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Mekong River Commission

Fisheries Habitat and Yield in the Lower Mekong Basin

MRC Technical Paper
No. 47
June 2015

Cambodia · Lao PDR · Thailand · Viet Nam

For sustainable development

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Acronyms and abbreviations

AIFP	Agriculture, Irrigation and Forestry Programme (MRC)
ATTZ	Aquatic-Terrestrial Transition Zone
DARD	Department of Agriculture and Rural Development (Viet Nam)
DLA	Department of Land Administration (Viet Nam)
DMFPF	Demonstration of the Multi-functionality of Paddy Fields (MRC project)
FAO	Food and Agriculture Organization of the United Nations
FPC	Flood Pulse Concept
FSL	Full Supply Level
FWAE	Fresh whole animal equivalent
GIS	Geographic Information System
IRMC	Integrated Resources Mapping Centre
LDD	Land Development Department (Thailand)
LRIAD	Land Resources Inventory for Agriculture Development (MRC Project)
LMB	Lower Mekong Basin
MASL	Metres above sea level
MRC	Mekong River Commission
MRCS	Mekong River Commission Secretariat
MSS	Multi-spectral scanner
OAAs	Other aquatic animals (other than fish)
Production	As a biological term, production is the rate at which biomass is produced per unit area (or volume) over a particular time interval, and is usually understood to be net production; i.e. after subtracting respiration losses.
RCC	River Continuum Concept
RIA2	Research Institute for Aquaculture No 2 (Viet Nam)

SIA	Stable Isotope Analysis
SPOT	Satellite Pour l'Observation de la Terre
TM	Thematic Mapper
VRSAP	Vietnam River Systems and Plains (hydro-dynamic model)
Yield	Yield is the part of biological production that is removed each year by people, so it is a product of both productivity of the system and the efficiency of its harvest. Yield is often referred to as production, e.g. in national accounts.

Executive Summary

This report classifies aquatic habitats in the Lower Mekong Basin (LMB) into broad zones and estimates their contribution to the yield of fish and other aquatic animals (OAAs). Over large scales, delineation of wetlands (i.e. all land covered by water for significant periods) is limited by the resolution of remote-sensing data, the quality of classification under GIS, the currency of different data sets (as land cover changes over time), and the difficulty of delineating aquatic from terrestrial habitats. After considering these issues in detail, MRC's land-cover data sets and prior-flood modelling were used to classify fisheries habitats as falling within three main zones as follows:

1 **The major flood zone** includes all land within the major (Year 2000) flood. This zone includes most major rivers and floodplains, such as the Tonle Sap – Great Lake system, including their permanent waterbodies and recession rice fields as well as some former floodplains, particularly in northeast Thailand which now rarely flood because of damming. This zone is 'water-resources rich' and virtually all of it becomes wetlands during a very wet year, when unbroken or continuous sheets of water 'drown out' barriers, allowing fish and other aquatic animals (OAAs) to move freely. As floodwaters recede, aquatic animals migrate to permanent waterbodies, either on floodplains or in rivers. Recruitment may be from local sources or by migration.

2 **The rainfed zone** includes land outside the major flood zone that is classed mainly as rice fields. Based on comparison with Google Earth images, about one third of this class includes other habitats which are not separately delineated such as small swamps, waterbodies, wetland crops and others. Most of this zone was formerly covered by forest which was cleared prior to being modified for rice farming, so most of this zone includes new (human-constructed) aquatic habitats. Rainfed rice fields are inundated by local rainfall or by water diverted laterally from watercourses into paddies which are typically 30-50 centimetres deep. Rainfed habitats are highly modified with numerous barriers that restrict migration of most aquatic animals, favouring amphibious species, predominantly black fishes such as snakeheads, walking catfish, swamp eels and climbing perch as well as OAAs such as frogs, snails and shrimps—all of which can travel over land to surmount or bypass barriers. Fishery species recruit mainly from local refuges or from resting stages buried below or near seasonal waterbodies.

3 **Permanent waterbodies** outside the major flood and rainfed zones mainly comprise large reservoirs, with a minor contribution from rivers and canals. The rivers in this zone could be further categorised as being upstream of and connected to reservoirs or connected to the major flood zone. It was not possible to further subdivide this habitat class using the GIS data, although this would have had only a minor effect on the overall assessment.

The extent of 'wetlands' varies depending on the definition used. Each of the habitat zones is totally covered by water at some time. Under some definitions, the entire area within each would be classed as wetlands. Under other definitions, only the wettest parts would qualify. Although it is possible to measure biological productivity of certain individual habitats (e.g. a rice field or a pond), this is not a very useful approach for estimating yields over large scales. Apart from the complexity of

aquatic habitats, nutrients and fixed carbon in monsoonal environments are moved large distances by water; and fish and other animals as well as fishers move through the landscape. So it is rarely possible to define precisely the origin of the biological production which supports the yield. The habitat zones are defined here as a 'first cut' to examine the sources of yield basin-wide and to guide a more rigorous examination of this issue. The GIS data are useful primarily for examining yield from lowland habitats, where most people live and where most fish and OAA catches are made. Elevated tributary streams or small waterbodies, particularly those under forest cover, are mostly not resolved within the GIS data. But it is assumed that they would directly contribute a small proportion of the basin-wide yield.

Data on fisheries yield-per-unit area were compiled from various sources to estimate the likely range of yield from each habitat zone. The area of each habitat zone was then multiplied by an estimate of yield-per-unit-area to produce estimates for the LMB, grouped by country. As well as suitable habitat, many other factors influence yields, but these were not considered in detail. Rather, empirical yield figures from a range other studies were used for the assessment.

The total area of fisheries habitats or 'wetlands' of 194,364 km^2 is about one third of the area of the LMB (622,584 km^2) and comprises most of the lowlands below about 370 metres above sea level. Rice fields are by far the dominant land-cover class in the lowlands, both in the major flood and rainfed zones. About 30% of the total wetland area is within the major flood zone (which includes most major rivers) and this area is considered to be about twice as productive for fisheries per unit area as the rainfed zone; the major flood zone is most important in Cambodia. However, the much greater area of the rainfed zone (lying mostly within Thailand) leads to an approximately equal contribution to yield from these two main habitat zones, with reservoirs and other large waterbodies outside the major flood zone making a relatively small but significant contribution to the total yield. Habitat fragmentation and reduction of the flood pulse by dams and weirs on some rivers, particularly in Thailand, have had negative effects on river fisheries, which have been at least partly compensated for by the creation of vast areas of rainfed rice fields and associated small waterbodies. In the Mekong Delta in Viet Nam, the presence of a large canal system and rice-field habitats also supports 'new' capture fishery production.

