervals in floodplains in southern Takeo province (Krapum Chhuk commune); red dots are GPS waypoints from the field visit to Chrouy Poun village (encircled), 10 September 2008

Landscape level analysis to assess floodplain development trends

The MODIS seasonality analysis was complemented by observations from higher resolution Landsat data and imagery from Google Earth. From the seasonal analysis and complementary Landsat ETM+ (Landsat 7) and Landsat TM (Landsat 5) imagery the yearly cropping and inundation cycle in Beel Mail are clearly discernable (

;

Figure 8). Beel Mail is a polder of ca. 40 ha, separated by a peripheral embankment from adjacent floodplains in order to protect rice from early pre-monsoon flooding. The rice crop is harvested towards late April / early May as a result of which EVI values decrease (

). The beel starts to recharge water during early June and fish stocking takes place around that time. The beel stays inundated for 5 – 6 months till late November – early December when a full annual cycle is completed. Landsat imagery at selected dates shows the seasonal inundation pattern in Beel Mail (

Figure 8). Around April the beel is fully under crop production (

Figure 8a, 13/04/2002, DOY 104). Floods start to recede towards the end of November each year (

Figure 8c, 23/11/2002, DOY 327) and the beel is draining towards the end of January (

Figure 8d, 26/01/2003, DOY 026). Cropping and rice transplantation in the beel start around that period, and the VI starts to increase rapidly.

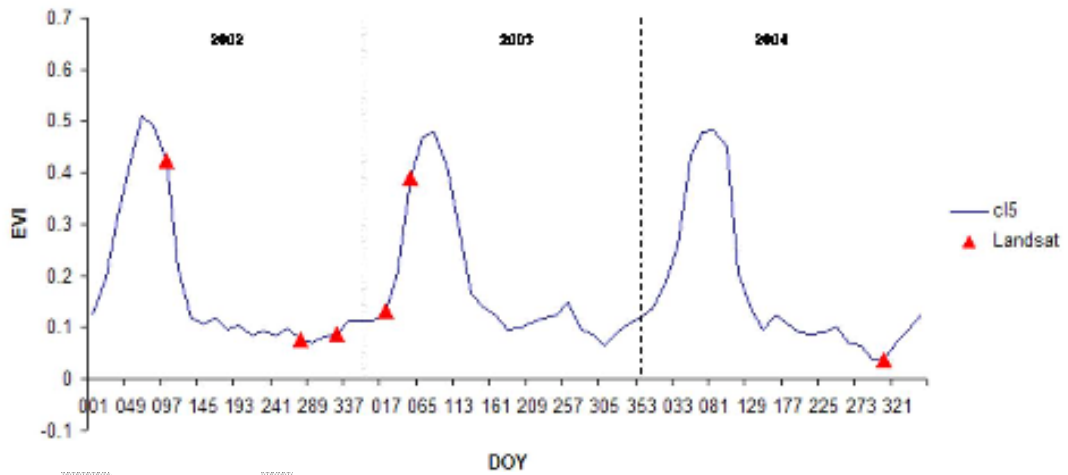


Figure 7: Three year cycles of floodplain seasonality and Landsat imagery at corresponding Day-of-Year (DOY)

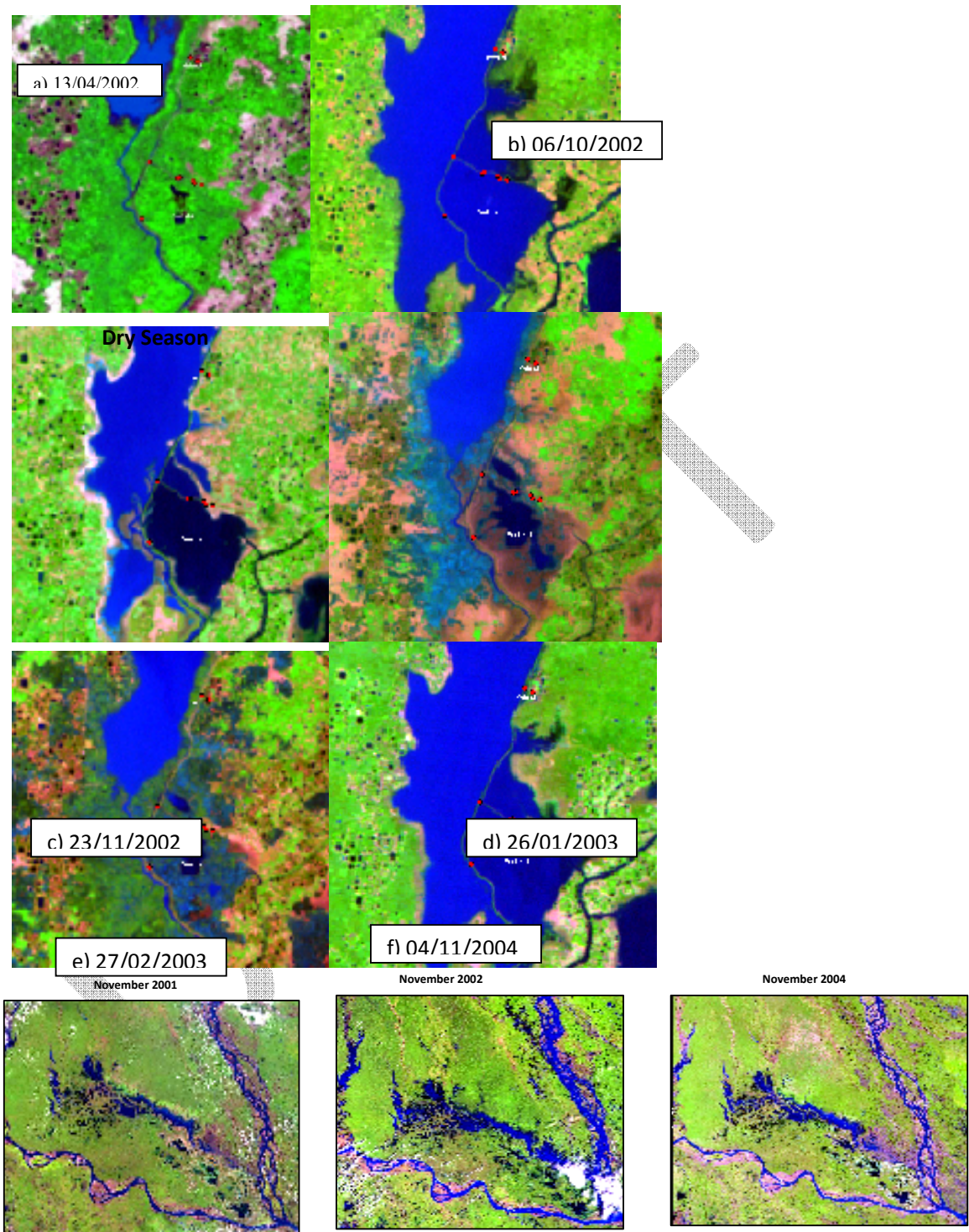


Figure 8: Landsat satellite imagery showing different stages of inundation in Beel Mail

In addition, Google Earth © provides detailed imagery covering Beel Mail during the dry season



(
a, image date 4 May 2004; N24 35.023 E88 35.480) showing irrigation ditches and remaining standing water in deeper parts of the beel, providing refuge areas for fish, and sluice gate water inlet from Shiva river



(
b; N24 34.498 E88 35.393).(need to mark that in the image, why image only from trail version ?)



Figure 9: Beel Mail a) refuge areas remaining in the beel during dry season, b) sluice gate (image © 2009 Digital Globe, © 2009 Google)

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Landscape Analysis: IGB-Bangladesh

To assess seasonal water availability for aquaculture facility, we started with landscape analysis to characterize the floodplain resources. For this activity, the earth observation data (Landsat TM data with a spatial resolution of 28.5m) was subjected to unsupervised classification in ERDAS-9.2 image processing software (Maximum like hood algorithm) to compute the aerial statistics of the major land cover and land use activities in the floodplain. The selected floodplain site is also representative of site-scale attributes such as the inundation period, effective water area, water inlet-outlet system; harvesting and marketing facilities for the fish. The landscape level analysis helps clarify the proportionality of scaling the intervention to improve the overall productivity of the floodplain

For landscape analysis we used an agroecological scale. The country is subdivided into thirty agro-ecological¹ units; and our sites are representative of three major floodplain zones *viz*; Ganges, Brahmaputra and Tista (Figure). This is crucial to understand the variation and appropriateness of the intervention at the basin-scale and assists in up-scaling to a wider area. The agro-ecology provides broad information on defining the geographical and the ecological boundary of the flood plain. Information on the flooding depth, elevation and the inundation level are more [locale] site specific parameters that determines the gradient of suitability for a need based livelihood intervention within the agro-ecological boundaries. For sites at Rajashshi, Mymensingh and Ranpur, the elevation is between 5-30 m that qualifies them as lowlands. The inundation level at Rajashahi and Mymensingh is intermediate; while it is comparatively low for Ranpur. This would mean that the standing water level in the wet season reaches above 1.5-2m hence suitable for the fish stocking and maintaining inflow-outflow hydrodynamics using low cost technical options. With water level above and below the specified level needs more investment and human effort to arrange technical means and to regulate hydrological flow. In summary, biophysical assessment significantly determines the appropriateness of the intervention for the site and also its replication potential for a broader context of floodplain management.

The biophysical characterization of floodplain at landscape level describes the resource pattern at basin scale, the distribution of major production systems and the land cover/use pattern in general. We analyzed the spatial dynamics for all sites that are representative of three different river basins. Explained in-depth is the case of Padma/Ganges floodplain.

The Landsat ETM for November 11/2000 for Bheel Mail represents the receding wet season (Figure 2a & b). The land cover categories in basin *i.e* water body/flooded area and shallow water area with surface vegetation covers more than 40% of the total analyzed area. The inundated area with grass/shrubs adds another 13.7 percent (Figure 3a). The open or non-cropped area (6.3%) is representative of water cleared ground with moist surface. Altogether, the seasonal flooding event in the basin impacts more than 55 percent of floodplain use in wet season, primarily in the of low-lying regions. The seasonal floodplain is rendered unsuitable for crop production from start of monsoon (generally July-August) to mid of November or early December annually.

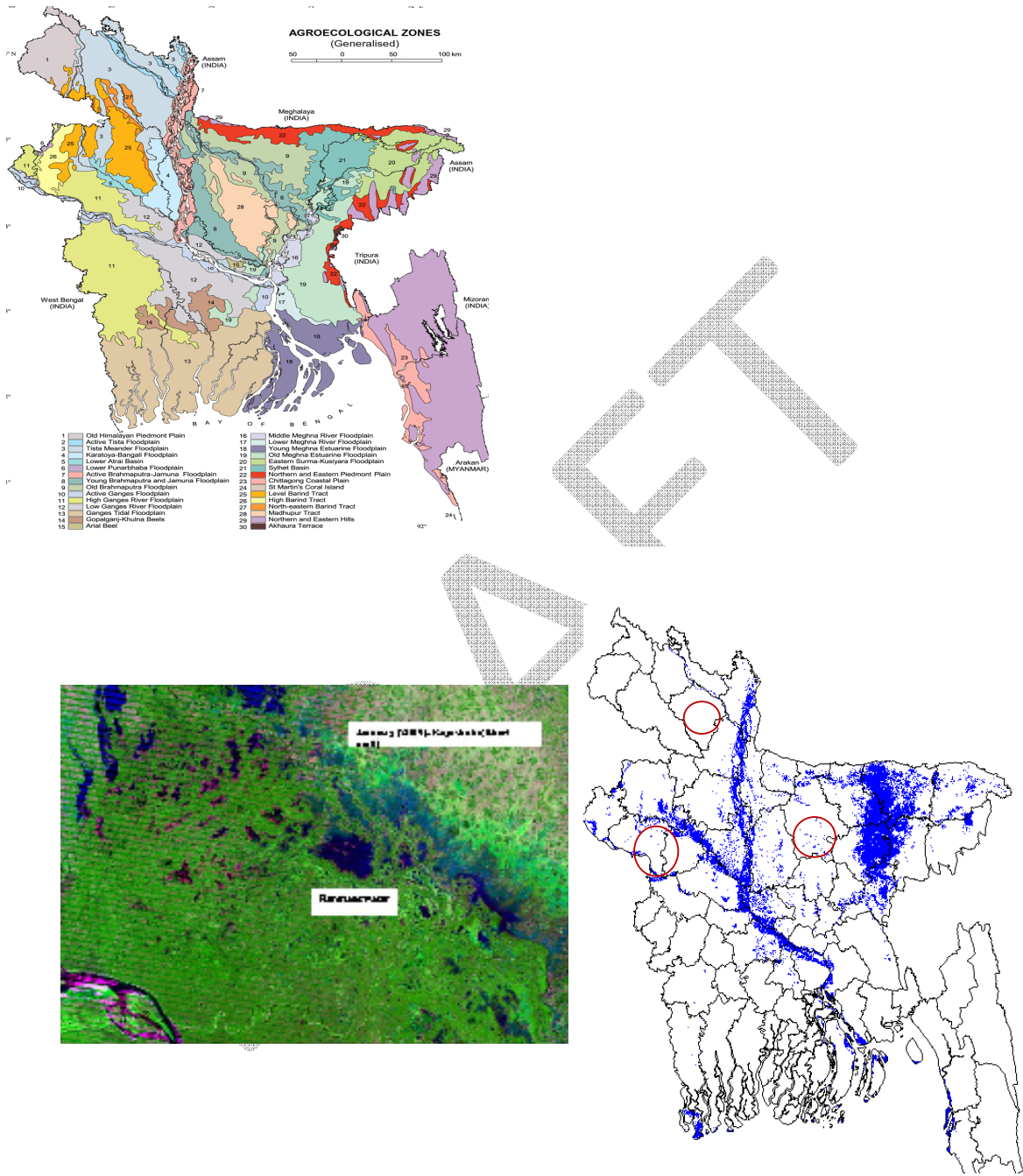


Figure: Agro-ecological zone and inundation. The sites are representative of Ganges, Tista and Brahmaputra river floodplains. Reflecting remnant water from post aquaculture harvest

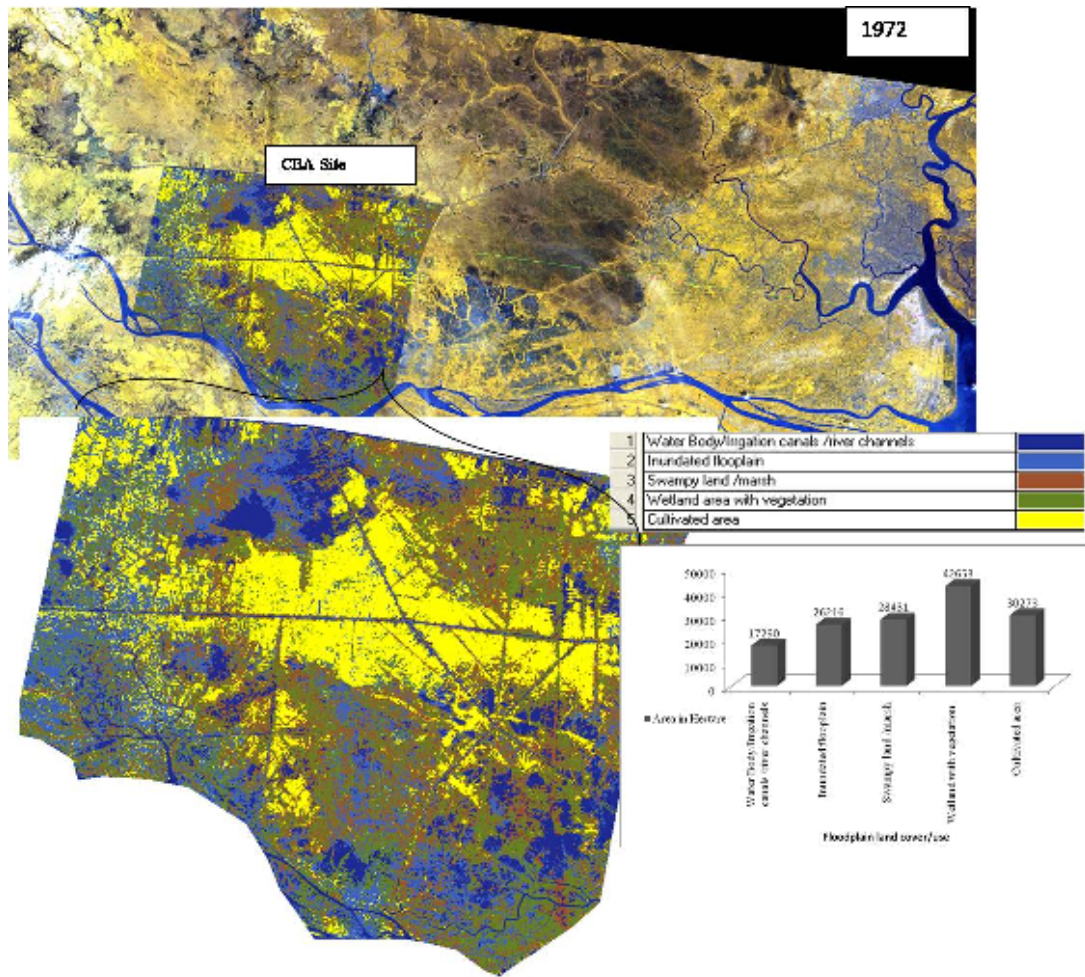


Figure: Spatial delineation of floodplain cover/ use pattern for Padma floodplain agro-ecosystem using Land sat data archive from 1972

B) Landscape Analysis: LMB-Cambodia

The site selected for landscape analysis in Cambodia (Pum Ed in Prey Ampok Commune, district Kirivong, Takeo Province) is the part of Lower Mekong basin, closely bordering Vietnam. The Google profile (November, 2008-Figure 11a) overviews the intervention site, alongside the wetland floodplain ecosystem (reservoir). The data archive from Google, helps depict the floodplain activities from nearly last decade. During 2000, the use of floodplain for agriculture was minimum (Figure 10c), perhaps due to lack of irrigation facilities. 2004 image (Figure 10b), shows the cropped (in green) region in dry season and the presence of reservoir. To better understand the temporal floodplain dynamics, the historical (2000 and 2004) earth observation data was referred (Figure 11 b and c). In addition, the dry and wet season floodplain was illustrated a set of images from LandSAT data series (Figure12)

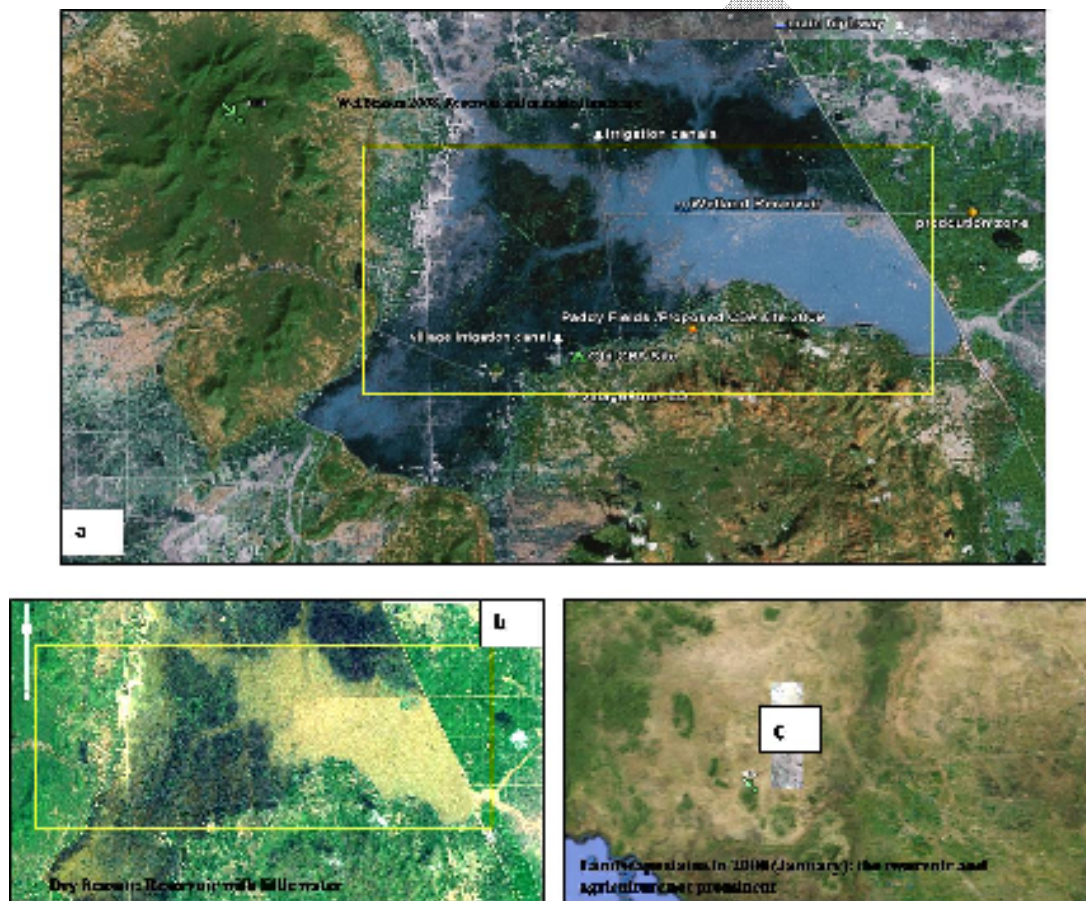


Figure 11: Pum Ed reservoir in Cambodia a) study site with landscape features (2008); b) reservoir area with remaining water in dry season (2004); c) landscape feature in 2000 (source : Google earth historic data

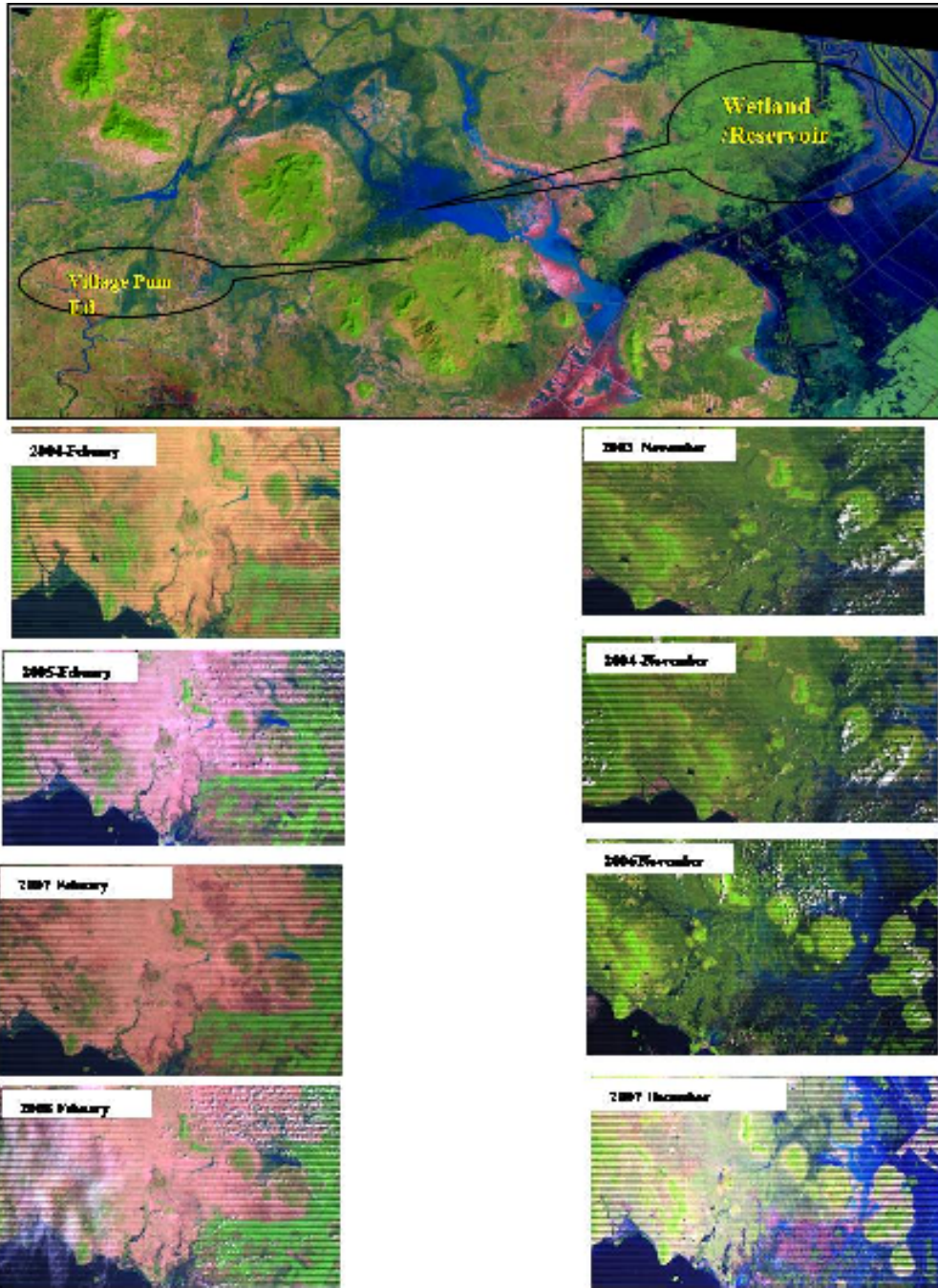


Figure 12: (A), Site location in Landsat TM (Resolution 28.5m) for 1992-December (end of wet season); (B) the dry season scenario (2004-2008); (C) the scene in wet season (2003-2007)

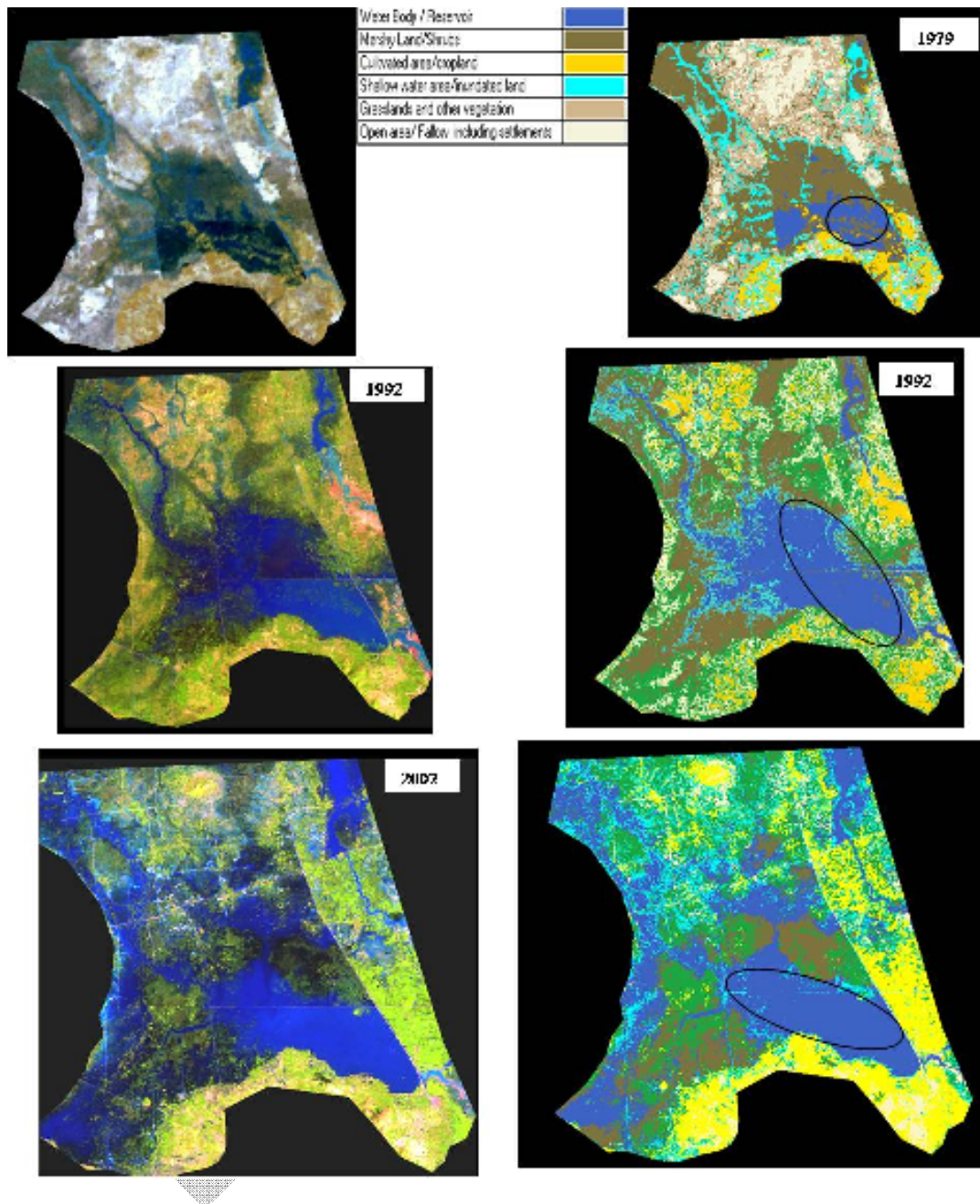


Figure 13: Temporal landscape analysis in LMB-Cambodia, showing spatial trend from 1979-2002. Series A are remote sensing images (Landsat) while Series B are classified images. The encircled area reflects the increasing water inundation in the basin.

Table: Aerial statistics of the temporal landscape analysis for Lower Mekong Basin in Cambodia; the shaded variable reflect the increase in cultivated area from 1979 to 2001

Temporal Analysis	Years (Area in hectare)		
	1979	1992	2001
Floodplain cover /use units			
Water Body / Reservoir	1060.1	3271.8	5205.2
Marshy Land/Shrubs	5956.4	4194.0	1575.8
Cultivated area	1391.9	1711.0	3171.3
Shallow water area/inundated area	2495.6	1632.2	2156.6
Grasslands and other vegetation	4047.0	4311.3	4302.4
Open area/ Fallow without any vegetation including settlements	2487.1	2297.9	997.7
Total Area	19410	19410	19410

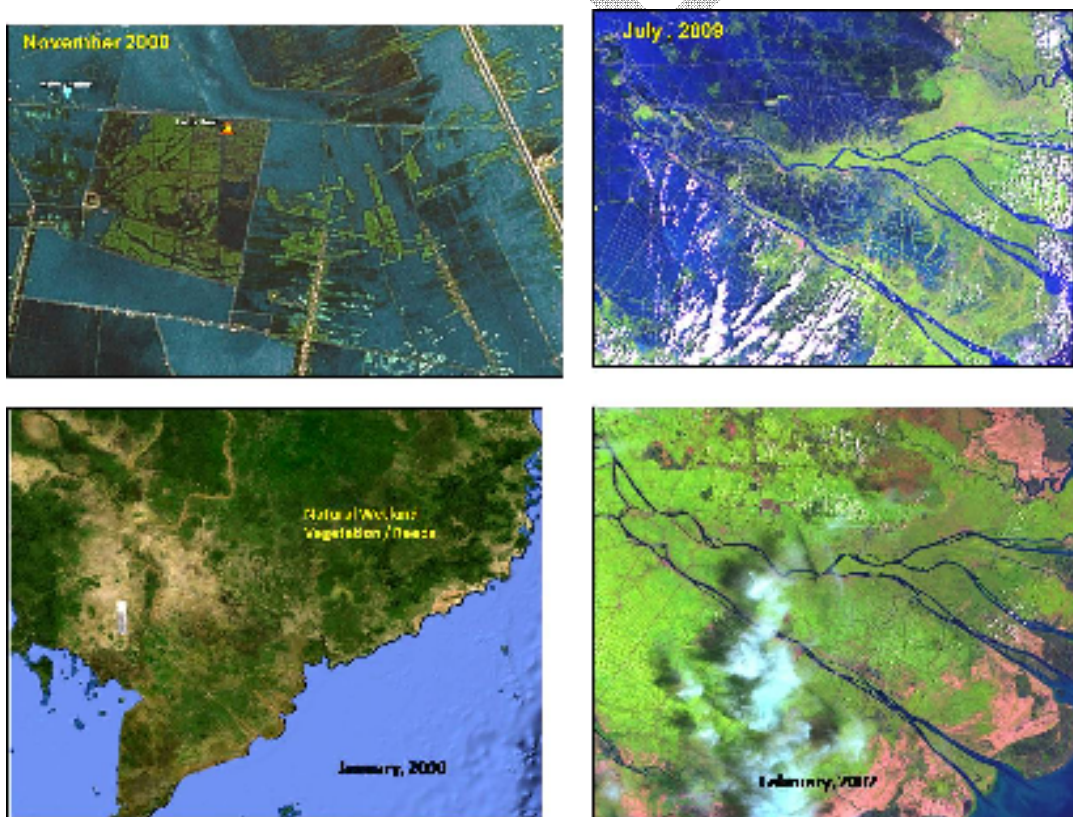


Figure 14: Floodplains in LMB of Vietnam with earth observation illustrating the seasonal impact on land use activities

Social and development context of Floodplain management

In addition to the Spatio-temporal analysis, generic poverty indicators and a population distribution model were used to estimate the number of people that are likely to be directly or indirectly dependent on seasonal floodplains for their livelihood.