Summary table of wetland areas and the range of yield estimates for the LMB

Refer to Table 11 for details and country breakdown

Wetland class	Area (000 km^2)	Yield (kg/ha/year) Low-high range	Total yield (kt/year)
1 Major flood zone including large rivers and floodplains	58,017	100 – 200	580 – 1160
2 Rainfed zone	129,835	50 – 100	650 – 1,299
3 Large waterbodies including reservoirs	7,512	100 – 300	75 – 225
Total	**194,364**		**1,305 – 2,684**

The estimated range of LMB yield (1.3 – 2.7 million tonnes per year) is similar to an earlier estimate that was based on the wetlands data set, but is now better supported and shows more clearly the probable source of the yield. Within this range, an estimate of 'most likely' yield was generated to balance the capture fisheries estimate from Year 2000 consumption data.

Summary table of 'most likely' yield of fish and OAAs in Year 2000, where the total yield was forced to balance the total capture fishery consumption data across the LMB

Units are kt/year – thousand tonnes per year. Note that this table refers to the source of the production, based on habitat area, rather than the place where the yield (catches) are actually made. Refer to Table 13 and further discussion in the text. Note that there are some slight rounding errors.

Habitat	Cambodia	Lao PDR	Thailand	Viet Nam		Total LMB
				Delta	Highlands	
1 Major flood zone	565	92	117	260	0	1,035
2 Rainfed	176	90	698	64	16	1,044
3 Large waterbodies outside Zones 1 and 2	26	64	106	25	5	226
Total yield estimate	**767**	**246**	**921**	**349**	**20**	**2,304**
Consumption estimate Year 2000	558	166	861	659	60	**2,304**
Surplus/deficit	209	80	61	-310	-39	0

Under this 'most-likely' yield estimate, Cambodia would have been producing significant surplus fish and other aquatic animals, whereas Viet Nam would have been in deficit. The transfer would be via migration and/or exports of fish and OAAs from Cambodia to Viet Nam, which is consistent with migration downstream from Cambodia during the flood recession and net exports of preserved fish from Cambodia. There is also a possible net downstream movement of fisheries species and fish food organisms from Thailand and Lao PDR.

The findings of this study are somewhat speculative because of the limitations of data which could be greatly improved as recommended in this report. Nevertheless, it is clear that each broad habitat zone makes a major contribution to yield so each should be explicitly targeted in fisheries assessment and management measures which are discussed briefly. Similarly, developments will cause different kinds of impacts on production and yield from each habitat class. For example, increasing irrigation to rainfed habitats may increase the extent and duration of available habitat and lead to higher yields. However, if irrigated rice is grown in shallower water and pesticide use increases, fisheries production is likely to decline. Storages and distribution canals may support additional fisheries production, but abstraction of water from rivers is likely to have negative effects on their fisheries. Dam construction on the Mekong mainstream is likely to primarily affect production from the major flood zone with limited or no effects on rainfed areas and habitats which are already upstream of tributary dams. Caution is required when predicting development impacts based on experiences from other regions, because the anthropogenic rainfed rice-field habitats that predominate in the Mekong Basin (and in other large river basins in tropical Asia) are absent or limited in extent elsewhere in the world.

1 Introduction

The Mekong is one of the world's largest rivers and its basin supports a population of over 70 million people, for most of whom the staple diet is rice, fish and other aquatic animals (OAAs). Within the Lower Mekong Basin (LMB) countries of Cambodia, Lao PDR, Thailand and Viet Nam, surveys indicate that the population of 56.2 million in the year 2000 consumed about 2.56 million tonnes (as fresh weight) of inland fish and OAAs (Hortle, 2007). About 90% of this consumption was supplied from capture fisheries, whereas aquaculture (mainly in ponds or cages) was estimated to account for about 10% of the total consumption in 2000. The population of the LMB grew to about 62 million people by 2010, so assuming per capita consumption of fish and OAAs remained constant, total consumption is likely to have increased to about 2.82 million tonnes. This increase in consumption would probably have been supplied by aquaculture, which is continually expanding (MRC, 2010). For the capture fishery, there are relatively few monitoring data and those that are available show that catches vary greatly from year to year, with no evident increase or decrease basin-wide. Therefore, the year 2000 figure of about 2.3 million tonnes per year continues to be the best available estimate of capture fisheries yield (fish plus OAAs) from the LMB.

Based on recent publications and reports, there appears to be a general acceptance of this consumption-based estimate of the size of the fishery. To follow on from that assessment of the size of the fishery, this report examines the contribution to catches from different habitats as a way of accounting for the basin-wide estimate derived from consumption. The habitat-based assessment as presented here can also support water-resources planning and management because the impacts of development vary by habitat. Classification of habitats and their fisheries should guide fisheries management and monitoring, and the results of this analysis can guide more focussed research within each class of habitat.

Yield over large areas, such as the entire Mekong Basin, can be estimated by multiplying yield-per-unit-area of habitat by the area of habitat. Previous habitat-based yield assessments for the LMB were calculated as follows:

- Hortle (2007) 0.7 – 2.9 million tonnes per year, based on a total wetland area of 193,896 km^2 and yield estimates of 25 – 200 kg/ha/year;

- Sverdrup-Jensen (2002) 2.23 million tonnes per year, based on a total wetland area of 96,900 km^2 and a mean yield of 230 kg/ha/year.

The wetland areas used in both of these estimates were derived from the MRC's 'wetlands' data set. The large difference in estimated areas and the lack of published documentation of the wetlands data set and yield-per-unit area estimates caused some concern over the validity of the estimates. This report aims to fully examine data sources, broadly categorise fisheries habitats and derive basin-wide areal yield estimates that are better substantiated as well as to present ways to improve data quality and fill critical information gaps.

The approach followed in this report is as follows:

1. **Section 2** assesses the quality and coverage of the MRC GIS data sets to show why the land-cover data set was selected for the classification of habitats. A landscape-scale classification of wetlands or habitat is proposed, based on ecology and the available data and its resolution. All land within the LMB is then classified into three broad habitat categories based on land cover and whether the land lies within or outside the major flood zone.

2. **Section 3** explains basic concepts of production and yield, and then published estimates of areal yield from different habitats are compiled and assessed to derive a likely range of yields from each broad habitat category in the LMB.

3. **Section 4** combines the habitat and yield estimates to derive national and basin-wide yield estimates as a range and also as 'most likely' yields to match the consumption-based estimate.

4. **Section 5** discusses the implications of this study for assessment and management.

5. **Section 6** outlines some recommendations for future work.

2 Wetlands and fisheries habitats

2.1 Definition of wetlands

All areas of land which are covered with water for any significant period may be defined as wetlands. Under the Ramsar Convention:

'wetlands are areas of marsh, fen, peatland **or water**, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres. This may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands'[2].

Taken literally, this definition is problematic because it is so broad that it could be interpreted to include any land that is inundated by any amount of water for even very short periods. Although some features of the landscape (such as swamps or marshes) are universally understood to be wetlands, the term 'wetland' is defined differently depending upon the purpose (e.g. regulation of development, land-cover classification or conservation of high-value wetlands). Some definitions cover only seasonal waterbodies (aquatic-terrestrial transition zones or ATTZs) and some specify criteria based on one or more of hydrology, vegetation, soil or slope; there are, for example, over 50 definitions of wetlands in statutes in the USA (Dennison and Berry, 1993). As well as the problem of delimiting wetlands from non-wetlands, there are many types of wetlands, with definitions of each type varying greatly.