Generic poverty indicators and a population distribution model were used to estimate the number of people that are likely to be directly or indirectly dependent on seasonal floodplains for their livelihood. A global population distribution model at 1 km resolution, known as LandScan™ (Oak Ridge National Laboratory, Oakridge TN, USA) provided the basis for a proxy indicator of the number of poor people living within or in the vicinity of seasonally flooded areas. LandScan is a population distribution model which combines four primary geospatial datasets that are key indicators of population distribution, namely land cover, roads, slope, and night time lights. The model is based on best available census counts and represents an ambient population distribution over a 24 hour period. This does not represent residential population density but instead estimates the average number of people encountered per grid cell over 24 hours.

The LandScan 2002 Global Population Database was used in this study because we did not have access to the latest version, LandScan 2007. LandScan 2002 incorporates important refinements over earlier versions. The IDRISI regional data disaggregation tool was used to redistribute the sub-district level poverty headcount (FGT 0) according to the LandScan model. This step provided a more realistic poverty distribution grid at a nominal 1 km resolution. The poverty counts were log-transformed (ln) for presentation of the counts on a continuous scale (Figure 10a). It appears from the figure that the poverty density is higher in the north-west of the country than in most other parts.

To explain the floodplain demographics in Bangladesh, a simple distance model (Figure 10b) was used to estimate the number of people living within or in the vicinity of seasonal floodplains. More than 9.5 million people live within or less than 1 km from seasonal floodplains. Roughly 3.8 million of these people can be classified as poor (any cross Ref). These people depend to a considerable extent of floodplain natural resources and are therefore highly vulnerable to declining productivity, both in terms of agriculture and fisheries, in these systems. More than 36 million people live within 5 km from seasonal floodplains. Within 10 km the number increases to 59 million (more than one-third of the entire population of Bangladesh). Well over half of the population lives within 25 km from seasonal floodplains (Table 2).

Table 2 : Number of people living within the vicinity of seasonal floodplains¹.

Distance to seasonal floodplains	Number of people (including those in floodplains)
< 1 km (including floodplain area)	9,500,501
< 5 km	36,722,480
< 10 km	59,000,748
< 25 km	91,833,224

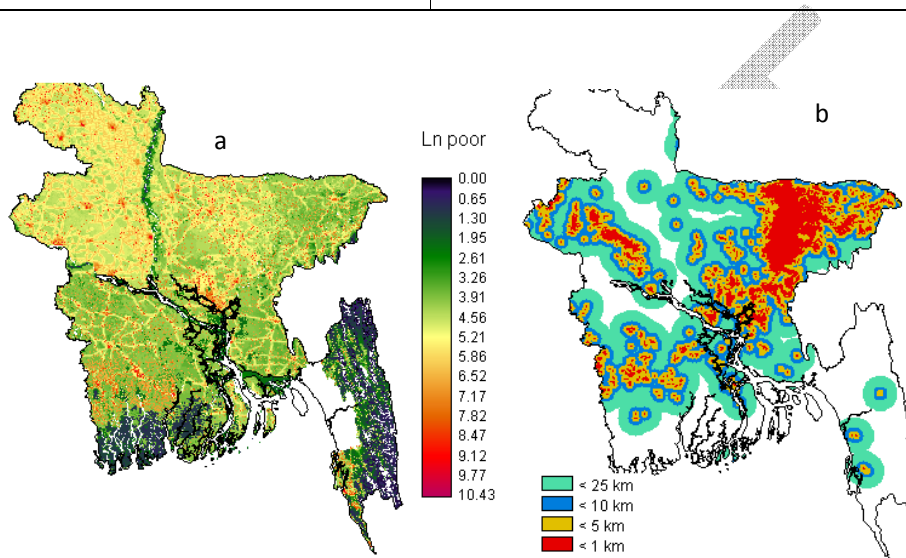


Figure 10: a) Poverty distribution in Bangladesh and b) distance to seasonal floodplains

¹ It must be noted that these high numbers are partly due to the inclusion of seasonal floodplain areas within or in the vicinity of the Greater Dhaka metropolitan area

Relevance of findings

Seasonal floodplains play a fundamental role in the livelihoods of millions of rural poor people in Bangladesh and the Mekong Delta. During the dry season they are predominantly used for rice cultivation. In Bangladesh these floodplains remain inundated for 5 – 6 months during and after the monsoon season, when they are suitable for community based fish culture. A seasonality analysis confirmed that ca. 861,150 ha of floodplain area potentially satisfy conditions for CBA, which could help support livelihoods of up to 3.8 million poor people who are dependent on seasonal floodplains.

Research by the CPWF project on Community Based Fish Culture in Irrigation Systems and Seasonal Floodplains has shown that modified floodplains under these conditions (i.e. 5 – 6 months inundation) can be brought under community based fish culture and produce on average 409 kg ha⁻¹ over this period. Even if only half of the available area could be brought under culture, fish production from CBA could contribute ca. 176,000 t to inland fisheries. At just over one-third of that suggested by Dey and Prein (2005), this is a considerably more conservative estimate, based on a realistic analysis of seasonal dynamics of floodplain ecosystems. While the extent of inundation varies from year to year, this study did not find any longer term trend or large scale changes affecting these seasonal floodplains.

Despite the considerable fisheries potential of seasonal floodplains there are also concerns over the effects of flood control, drainage (FCD) and irrigation projects on overall productivity of these systems. FCD projects in beels of the north-west region have had major adverse impacts on capture fisheries. Concerns have also been risen about adverse impacts of CBA on poor people. The CBA project in Beel Mail has nevertheless demonstrated that it is possible to increase yields of both stocked and non-stocked species, while maintaining or even slightly increase fish biodiversity within the FCD scheme. Poor and better-off floodplain communities alike have benefitted from the intervention. Establishing and ensuring the continuity of CBA is however costly in terms of time and resources. In closed systems such as Beel Mail it is relatively easier to achieve and to assure equitable distribution of benefits. In most rivers and extensive floodplains, open access will make it much more difficult to realise the potential effectiveness of co-management (Craig et al. 2004).

Several floodplain fisheries enhancement projects have been undertaken in Bangladesh. The results of these projects indicate that a more systematic approach is required to develop management models and policies, and that habitat restoration may be a more appropriate way to improve resource availability or enhancing fish stocks than floodplain stocking. There also must be a social reason for undertaking enhancement so that people involved may share the benefit. There are concerns that introduction of large scale stocking of carps in open water might imbalance the ecosystem and adversely impact on biodiversity of non-stocked indigenous fish (Ali 1997). In some occasions stocking with major carp has negatively affected catches of small indigenous species (SIS) and has resulted in poorer nutritional outcomes in women and children who consume SIS.

Seasonal floodplains in Cambodian parts of the Mekong Delta are currently much less modified by human intervention than those in Bangladesh or the VMD. Cambodia's rice fields and floodplains still produce a significant amount of aquatic products. Fish yields in Cambodian floodplains are estimated at 139 to 230 kg/ha/year. This amount is higher than in any other tropical floodplains. According to Baran (2005) this can be explained by three interconnected factors: high biodiversity, accessibility of the floodplains and a very high exploitation rate. Three hydrological factors important to fish production are:

- 1) maximum water level and related flood extent: the higher the level and extent, the more habitat is available for fish feeding and breeding;
- 2) duration of flooding: a longer wet season is beneficial for fish growth, and
- 3) onset of flood: early flood is beneficial to fish recruitment.

Other important features for fish production in floodplains are seasonality and connectivity. Official figures for inland capture fisheries production for the period 2001 – 2006 (MAFF, Table 2) and our estimates of yearly flood extent over the same period show a positive correlation ($r = 0.32$) between total inundated area and fisheries production in the lower Mekong, (Table 4). A similar relationship could not be found between fisheries production and flood extent in Bangladesh. River and estuarine fisheries in Bangladesh have slightly decreased in the period 1997 – 2007, whereas fish production from flooded land has doubled over the same time period.

The latter trend suggests that the scope for increasing fish production in seasonal floodplains further through community based fish culture is considerable. Such interventions are however potentially more successful in already modified floodplains where enclosures can be established to manipulate and maintain water levels for fish culture and irrigation purposes. Less modified or long term seasonally inundated floodplains such as those in the Cambodian Mekong Delta and Haor Basin in Bangladesh still yield significant capture fisheries.

The temporal analysis depict nearly 40% cropped lands in November showcasing medium to high altitude lands of the basin or the topographical formations that facilitate hydrological flow in the wet season. The basin wide analysis at landscape-level provides fair insight for the scaling the fish-targeted interventions in seasonal flooded areas. For example, if the fish culture intervention has to be scaled up in the High Ganges (Padma) river floodplain agro ecosystem that spread more than 30,000 hectares, the low to medium altitude areas have the optimum hydrology and topology to support the intervention. However, the appropriateness of the localized features such as field dykes, embankments; along with social inclusion, exclusion and benefit of the beneficiaries remain important to determine the success of the intervention.

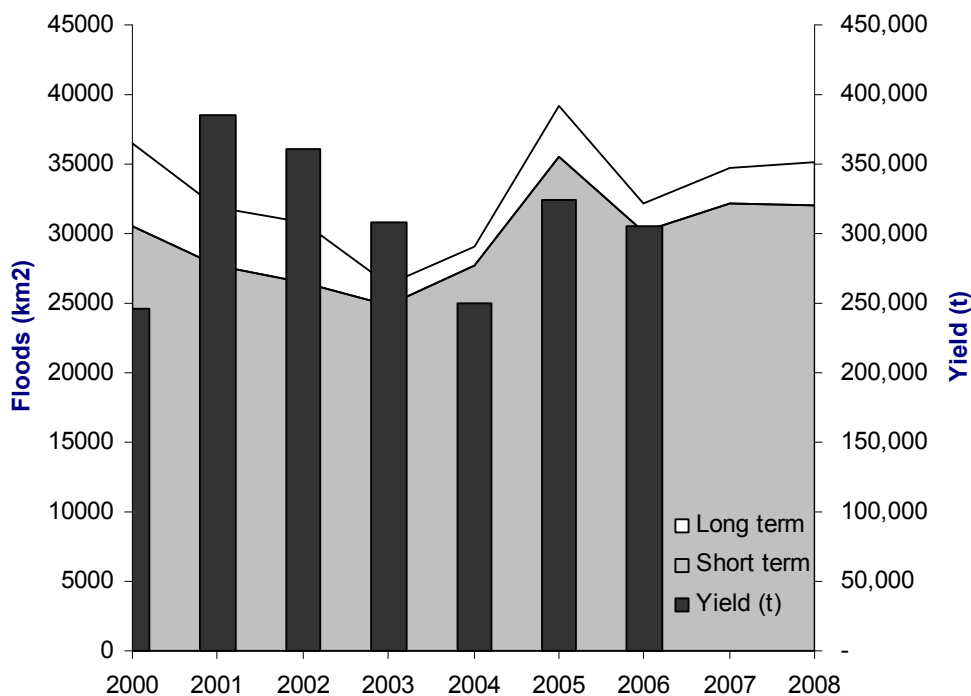


Figure 11: Correlation between annual capture fisheries production in Cambodia (source: MAFF) and annual flood extent

The landscape level spatio-temporal analysis of seasonal floodplains presented in this study provides a planning tool for targeting community based fish culture and enhanced fisheries at seasonal floodplains with comparably favorable characteristics for its development, and assess underlying floodplain development trends and related fisheries productivity. Landscape pattern and topography were important determinants of hydrological flow and the interactions that can potentially support or undermine fish culture activities during the wet season. This findings show that seasonal fish production supported by understanding of the biophysical characteristics helps assist for increased productivity of rice-fish production systems and cross scaling of such intervention within or across basins.

Floodplain agricultural land in Bangladesh a valuable commodity, subject to competing claims for production. It was found that where flood waters are relatively low (less than 2 m), sufficient water management infrastructure may continue to bring the flooded area under production by controlling the height of flood waters (UNDP, 1989; World Bank, 1989). The importance of rice for both domestic consumption and export means that a third rice crop is often preferred over capture fisheries or aquaculture. This was observed in the low flooding regions of Vietnam, where fish culture activities gave way to an additional rice crop when fish production was not sufficiently lucrative to make fish culture worthwhile. Where households have continued fish culture in smaller groups, low water levels or short flooding periods have been offset by modifications to the rice field environment. Construction of ditches on the perimeter of the rice fields has been used to successfully extend the culture period, and increase production. Additionally, the landscape pattern and relief are important

parameters to determine the hydrological flow and interactions that can potentially support or undermine the fish culture activity during the wet season.

We anticipate that floodplain areas are likely to be found in Ganges and the Mekong basin; but this has to be further assessed. The agroecological zonation, which takes into account seasonality, landscape characterization and dynamics, can be the guiding framework to assess such areas. Scenarios based on a thorough understanding of agro-ecological conditions and incorporating lessons learned from the community-based fish culture project described above, might usefully inform the development of similar interventions across or cross basin. The pilot-scale community-based management of fish culture experiments demonstrated potential for broader application in equivalent floodplain systems, net production benefits and the way that the benefit is shared at community level are shared, can be likely to vary, in cross-basin scaling. In addition appropriate local water management strategies that are supported by local authorities, and taking account of the biophysical and ecological characteristics of floodplains, typically their high variability and seasonality, can play an influential role in enhancing floodplain productivity in the basin. While more at the local level it is more appropriate for publically owned lands, the inclusion of local authorities for fish culture management in case of privately owned lands can be challenging.

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Annex I: Tables

Table 1: Year-wise inland capture fisheries production in Bangladesh (source: Fishery Statistical Yearbook of Bangladesh, 2006-2007)

Inland capture	1997-98	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07
River & estuaries	156894	151309	154335	150129	143592	137848	137337	139798	137859	136958
Flooded land	378280	410436	424805	445178	449150	475116	497922	621443	718491	768830
Beel	67812	69850	72825	74527	76101	75460	74328	74925	76365	75137
Sundarbans	7031	11134	11648	12035	12345	13884	15242	15724	16423	17751
Kaptai lake	5932	6689	6852	7051	7247	7025	7238	7379	7548	8085
Total	615949	649418	670465	688920	688435	709333	732067	859269	956686	1006761

Table 2: Year-wise inland capture fisheries production in Cambodia (source: Ministry of Agriculture, forestry and Fisheries)

Inland capture	1996-97	1997-98	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06
Lots / middle			71000	85600	135000	110300	94750	68100	94500	139000
Family fishing			115000	115000	140000	140000	120000	106400	137700	102000
Family rice field			45000	45000	110000	110000	94000	75500	91800	64000
Total	73000	75700	231000	245600	385000	360300	308750	250000	324000	305000

Table 3: Total number of people (N pop) and poor people (N poor) living within (< 1km) or in the vicinity of seasonal floodplains in the northwest (Rajshahi Division) and northeast (Dhaka Division).