Because the term 'wetlands' has many different meanings, it was decided to include as fisheries habitats any parts of the landscape which experience significant floods or inundation each year. It was assumed that all flooded or inundated land contributes to some extent to fisheries production, either because some fisheries species feed there, or because drainage from the land carries foods (terrestrial and aquatic) into downstream waterbodies where they supports fisheries species. It should be noted that much of the LMB lowlands in the dry season are simply bare ground or rice stubble which might not be recognised as wetlands or fisheries habitats, potentially leading to significant misconceptions regarding the basis of production for the fisheries of the LMB.

2.2 Methods to classify land-cover classes

Over a large area such as the Mekong Basin, there are two main ways to acquire data which can be interpreted to estimate the areas of wetlands:

- remote sensing, using images from satellites or aerial photography, or
- on-the-ground sample surveys or censuses, which may be used also to ground-truth the classifications from remote sensing.

[2] Ramsar Information Paper No. 1 available on www.ramsar.org. Bold added for emphasis.

Satellite-derived data can provide complete coverage of large areas at relatively low cost but provide less resolution than with aerial photography which is more expensive.

2.2.1 Background to remote-sensing data

Most remote-sensing satellites (e.g. Landsat and SPOT) collect passive data on the reflectance of energy from sunlight or re-emitted thermal radiation. By contrast, microwave (radar) satellites emit relatively high energy signals that penetrate vegetation but are reflected by water.

The MRC GIS data sets assessed in this report were mainly derived from Landsat satellites, which circle the Earth at an altitude of 705 km, covering the entire planet every 18 days. Their sensors collect data from a track 185 km wide, so images are provided as 185 km-square scenes. Sensors[3] register the intensity of reflected energy in six parts (channels) of the visible-infrared spectrum, as well as one channel (thermal infrared) that registers re-emitted energy. The final data are digital or 'raster', based on pixels that represent a 30 x 30 m square on the Earth's surface, with corresponding data for radiation intensity for seven channels. SPOT satellite data have been less used in the LMB; the SPOT satellites (pre-2002) collected panchromatic ('black and white') 10 x 10 m data, and three channels of reflected data in 20 x 20 m pixels. SPOT data have better spatial resolution than Landsat data, but poorer spectral information. A SPOT satellite (launched 4 May 2002 – later than the most recent data used for the data sets assessed in this report) collects data with a resolution of 2.5 to 5 m in panchromatic mode and 10 m in multispectral mode.

Landsat and SPOT data are provided by agencies after they have been corrected: radiometrically (for noise, changes in the atmosphere, slope and terrain) and geometrically (to eliminate the effects of curvature of the earth, variations in satellite orbit and stability, and surface elevation). The corrected final data are assumed to provide the same intensity of signal in each channel for identical surfaces anywhere on earth, i.e. regardless of conditions at the time the image was obtained.

Reflectance from clouds may make large parts of any particular scene unusable. Therefore, interpretation over a large area is usually based upon dry-season images and data are usually combined from images that have been taken at different times.

2.2.2 Google Earth

Google Earth is very useful for checking the quality of the GIS data. Google Earth provides false-colour images of the earth's surface based on satellite images (including SPOT) and aerial photography. Currently, Google-Earth imagery over the LMB has an apparent resolution of 5 – 10 m at worst and 1 – 2 m at best, allowing features such as buildings, fish ponds or fish cages to be readily distinguished. The Geo Eye 1 is a commercial satellite launched on 6 September, 2008 to provide images exclusively for Google Earth. This satellite collects data at 0.41 m (panchromatic) and 1.65 m (multi-spectral) resolution, so it can be expected that the imagery over the entire basin will be progressively updated to a resolution which is much higher than that of the older imagery which was used to create the data sets assessed in this report.

[3] Thematic mapper (TM) sensors are referred to here as they the source of most data used, Landsat satellites also have multi-spectral scanner (MSS) sensors.

2.2.3 Processing remote-sensing data

Data supplied from satellites specify the location and the strength of the signal in each spectral channel for each pixel. The data supplied are not useful until they are processed, which usually entails either colour enhancement or classification or both. Colour enhancement assigns false colours to each channel to produce a false colour in each pixel. When viewed as a map, features with similar spectra will tend to have a similar colour, which allows a manual interpretation of features. Classification of each pixel to a particular class may be done in two main ways. 'Supervised' classification takes subsets of data which have known surface information (from maps or from ground-truthing) and establishes the correlation between spectral data and features; this 'training' then allows extrapolation (using a program) across an entire image. 'Unsupervised' classification usually uses statistical clustering to group pixels objectively based on the similarity of their spectra, with clusters later being assigned to classes based on comparison to maps or ground-truthing.

Each pixel in processed data is shown representing a particular type of feature, which may be more or less accurate depending on the purpose of the exercise and the complexity of the analysis. Thus broad classes such as water, forest or grassland may be readily distinguished. Landsat data are based on a pixel which covers a ground area of 30 metres square (900 m^2 or about 1/11 of a hectare). A single pixel in a processed image is shown as a particular 'false colour', which is derived from combining the percentage reflectance of several spectra. Interpreting the image requires classifying pixels to a particular land-cover class based on their false colour based on water, for example, or vegetation type or bare land. Uniform surfaces provide the same spectral pattern (i.e. the same strengths of reflectance of each spectrum). But most surfaces produce a range of responses in each spectrum, which also change depending on season and stage of a crop. As plants grow, age and die, for example, their spectral reflectance changes which could, for example, allow processors to discriminate fields of young from old rice, based on their differing spectral signatures.

Where two kinds of surfaces happen to fall within a pixel, the final spectrum of the pixel is a result of spectral mixing, i.e. an averaging of the signals from the surfaces. For example, a pixel which actually covers water and rice on the ground will produce signals in each band of intermediate strength between the rice and water signals. During image processing, the pixel may be classed as either rice or water, whichever occupies more than 50% of the pixel, or the pixel may be 'unclassified' if its particular spectral pattern falls outside the ranges that are set for rice or for water.

As the LMB covers some 622,584 km^2, if data were stored at the maximum resolution (as individual pixels 30 m square) the GIS data sets would need to store information for over 692 million pixels. To reduce the volume of data and to increase the speed of processing, the pixel-based (raster) data are combined into polygons (vector data). The land-cover data sets, for example, contain information on about 256,600 polygons which have a mean size of 2.4 km^2.

As a result of the limitations of pixel size and the blending effect when polygons are digitised, land-cover classes that typically occur in small patches are generally included within broader land-cover categories, whereas land-cover classes that mainly occur in large patches (such as rice fields) tend to be overestimated. Thus 'rice fields' as a class contains mainly rice fields but also includes roads, houses, canals, ponds, smaller patches of other wetland crops and some remnant natural wetlands.

In the final GIS data sets, the size of the smallest polygons varies depending on the original data and the approach of the processors. Ideally, the processing would be carried out systematically:

- the minimum polygon sizes would be the same and consistently applied within and between countries; and
- each polygon would represent a single contiguous 'block' of a particular land-cover class.