Distance to floodplain	cl5 NW			cl5 NE (including Dhaka)		
	N pop	N poor	% poor	N pop	N poor	% poor
< 1km	628,126	354,778	56	3,408,798	1,234,555	36
< 5km	3,193,307	1,757,503	55	15,518,556	4,982,014	32
<10km	6,415,226	3,410,548	53	28,067,260	9,026,233	32
<25km	14,889,321	6,661,311	45	40,649,032	14,313,947	35

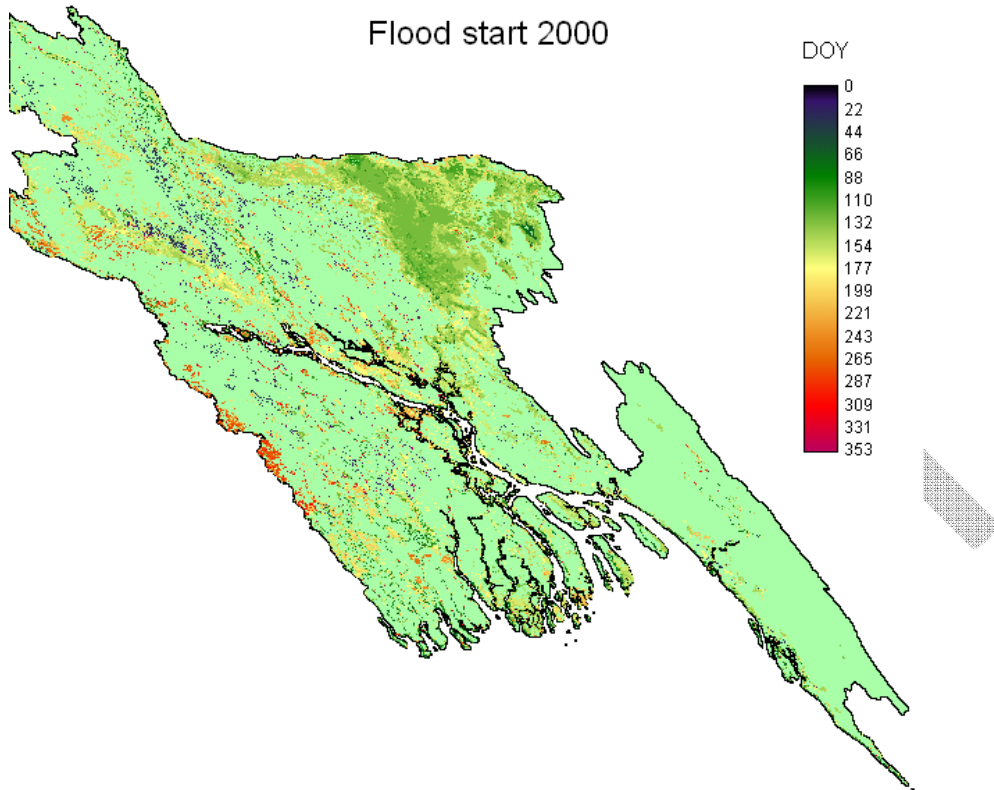
Table 4: Yearly flood extent (km²) in Cambodia and VMD

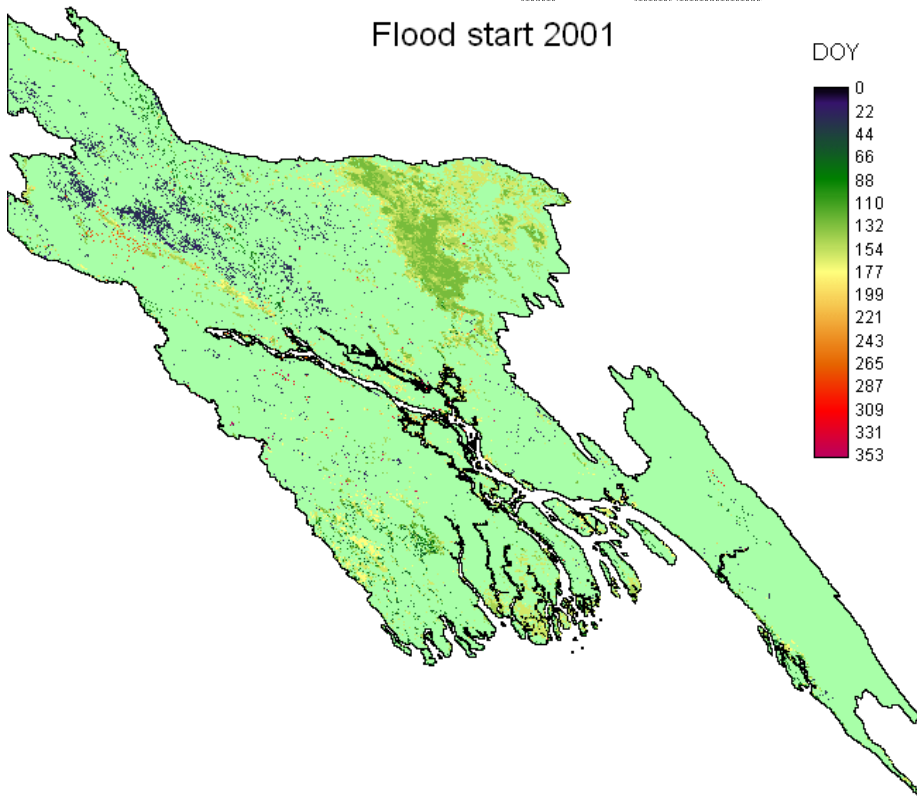
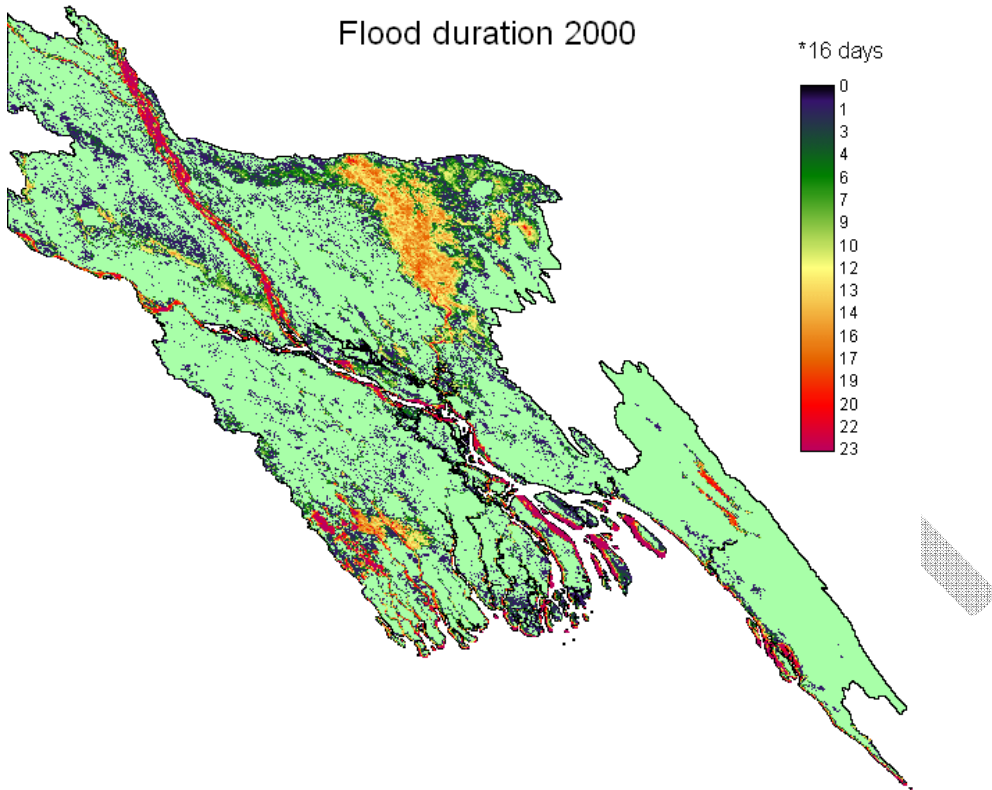
Flood (km ²)	Duration (month)	2000	2001	2002	2003	2004	2005	2006	2007	2008
Short term	0.5 - 3.5	30538	27746	26512	24914	27666	35608	30075	32167	32055
Long term	4 - 7	6003	4121	4310	1427	1375	3609	2039	2518	3024
Semi-annual	7.5 - 9	906	866	729	1110	693	926	873	972	1005
Perennial	> 9.5	2207	2217	2253	2101	2249	2188	2173	2205	2173

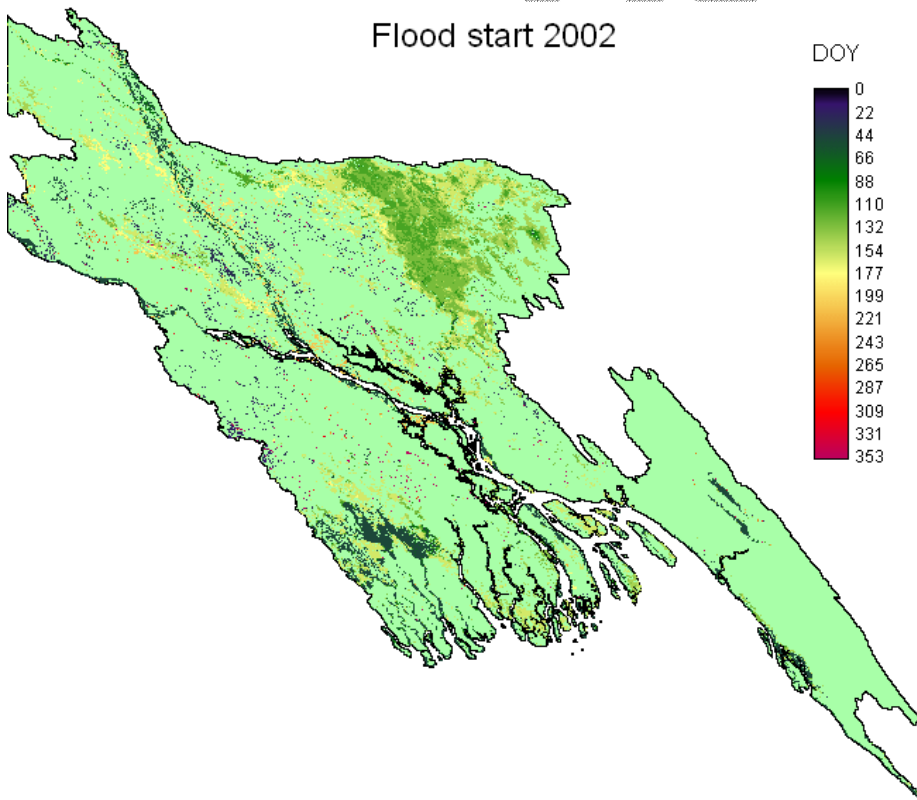
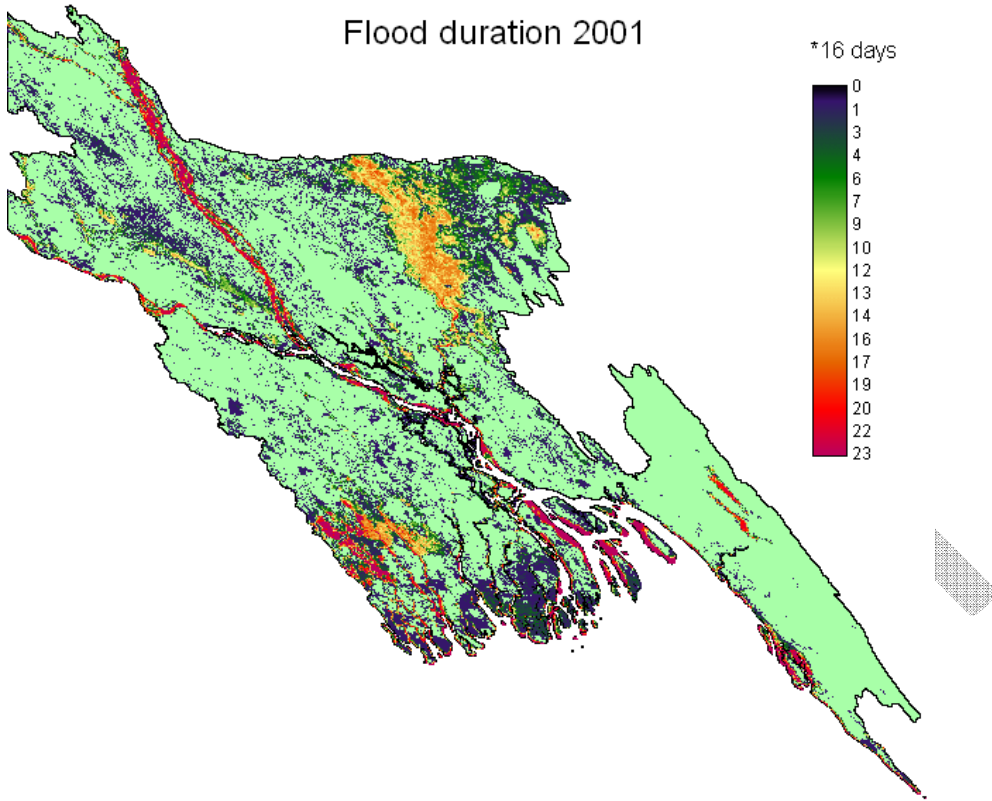
Table 5: Yearly flood extent (km²) in Bangladesh

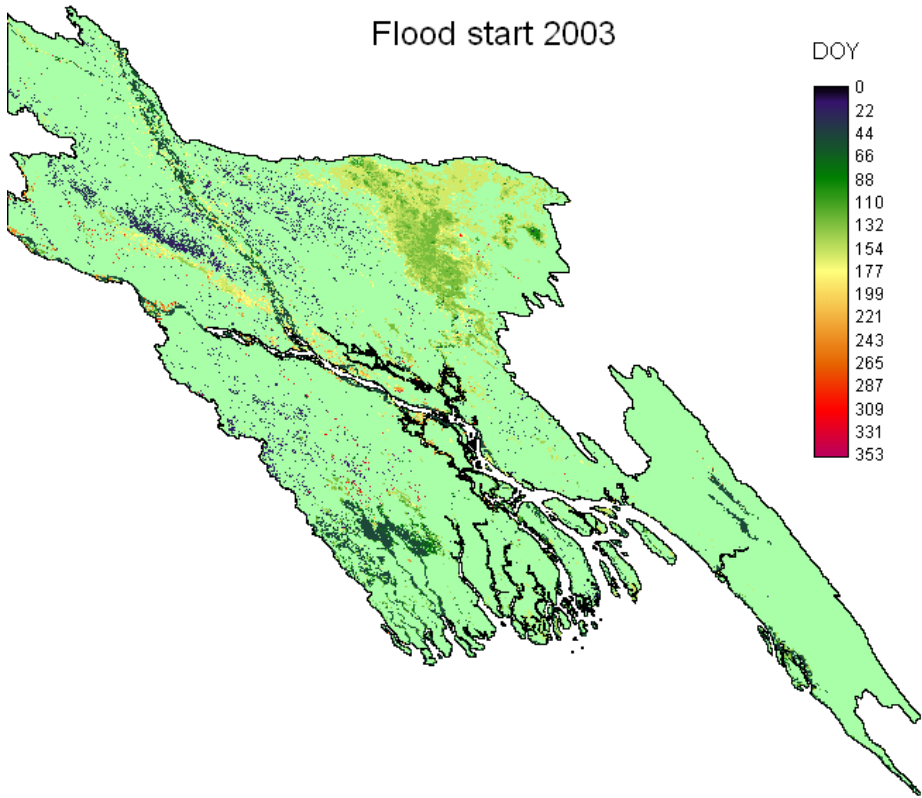
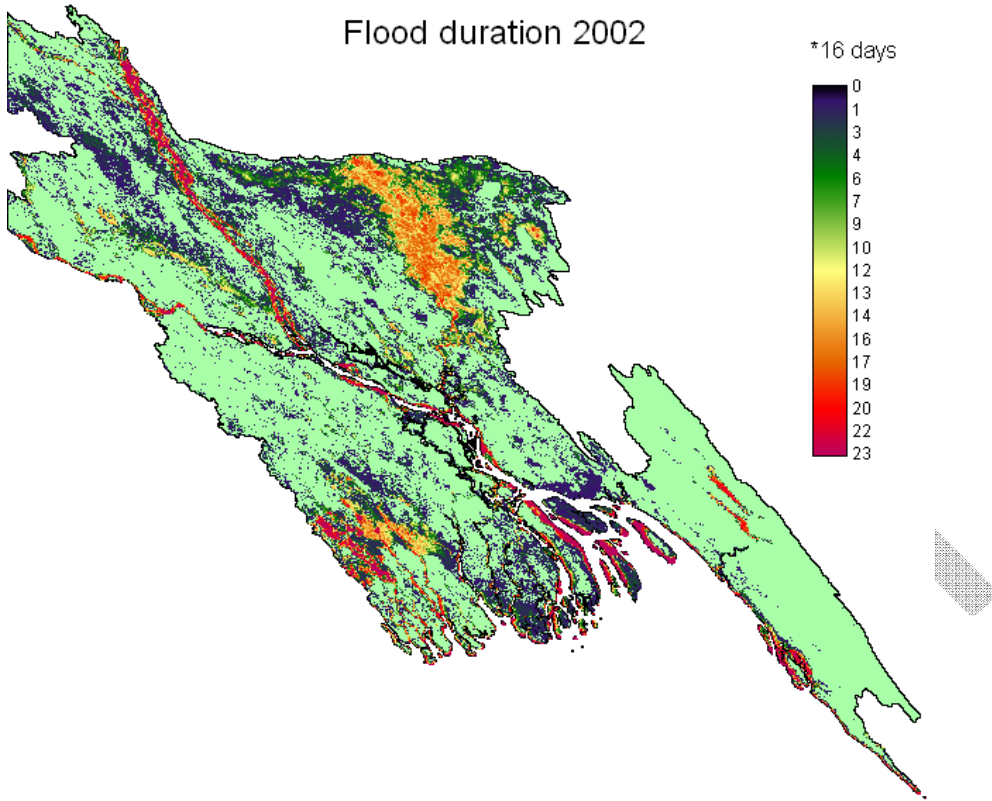
Flood (km ²)	Duration (month)	2000	2001	2002	2003	2004	2005	2006	2007	2008
Short term	0.5 - 3.5	31197	36136	41303	35651	37656	29330	37206	39700	44210
Long term	4 - 7	10411	8488	8952	8598	9989	8701	9541	10659	10082
Semi-annual	7.5 - 9	4199	3927	4903	3762	4850	3594	3136	4527	3430
Perennial	> 9.5	5208	5437	5236	5069	4996	5428	5812	5529	5955