Such an approach would allow users to generate frequency distributions of the number of land-cover blocks in each size class. It would be of particular interest, for example, to separate the total area of permanent standing waterbodies into different groups based on size. Unfortunately, metadata for the MRC GIS data sets includes only basic information on primary data sources but no information on the exact approach to classification used by agencies in each country. It is, however, apparent from appraising the images produced from the MRC data sets that the minimum polygon sizes vary greatly both within and between countries, and that even small blocks may comprise several polygons. This is apart from the issue of incorrect classification as discussed below. Hence the MRC GIS data cannot be used for this purpose. In the land-cover data, for example, set the minimum size of standing waterbodies digitised in each country varies by approximately 0.7 ha in Cambodia, 0.3 ha in Lao PDR, 1 ha in Thailand and 0.1 ha in Viet Nam. However, these minimum sizes have not been consistently applied. Based on comparison with Google Earth images, many small waterbodies of 0.1 – 1 ha in size are not digitised and none of the millions of small farm ponds which are less than 0.1 ha in area are digitised, most of these being simply included within the rice-field class.

2.3 MRC GIS data sets

The MRC holds several GIS data sets which are potentially useful for estimating wetland areas in the year 2000, as discussed below.

2.3.1 Wetland data sets

The MRC Environment Programme (EP) collected data and information on wetlands of the LMB from line agencies of the MRC member countries under a Wetlands Project. Classification of wetlands followed a five-step hierarchical procedure, which developed from the system outlined by Dugan (1990) and as discussed by MacAlister (2009). Wetlands are first classed as coastal saltwater or as freshwater. Then these two broad classes are further subdivided. At the second level, coastal saltwater is classed as marine/coastal, estuarine, coastal lagoons or inland saline lakes, while freshwater environments are classed as riverine, palustrine (marshes and bogs) or lacustrine (lakes or open waterbodies). Three further levels of subdivision are applied based on duration of inundation or seasonality, biological features and land cover, which result in over 140 classes at the fifth and final level.

Some problematic features of this data set include the age of the original data, differences in approach to data acquisition and inconsistencies in classification between countries, lack of metadata for some sets, incomplete coverage, and a high proportion of unclassified wetlands or land. Some of the issues with individual countries are summarised as follows:

1. **Cambodia:** the data appear to be based on the Cambodian land-cover data sets created in 1992-1993 under the project CMB/92/2005 by the Interim Mekong Committee, the MRC's predecessor, in collaboration with the United Nations Environment Programme (UNEP) and the Food and Agriculture Organization of the United Nations (FAO). Hard copy maps are kept at the MRC Documentation Centre. However, the digital data sets have no metadata to confirm their source and the quality of data sets is still in doubt.

2. **Lao PDR:** the data set was created under the LMB Wetland Mapping Project by the Interim Mekong Committee in 1993. The data cover only the land within 50 km of the Mekong River. Data sources were topographic maps at 1:250,000 scale and Landsat and SPOT images acquired from 1987 to 1992, supplemented by some field surveys.

3. **Thailand:** the data set covers northeast Thailand only partly and does not include northern Thailand. Data were supplied by the Land Development Department (LDD). Data sources were soil and land-cover maps at 1:50,000 scale and field survey data in 2003.

4. **Viet Nam:** The data set covers only the delta and not the Central Highlands portion of the LMB. This data set is based on geomorphological maps, land-cover maps, and satellite images of 2000 (used for validation of classification). The scale of source data sets was 1:250,000. The data set was updated in 2002 by the Integrated Resources Mapping Centre (IRMC).

A separate internal report is available from the Technical Support Division (TSD) of the MRC which summarises classifications that were applied in each country and illustrates the differences in categories that were used as well as the level of subdivision, in particular showing that the Vietnamese classification is much more detailed than others (Bamrungrach, 2009). The wetland classes were also compared in detail to the land-cover classes. In general, the wetland data set in many areas does not match the actual types of land cover by, for example, overestimating the extent of 'natural' wetlands (such as swamps) and misclassifying some forest and other land as rice fields.

Figure 4 represents a simplified version of the wetland data set and indicates the missing areas, i.e. those not included in the wetland data sets, as well as unclassified land. As shown in Table 1, unclassified land generally appears to be wetlands, except in Thailand where it also includes an unknown proportion of non-wetlands.

Table 1 *Summary of the areas classified and unclassified in the wetland data sets in the LMB*

Category	Cambodia	Lao PDR	Thailand	Mekong Delta in Viet Nam	Total
Classified wetlands	48,017	10,091	81,086	33,450	172,644
Unclassified land-cover classes	2,196	532	74,565	5,877	83,170
Total	**50,213**	**10,623**	**155,651**	**39,327**	**255,814**
Percent unclassified	**4.4%**	**5.0%**	**47.9%**	**14.9%**	**32.5%**

Table 1 and Figure 1 are based on the same data as used in Hortle (2007), except that in that report larger wetland areas were estimated for Cambodia and Viet Nam based on a more eastward catchment boundary in part of the lower basin. Only classified wetlands were included, leading to a likely underestimate of the wetland area in Lao PDR and Thailand (Hortle, 2007; Table 32).

The wetland data sets were not used for the analyses in this report. As discussed above, they are out of date, much land is unclassified and they are inaccurate in some areas. The estimation of fisheries habitat areas was based on land-cover data sets as discussed below.

2.3.2 Land-cover data sets

MRC's land-cover data sets originate from the Land Resources Inventory for Agricultural Development (LRIAD) project of the MRC Agriculture, Irrigation and Forestry Programme. These were recently updated by the programme's Demonstration of the Multi-functionality of Paddy Fields (DMFPF) project. The data sets now cover virtually all of the LMB. Although there are some differences in sources and approach, the data are reasonably compatible and of similar currency (approximately 2000-2003).

The origins of the land-cover data in each country are as follows:

1. **Cambodia** – data were derived from a land-cover map produced by the Ministry of Public Works and Transportation under the project 'Cambodia Reconnaissance Survey Digital Data' supported by Japan International Cooperation Agency (JICA) and released in 2003. The data sources for this map include:

   (a) Landsat TM images acquired during 1995-1996 and in 2000;

   (b) SPOT (panchromatic images) acquired during 1995-1996 and 1998-2001;

   (c) Aerial photos acquired during 1992-1995 and 2001-2002;

   (d) Topographic maps at a scale of 1:50,000 (1967 - American Map Series); and

   (e) Ground-truth data (limited).

   Satellite images were visually interpreted and manually digitised into the GIS system. The data set contains 40 different types of land cover.

2. **Lao PDR** – data were compiled by the Forest Inventory and Planning Division, Ministry of Agriculture and Forestry in 2000 with updated agricultural land classification in 2003. The data set contains 25 different types of land cover. There are no other detailed meta-data available.

3. **Thailand** – data were compiled by the Land-Cover Analysis Division, Land Development Department (LDD). Mapping was done using different data sources obtained on different occasions:

   (a) Landsat images (30 m resolution) were acquired from 1999 to 2001;

   (b) Aerial photos at scale 1:50,000 were acquired in 1997; and

   (c) Ground-truth data were collected during 2000 to 2002.