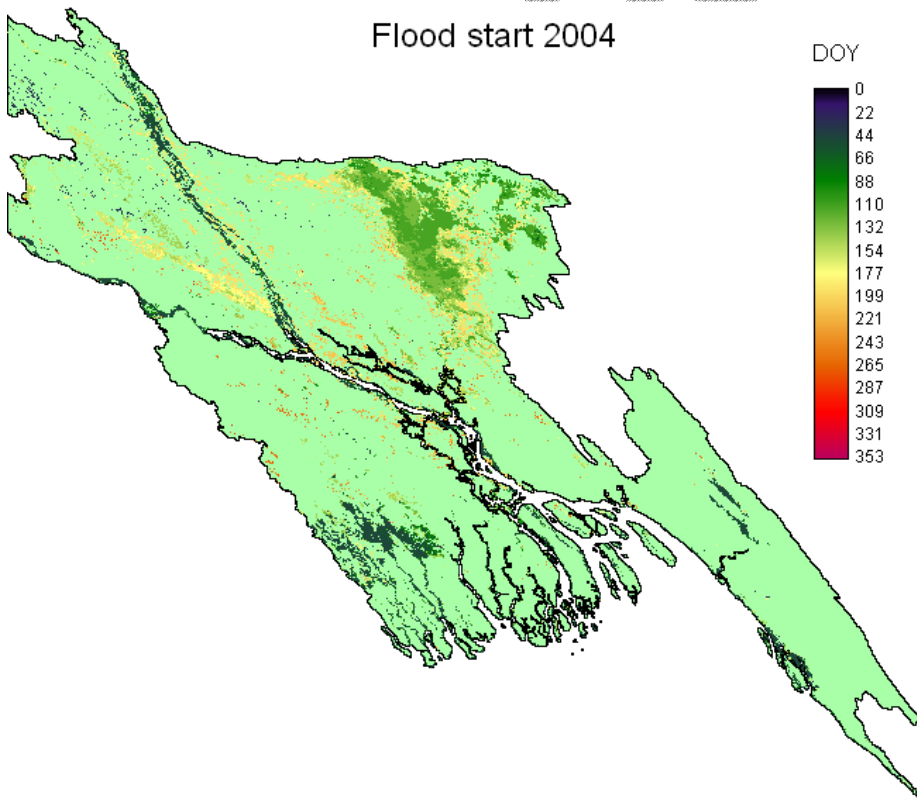
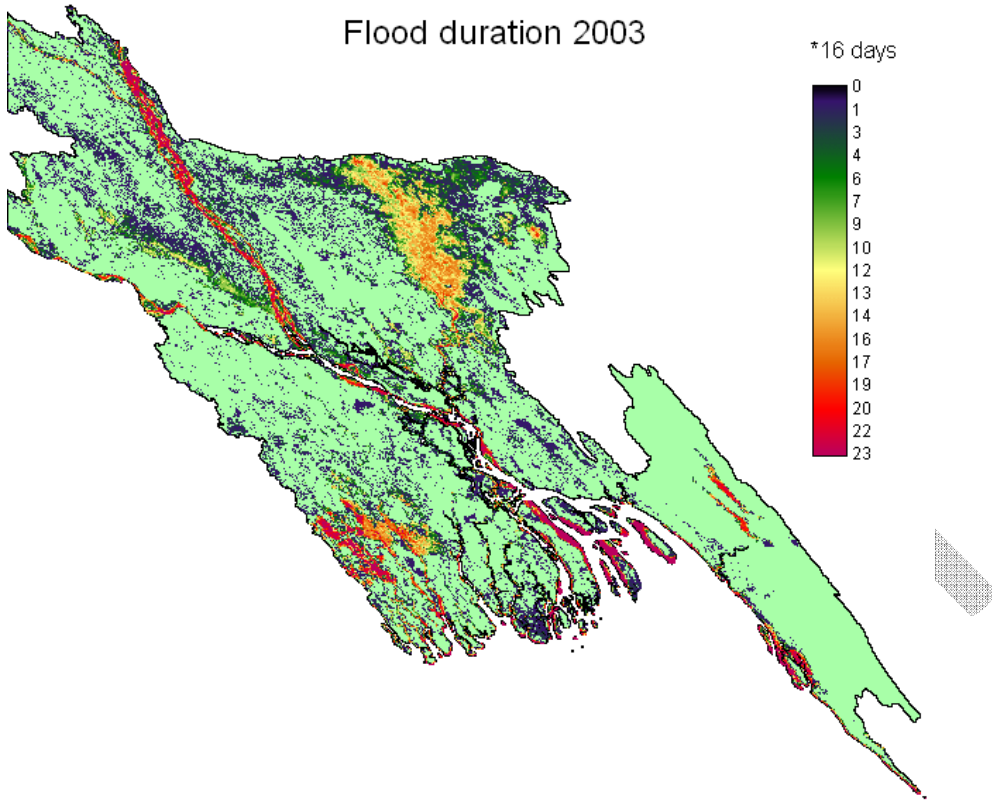
Annex II: Flood timing and duration

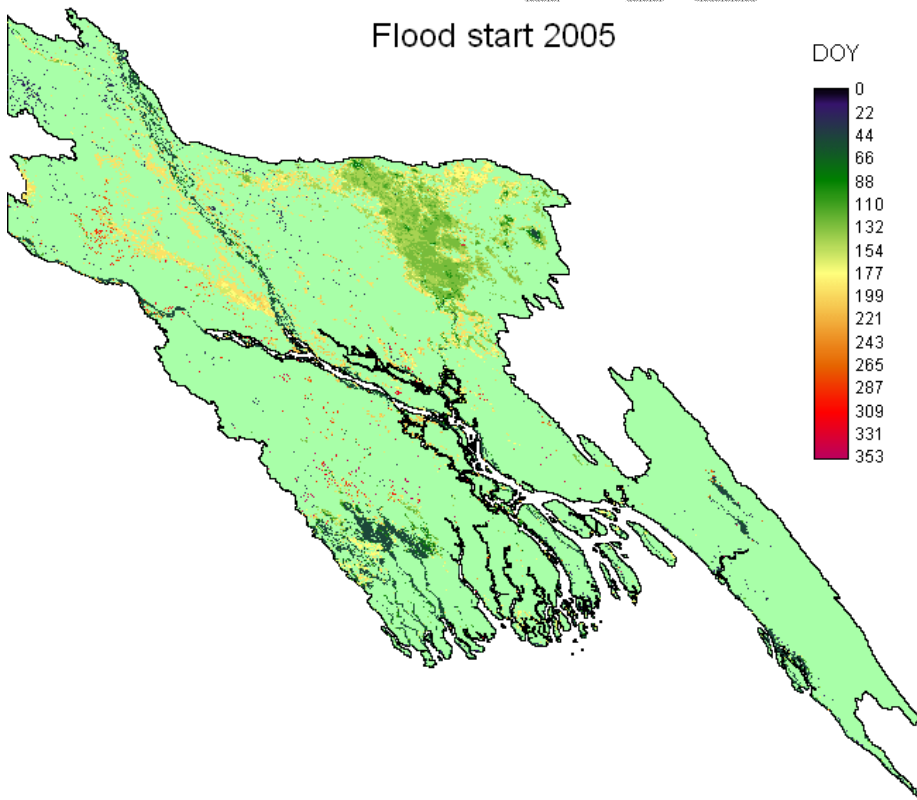
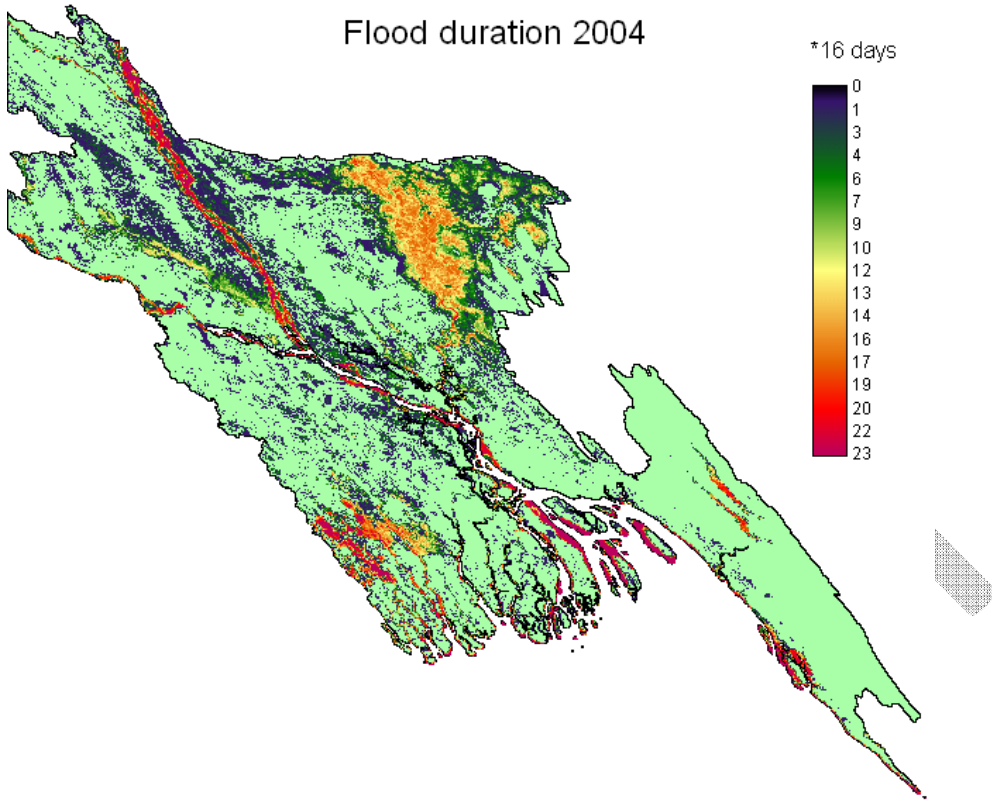


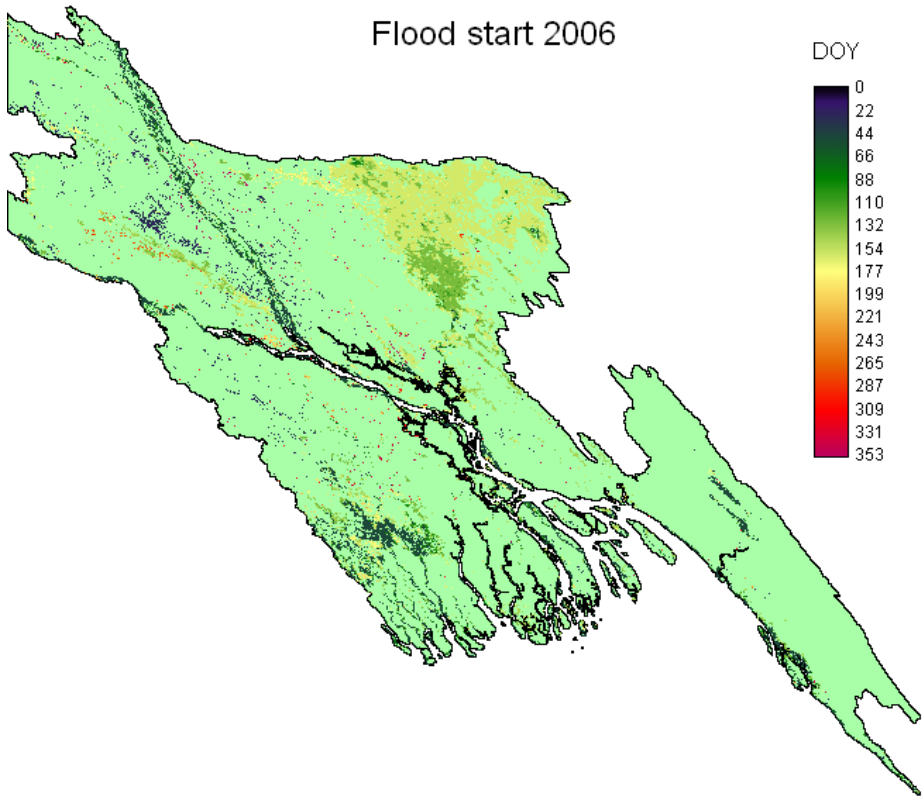
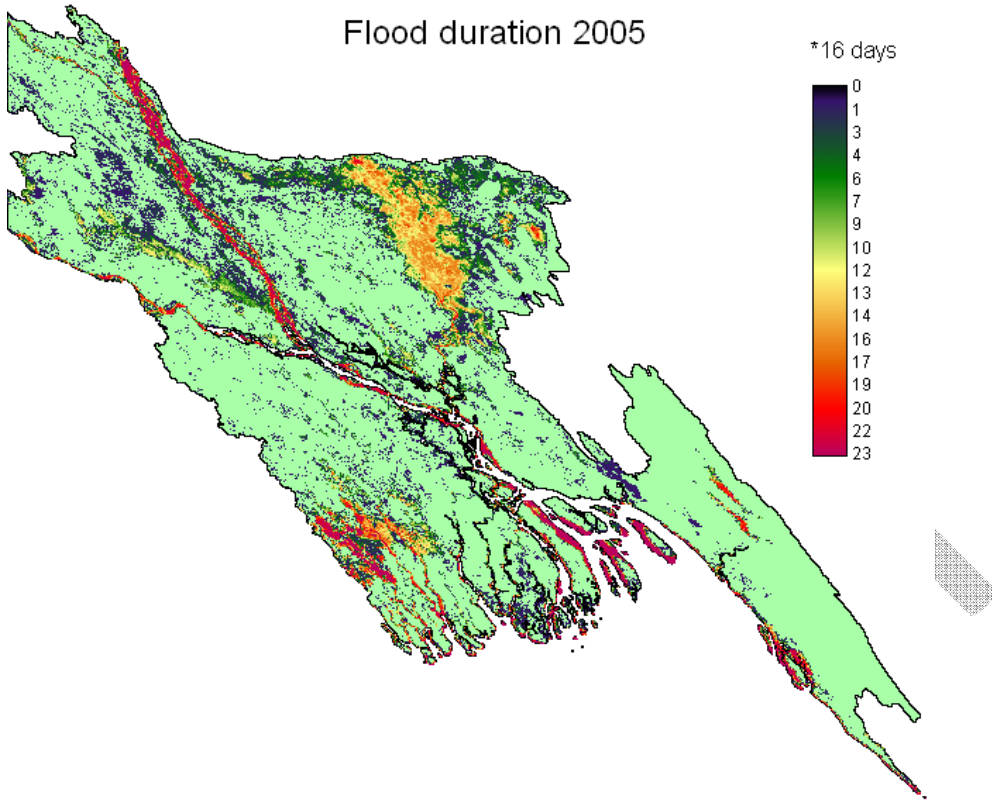