Data were visually interpreted and manually digitised into the GIS system. Outputs were provincial maps at 1:50,000 scale, with land cover detailed to the 'level-3' classification of the Land Development Department (LDD). Data were then combined to a less detailed 'level-2' classification to make regional maps. Metadata can be found in 'Final report on data collection in Thailand for the programme to demonstrate multi-functionality of paddy fields over the Mekong River Basin (DMFPF)' by the Thai National Mekong Committee, September, 2004, which is available on the CD included with MRC (2008).

The classification was further simplified (i.e. by combination) by the AIFP to fit its objectives. Unfortunately, no original classification remained in the GIS attribute table. The final simplified land-cover classes are:

- aquaculture;
- paddy fields;
- field crops;
- plantations (includes orchards and horticulture);
- swidden agriculture;
- waterbodies; and
- forest and other land (includes urban and built-up areas, disturbed and undisturbed forest, pasture and farm houses and any other land).

4. **Viet Nam** – Maps were compiled from several data sources including:

   (a) Land-cover maps (1:50,000 and 1:100,000 scale), year 2000 from Provincial Departments of Land Administration (DLAs);

   (b) Agricultural land-cover data for 2000 from Provincial Departments of Agriculture and Rural Development (DARDs); and

   (c) Landsat images, year 2000, used for data validation through visual interpretation.

Provincial land-cover maps were converted into digital maps and combined into one regional map of the Mekong Delta and Central Highlands. Land-cover classes were grouped in nine broad categories, with wet paddy further divided into four sub-categories:

- Built-up and urban
- Wet paddy
    - irrigated
    - rainfed
    - upland crops
    - shrimp/fish

- Upland crops
- Grassland, bush
- Fruit tree crops, perennial crops
- Forested land
- Aquaculture pond
- Waterbody
- Others

Metadata can be found in 'Final report on data collection in Viet Nam for the programme to demonstrate multi-functionality of paddy fields over the Mekong River Basin (DMFPF)' by the Viet Nam National Mekong Committee, September, 2004 which is available on the CD included with MRC (2008).

Missing data

The land-cover data sets were missing data for some small portions adjacent to the boundaries of the LMB catchment. These were infilled using the GIS data sets of the MRC Land Cover Data Set (1997). The infilled area in Thailand was 2,756 km^2 or about 1.4% of the area of the Thai LMB, and in the Central Highlands in Viet Nam was 3,145 km^2 or about 9.7% of the highlands' area. Only non-wetland elevated areas close to the LMB catchment boundary were infilled, so there was no effect on the estimated wetland areas.

Snapshots of images based on land-cover data

In Appendix 2, some snapshots of images based on the land-cover data sets are shown with brief notes to provide an indication of their accuracy and level of detail.

Combining land-cover data sets

The country classifications were simplified by grouping similar types together as shown in Table 2 and Figure 2, and then further classifying land as within or outside the major flood zone as discussed below.

Table 2 *Simplified land-cover categories inside and outside the major flood extent*

All categories that are highlighted in blue are considered to include a large proportion of wetlands. The total areas differ from those shown in Hortle (2007) because of improvements to the country boundaries and infilling of missing areas.

Land-cover type	Cambodia		Lao PDR		Thailand		Viet Nam Delta		Viet Nam Highlands	Total inside the flood	Total outside the flood	Total LMB
	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Outside			
Rice fields	11,274	17,208	1,910	8,714	5,133	93,119	11,585	8,573	1,576	29,902	129,190	**159,092**
Flooded forest/grassland/shrub	7,145	114								7,145	114	**7,259**
Natural swamps	31	283	326	248						357	531	**888**
Aquaculture					12	58	62	2,315		74	2,373	**2,447**
Waterbodies (large)	4,105	853	257	2,143	1,000	3,521	947	839	156	6,309	7,512	**13,821**
Forest (in Thailand forest and other)	4,173	102,030	2,046	182,277	1,385	56,160	1,006	1,687	25,753	8,610	367,907	**376,517**
Field crops	1,455	3,471	12	1,189	157	35,389	263	421	1,808	1,887	42,278	**44,165**
Plantations	5	723			108	5,641	3,335	3,035	2,055	3,448	11,454	**14,902**
Swidden agriculture	3	3,058	23	5,195		1,377				26	9,630	**9,656**
Other	71	433	43	2,237	0	0	145	160	1,052	259	3,882	**4,141**
Total	**28,262**	**128,173**	**4,617**	**202,003**	**7,795**	**195,265**	**17,343**	**17,030**	**32,400**	**58,017**	**574,871**	**632,888**
Total LMB		**156,435**		**206,620**		**203,060**		**34,373**	**32,400**			

2.3.3 Major flood zone based on the Year 2000 flood

The Mekong is a highly seasonal river which floods in a fairly predictable fashion once each year. While the damaging effects of flooding are often noted in the mainstream media, flooding in the LMB can be generally regarded as beneficial to fisheries and traditional agricultural systems on floodplains and along riverbanks. Fisheries production in monsoonal river systems is usually highly correlated with flooded area, which was estimated based on a map prepared under the LRIAD (MRCS, 2002) and DMFPF projects. The flood map (Figure 3) shows the estimated maximum spatial extent of the flood based on the large flood in the year 2000. It should be noted that flooding is not simultaneous; the peak takes approximately one month to progress from Lao PDR and Thailand to the Mekong Delta in Viet Nam (during August and September). This map was produced from several data sources:

- ‘inundation’ data sets;
- in Lao PDR and Thailand, field surveys of flood levels based on silt marks in 1995, 1996 and 2000;
- in Cambodia and Viet Nam, field surveys of flood levels in 2001 which were slightly lower than, and adjusted to, year 2000 levels;
- flood reports from various sources;
- topographic mapping and a digital terrain model;
- radarsat images which showed the extent of the peak of the flood in 2000 in Thailand and Viet Nam and sub-peak flood extents in Cambodia and Lao PDR; and
- hydraulic modelling using the Mike 11 model, and the Vietnam River Systems and Plains (VRSAP) hydro-dynamic model.

As shown in Figure 3, the most extensive flooded areas surround the Tonle Sap and Great Lake and extend into the Mekong Delta in Viet Nam, with relatively minor floods along tributaries in Lao PDR and Thailand. Note that detailed maps are available from the MRC that show estimates of the depth and duration of flooding for the lower part of the basin. By combining Figures 2 and 3 to produce Figure 4, it becomes evident that **most of the fisheries habitat area is not within the flood zone**, nor is it permanent water. It mainly comprises land classed as rainfed rice fields, as discussed further below. It should also be noted that most of the tributaries and their flooded areas in Thailand are now disconnected from the main river systems by dams or weirs which would limit or completely prevent access of migratory species to the tributaries and their floodplains. Some idea of the degree of fragmentation can be judged by superimposing the map of MRC-registered irrigation schemes as shown in Figure 5.