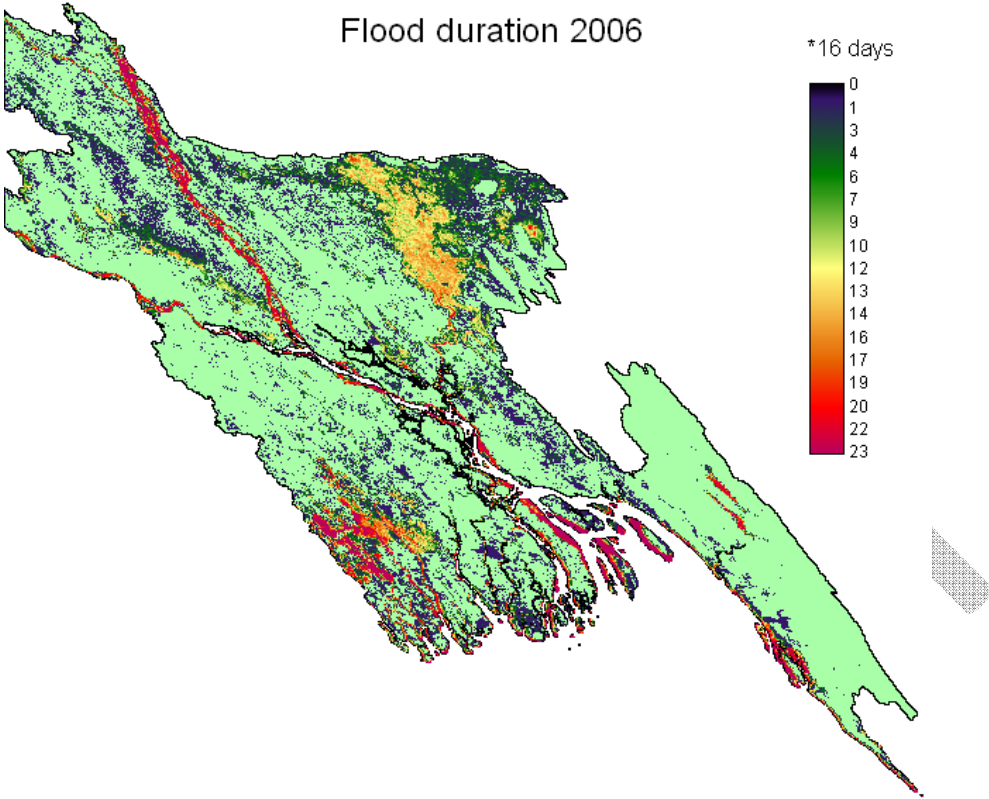




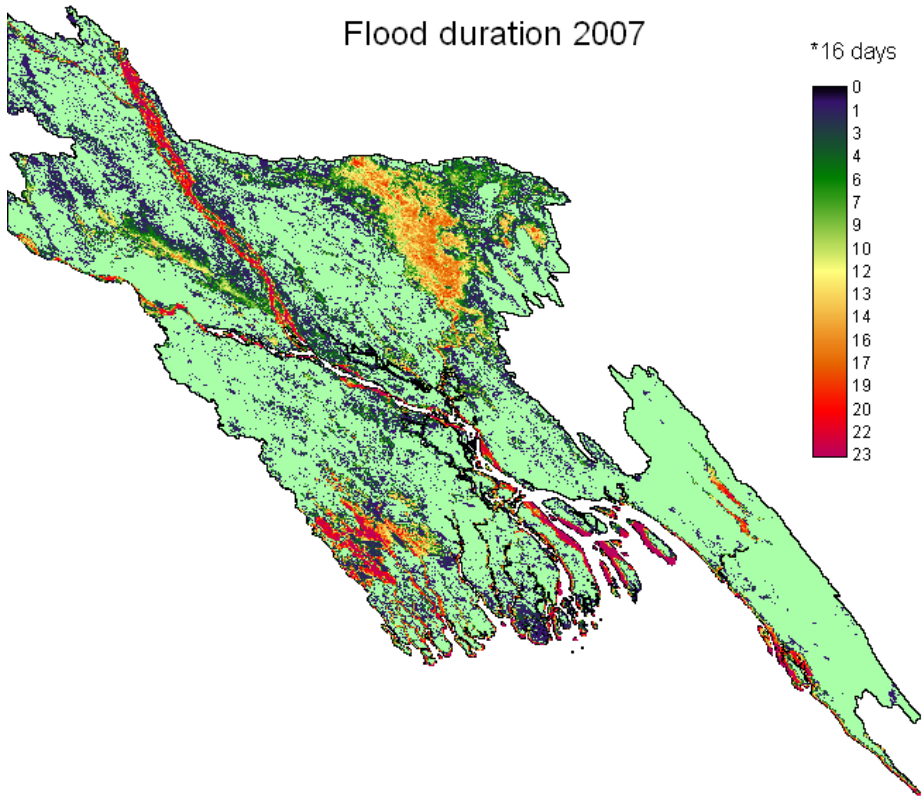
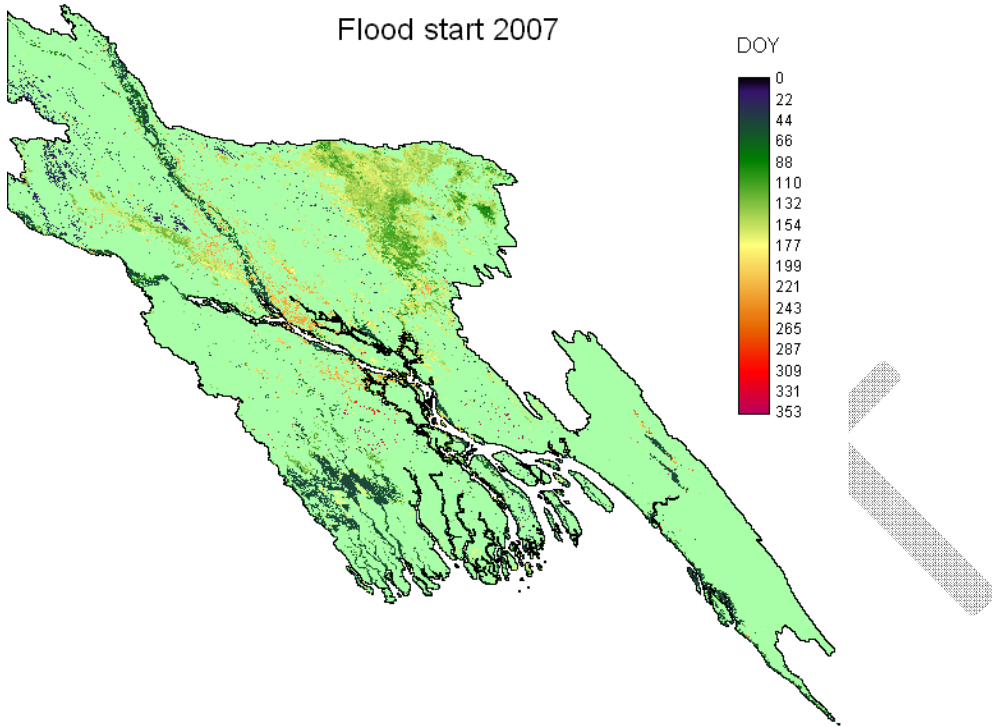


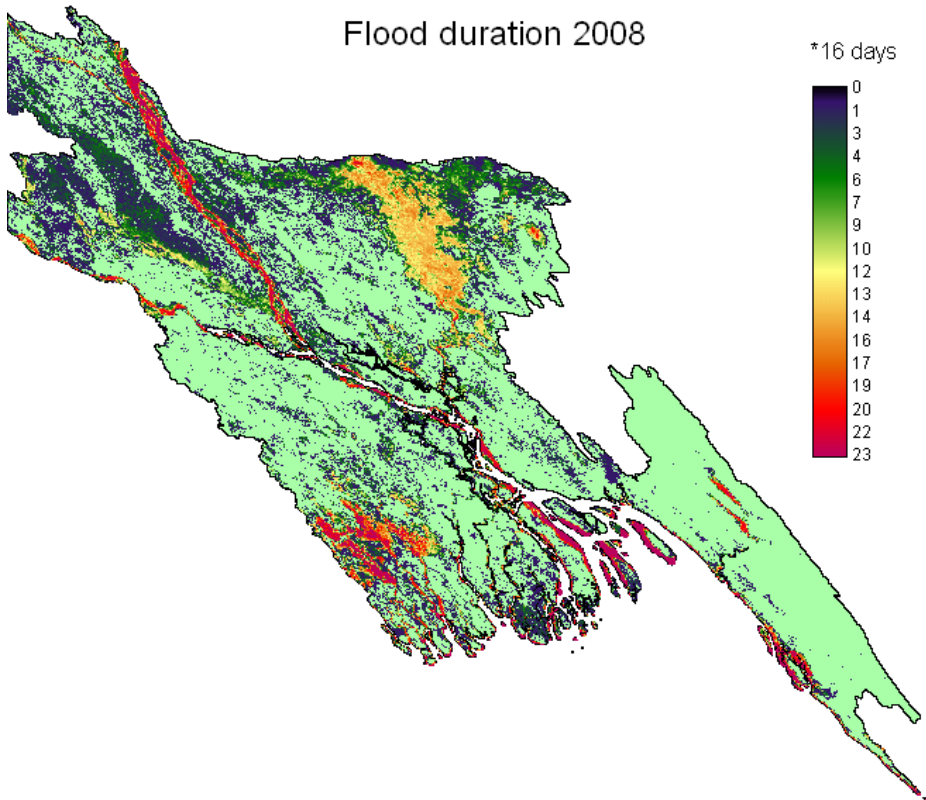
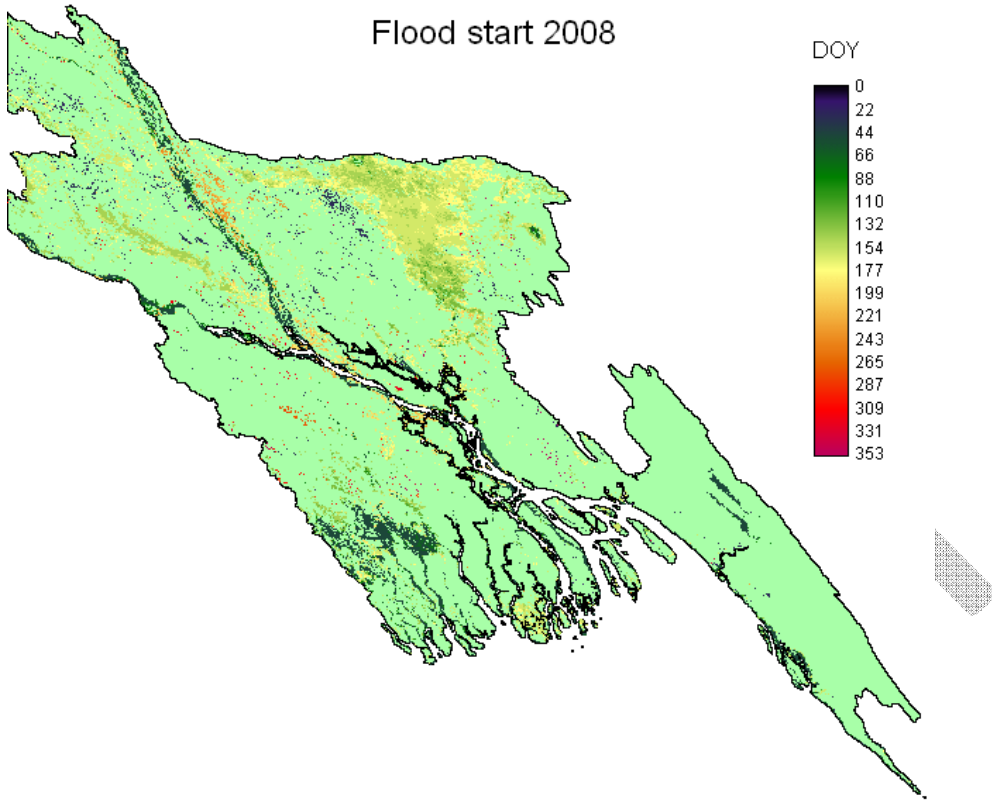


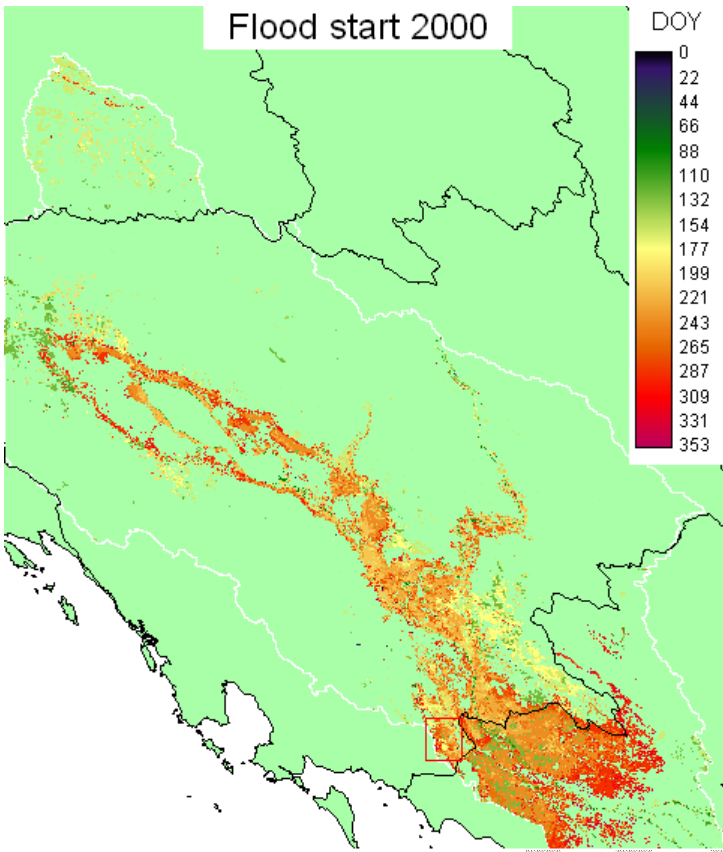
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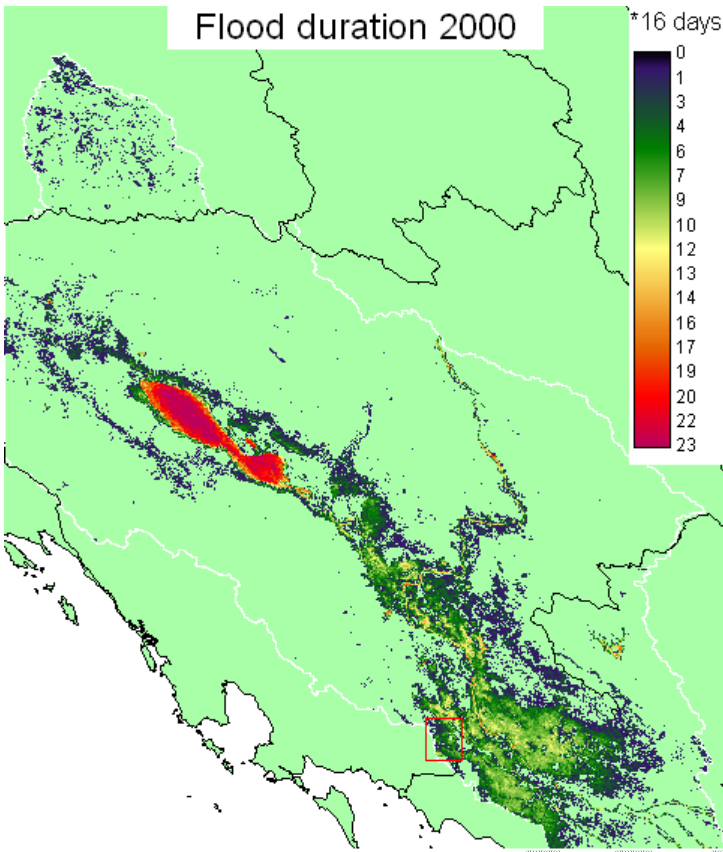


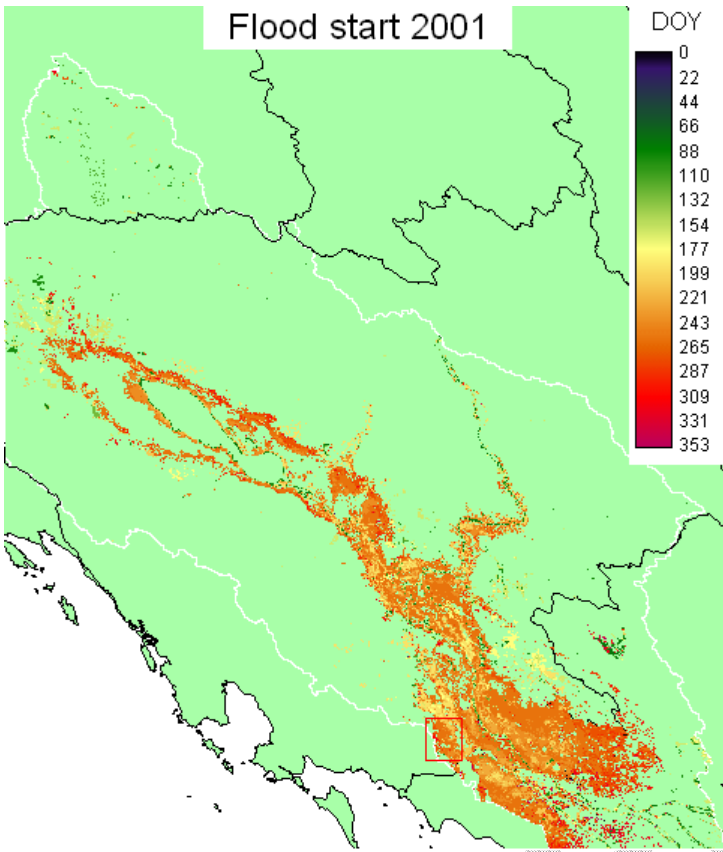
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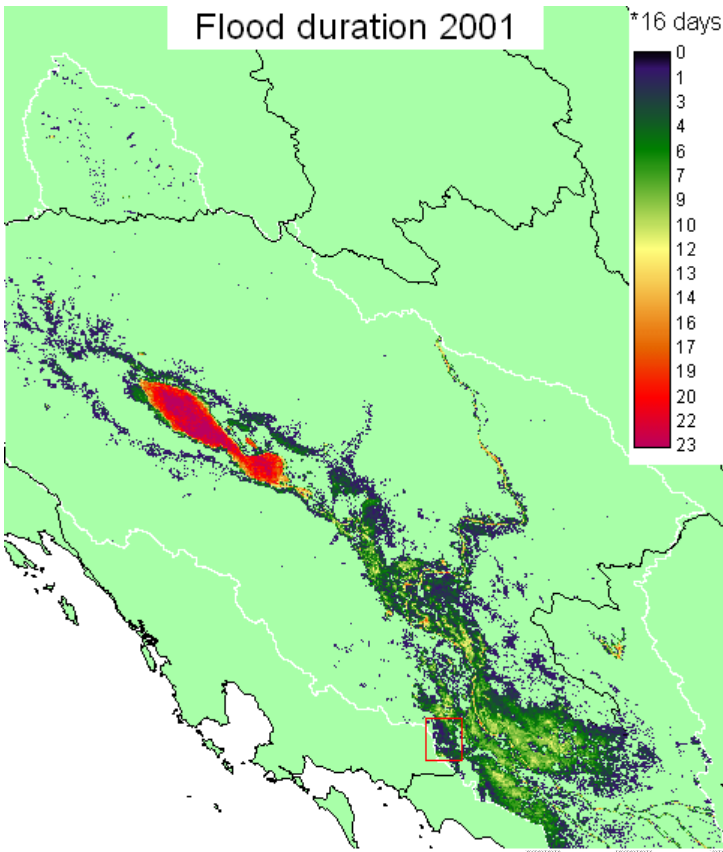




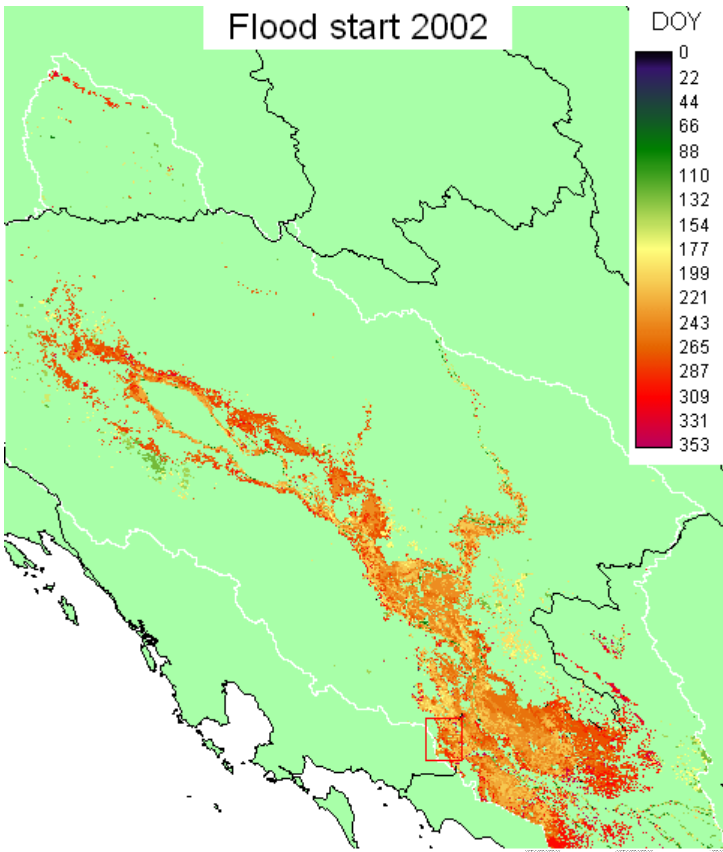


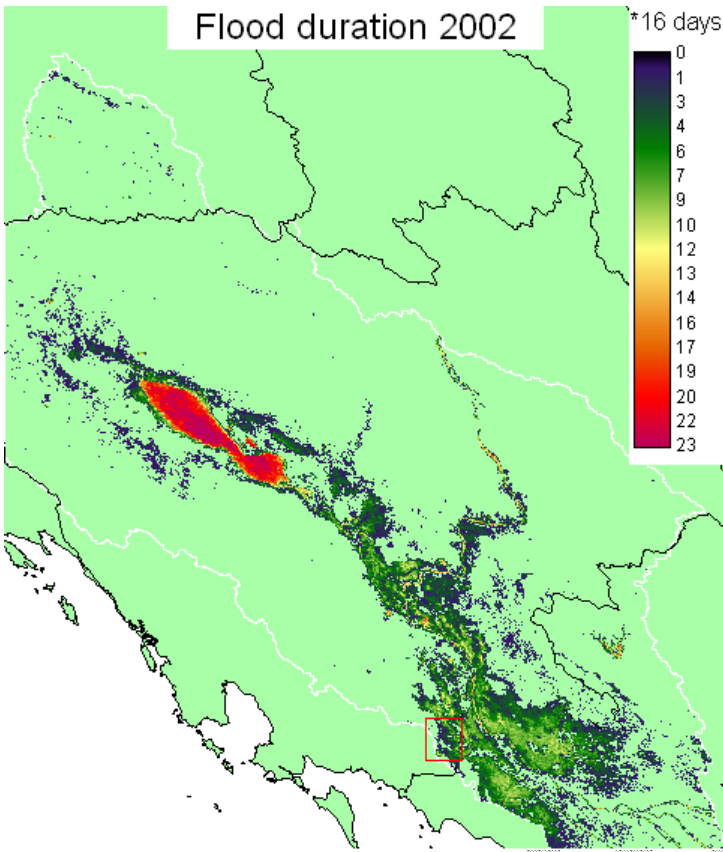


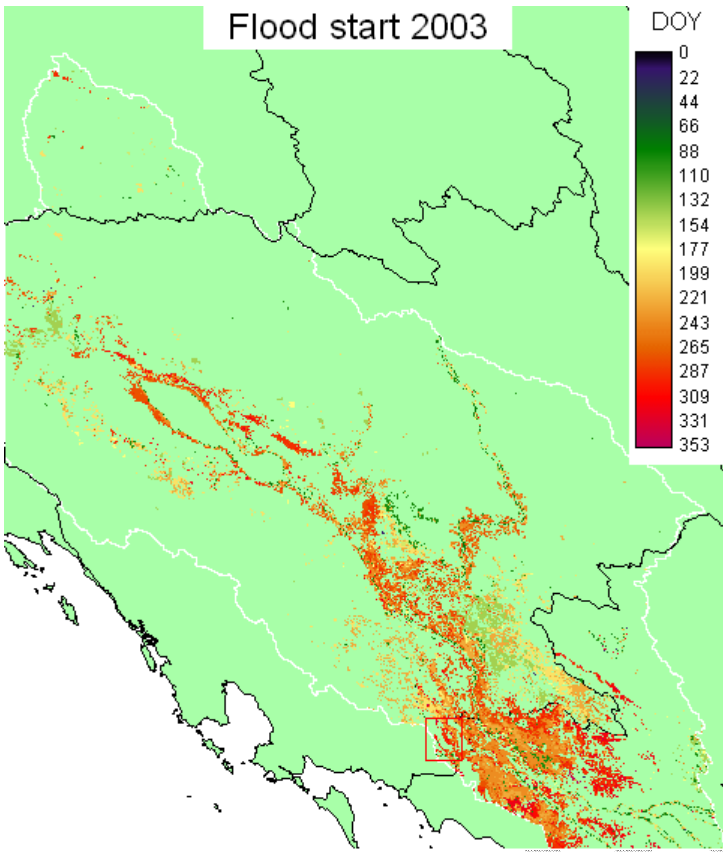


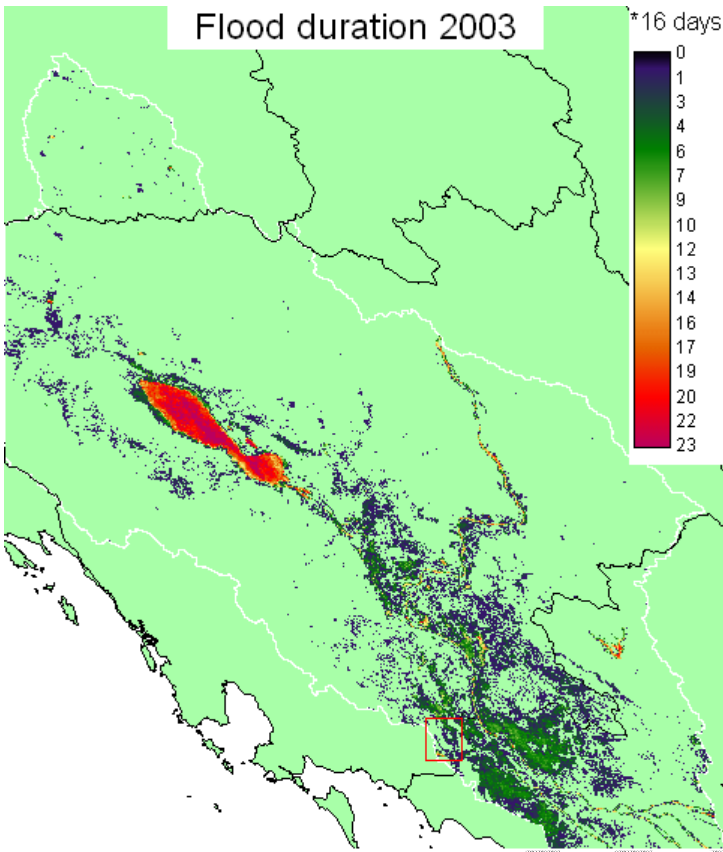


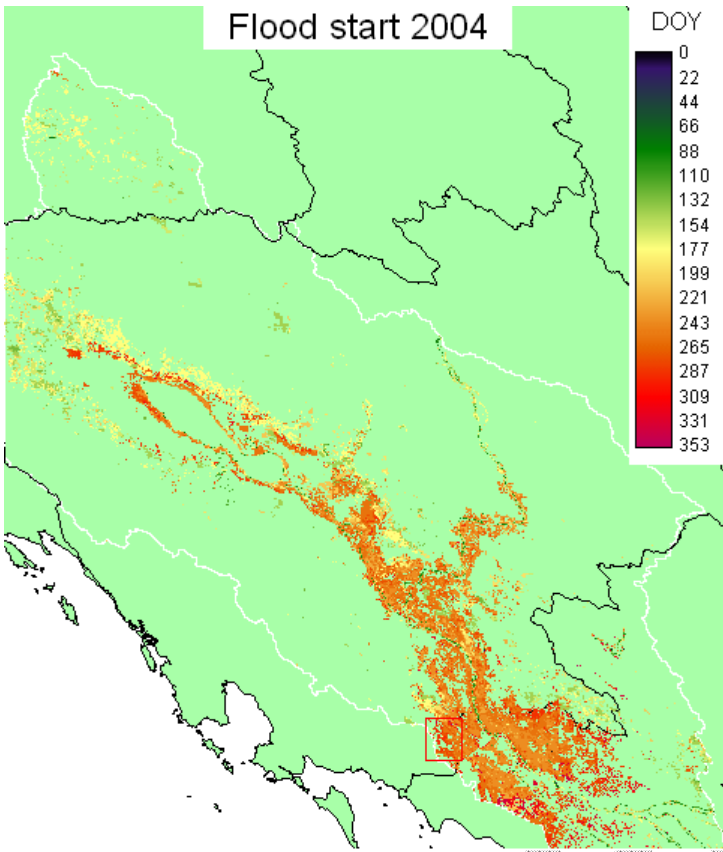
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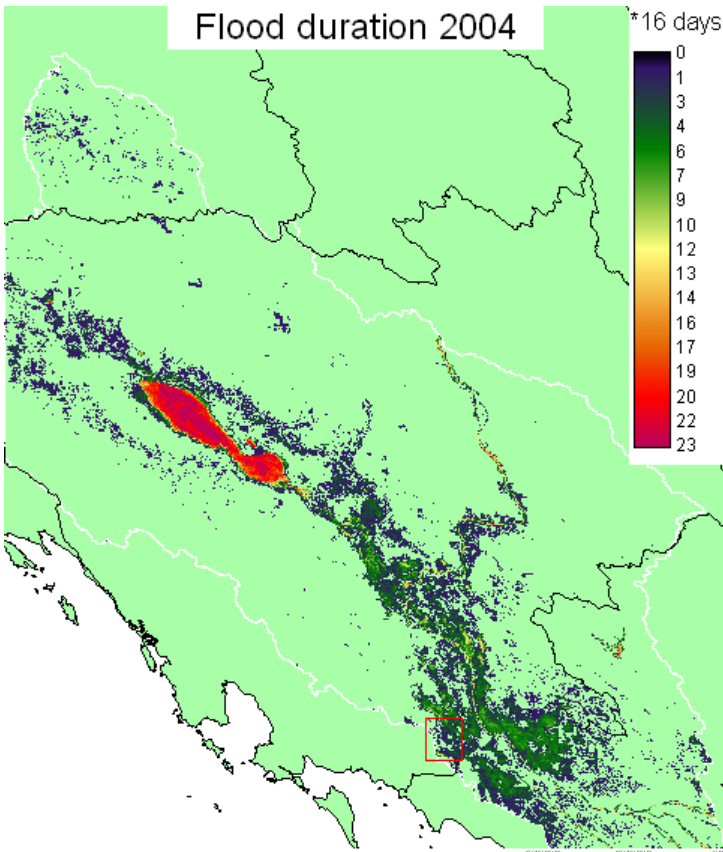