In MRC data sets, there are 12,312 irrigation schemes. Along large tributaries and the mainstream Mekong, irrigation is based on pumping. But most of the other schemes depend upon dams or weirs which create barriers. Wild capture fisheries production from the Thai floodplains may have been less (per unit area) than in the lower part of the basin (because of the lesser extent and duration of flooding), but have no doubt been further reduced by fragmentation and reduction of the flood pulse. Important floodplains remain along several major tributaries in Lao PDR, but these are likely to be progressively impacted by the tributary dams currently under construction or planned. In Cambodia, weirs are significant barriers on some large tributary rivers, but the Mekong and the Tonle Sap rivers have no dams or weirs. In the Mekong Delta in Viet Nam, the main river channels are unobstructed, but the most easterly Mekong distributary is blocked by the Ba Lai Weir, and many canals are obstructed by water gates.

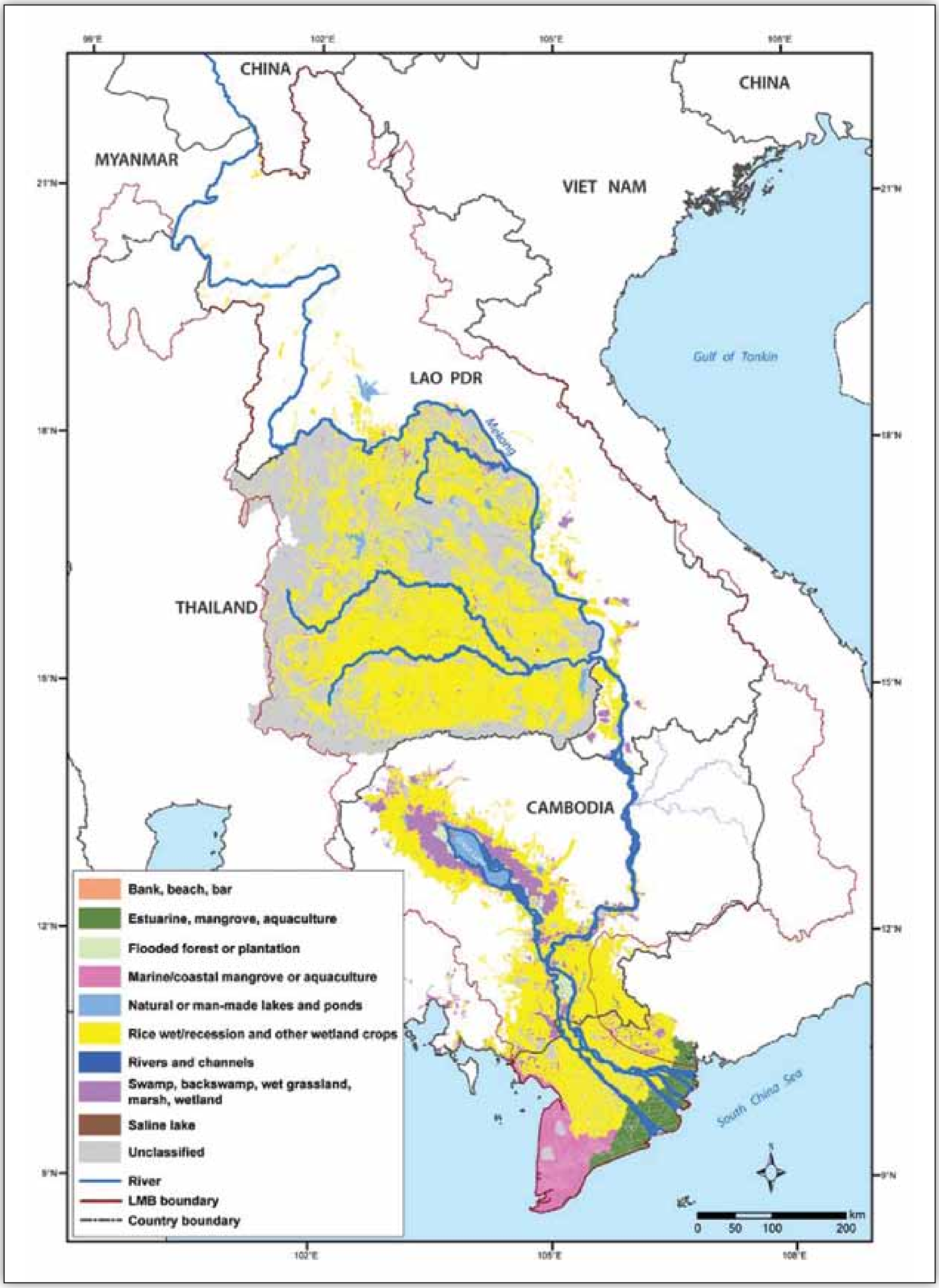

Figure 1 LMB map based on GIS data sets from the wetland project

Note that the courses of some major rivers have been added for clarity from a different layer.