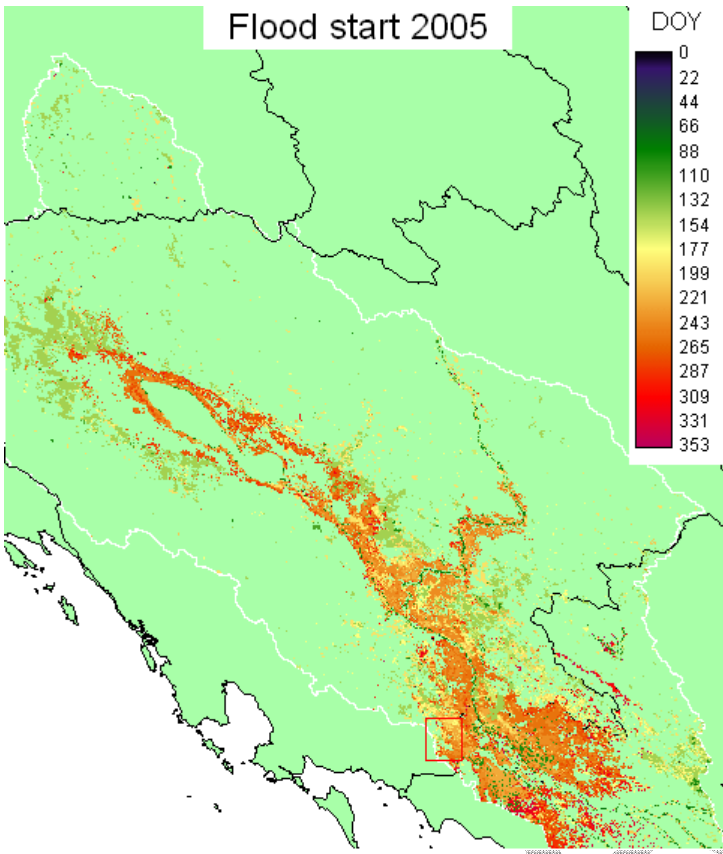


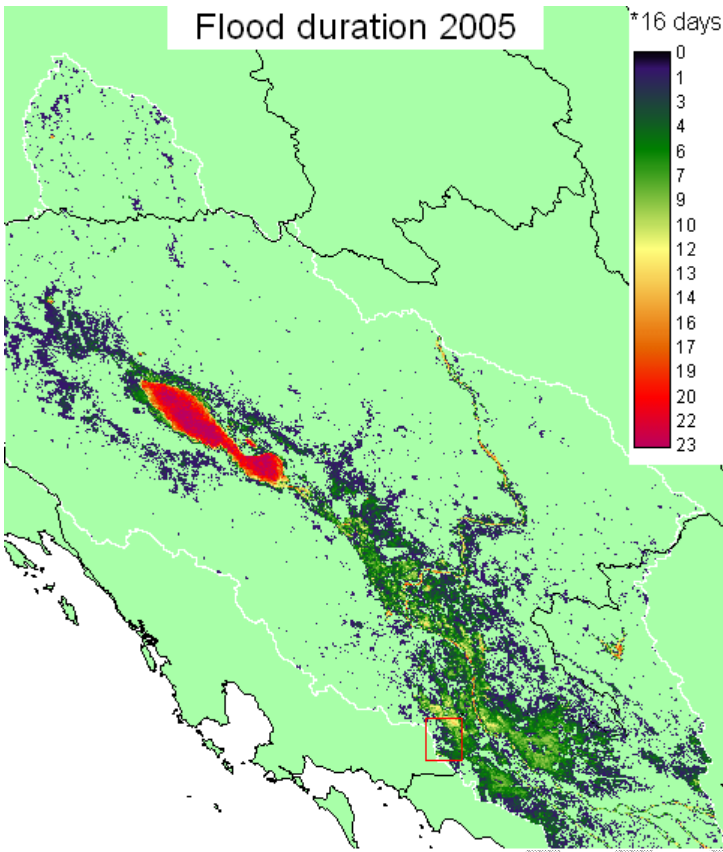




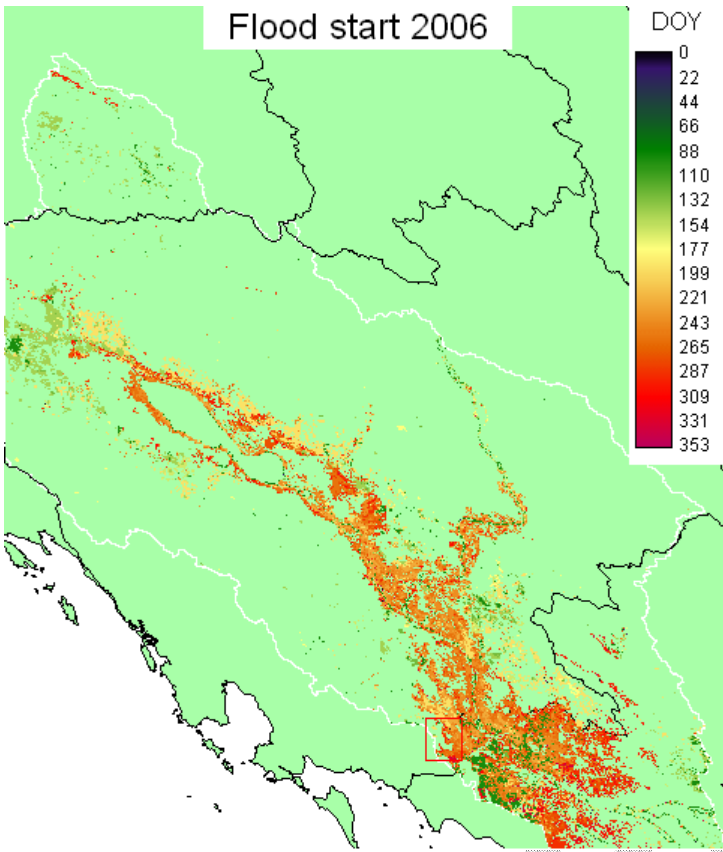


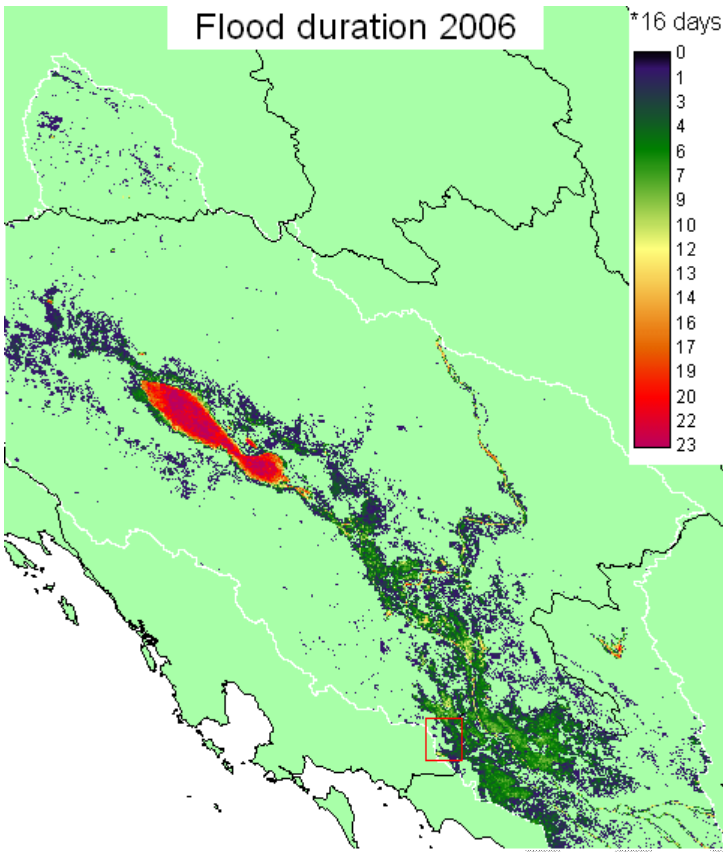
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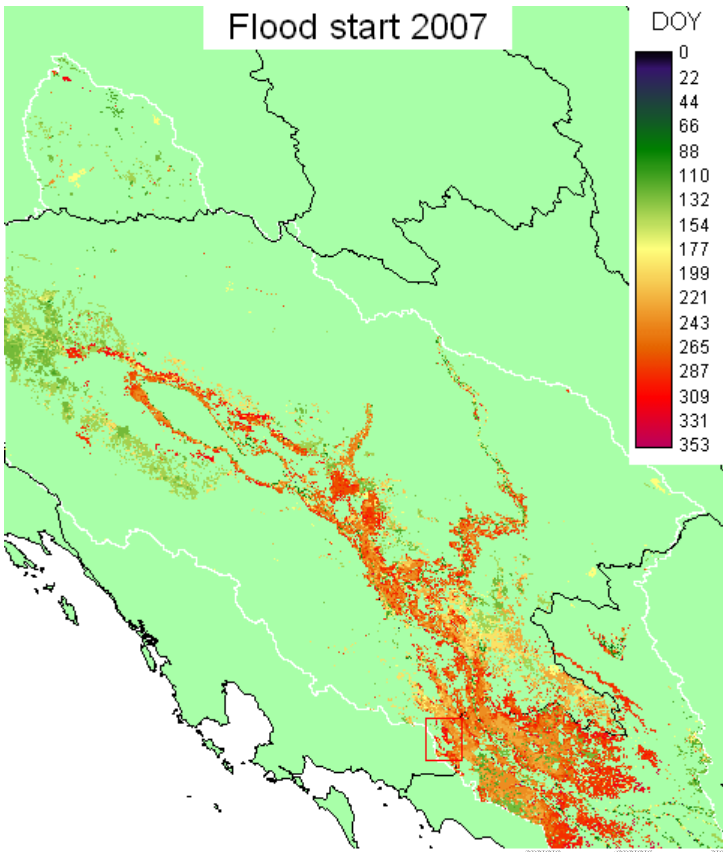


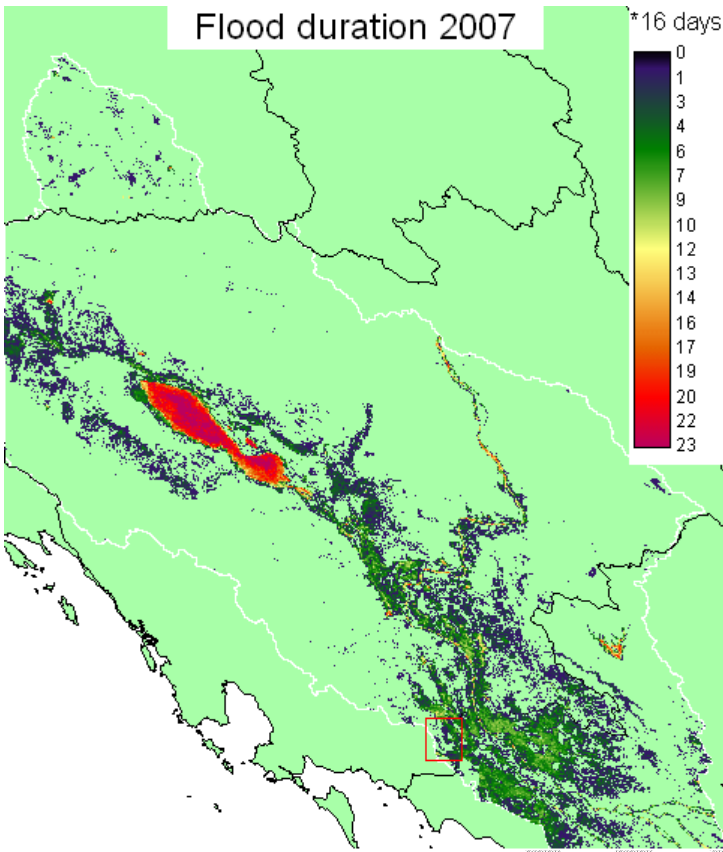


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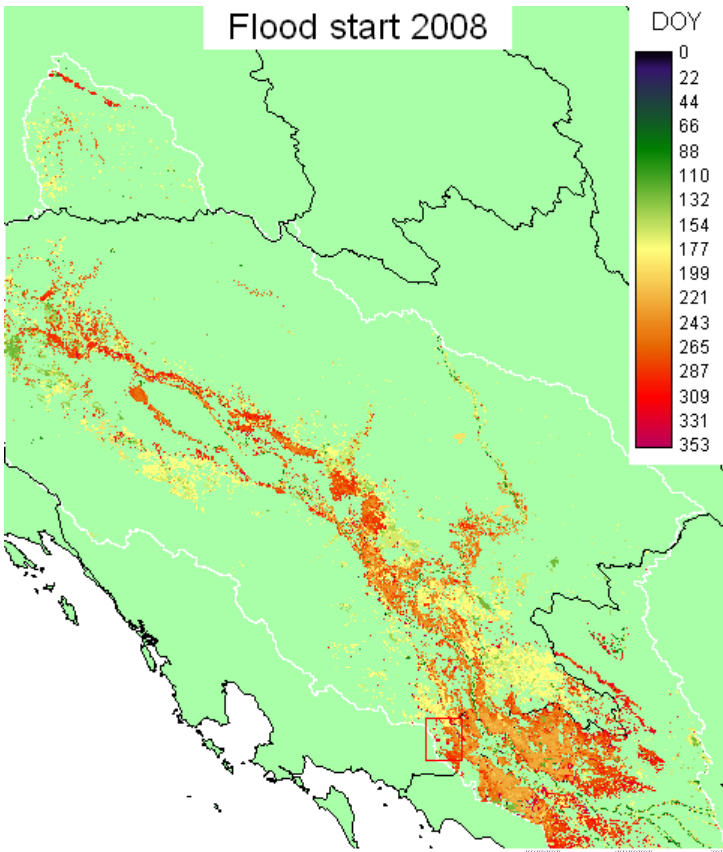


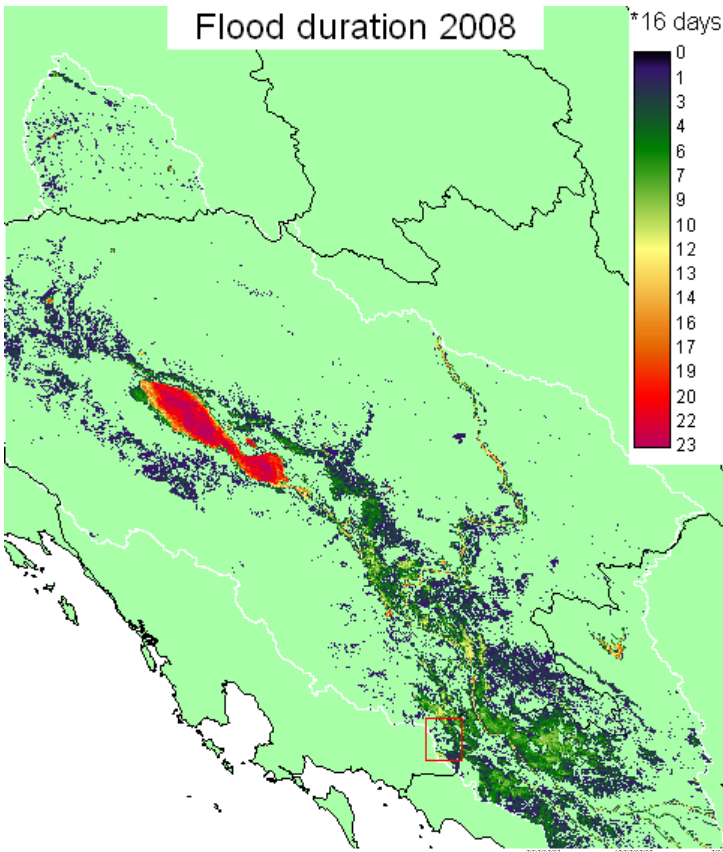






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