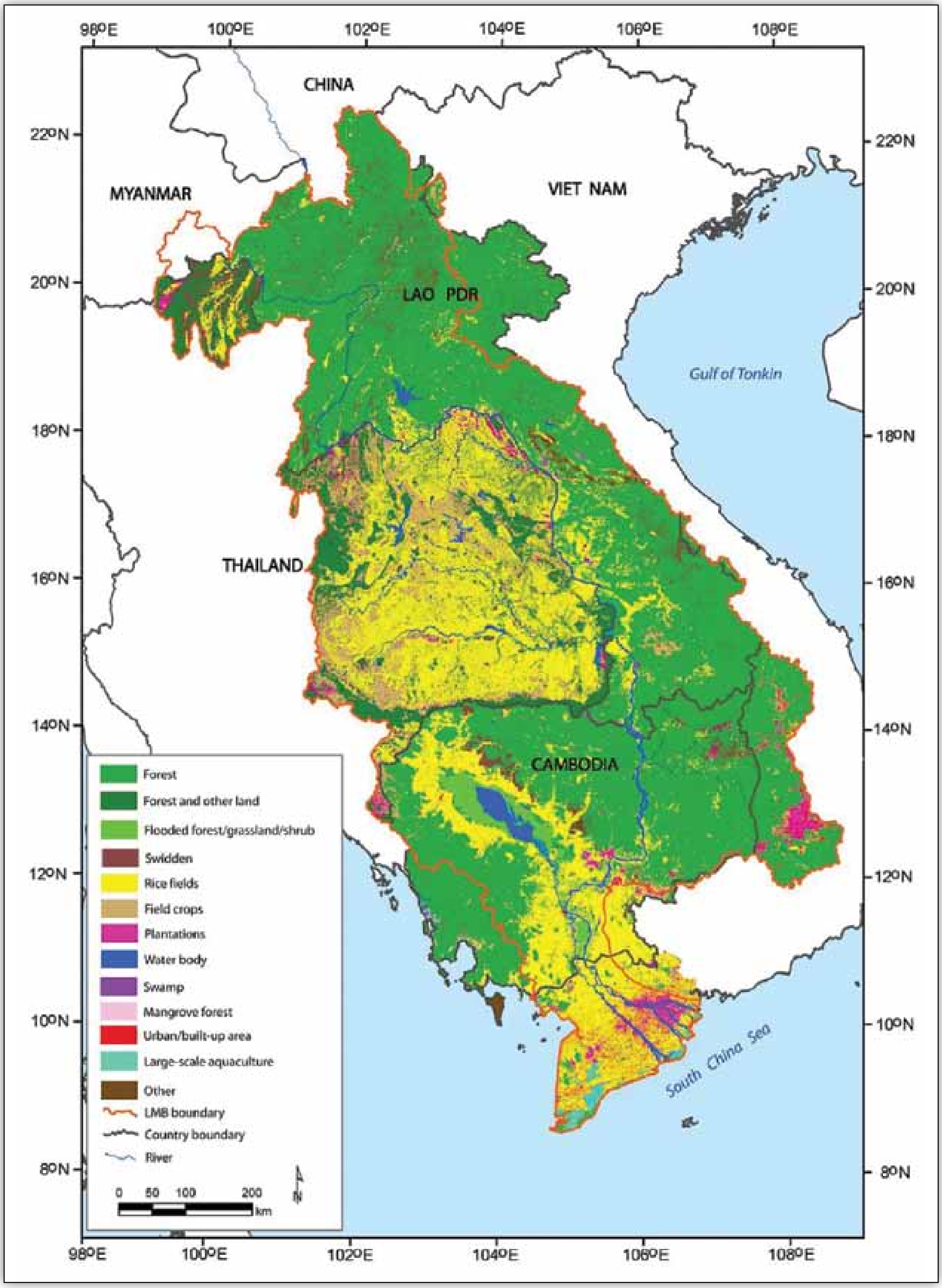

Figure 2 LMB map based on summarised land-cover data

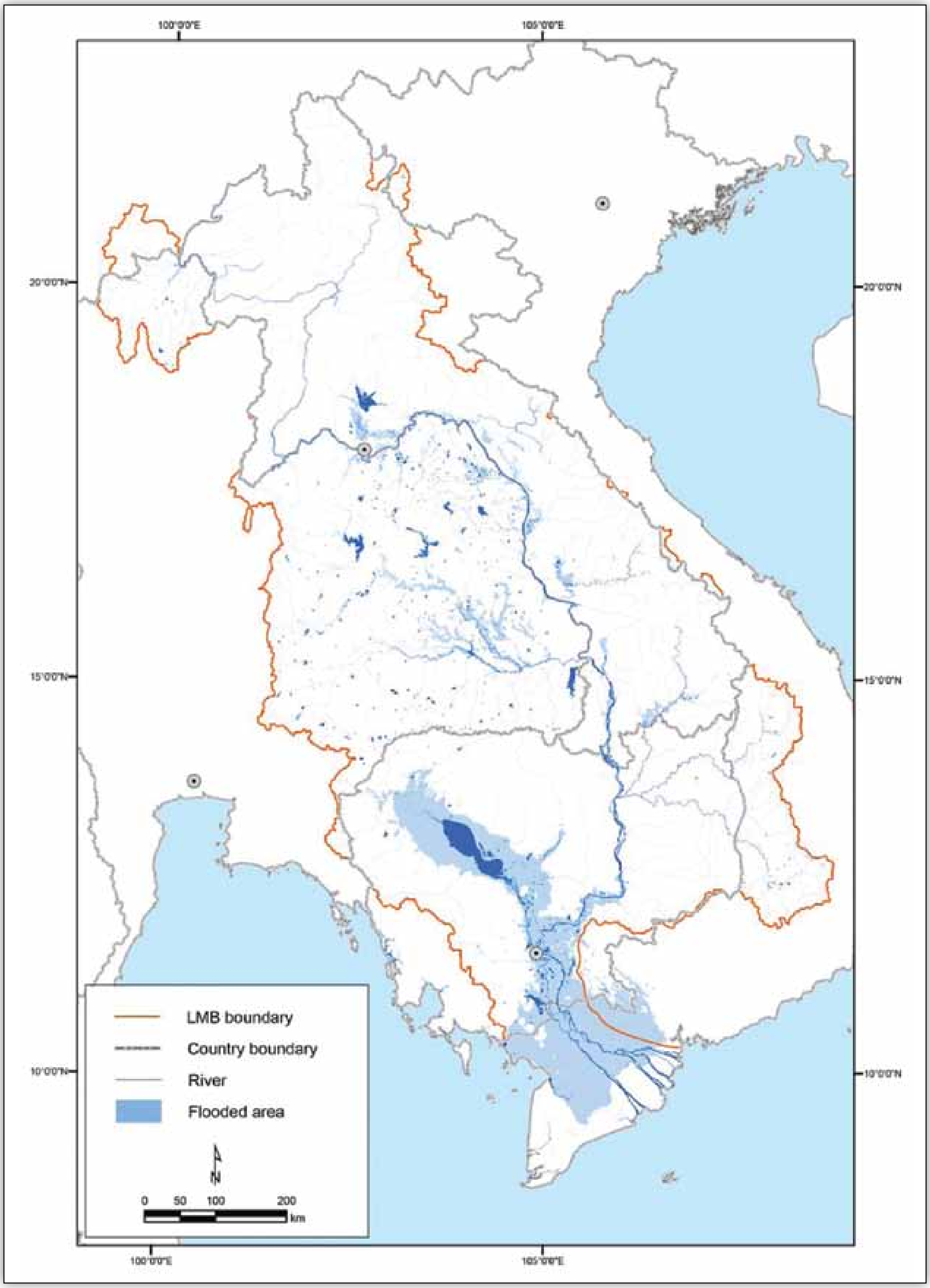

Figure 3 Composite map of the major flood extent in the LMB, based on the Year 2000 flood.
The flooded area defines the major flood zone.

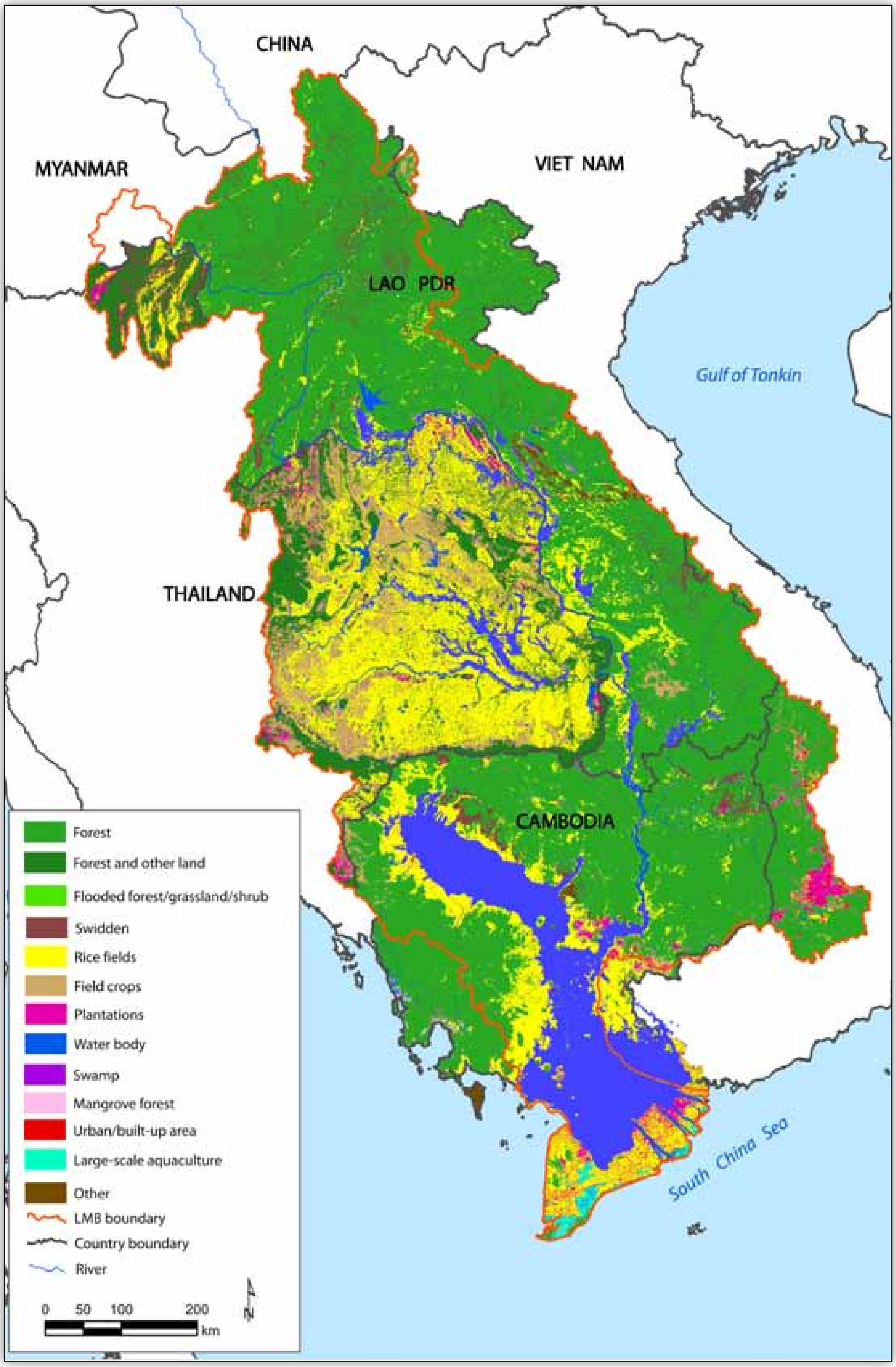

Figure 4 Map of land-cover classes with the major flood overlaid, showing that most wetlands are rice fields and most are rainfed and outside the major flood zone

Note that the courses of some major rivers have been added for clarity from a different layer.

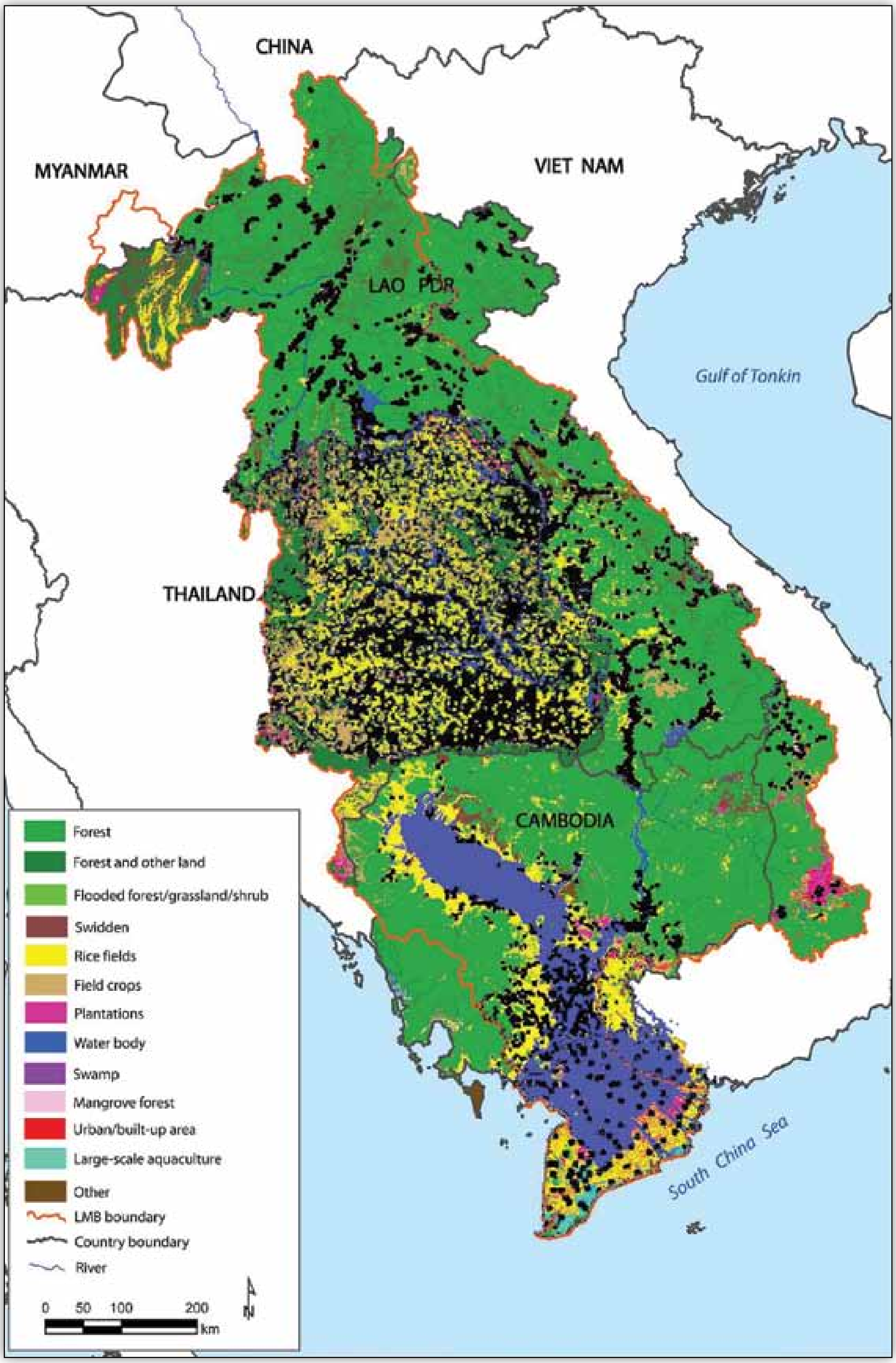

Figure 5 Combined wetland/flood map, showing MRC-registered irrigation schemes. Each black dot represents one irrigation scheme.

2.3.4 Estimated areas of fisheries habitat

The areas of land cover within each category in the GIS data sets were calculated for each country (as shown in Figure 2) within and outside the major flood zone (as shown in Figure 4) and are presented in Table 2 after some minor adjustments discussed in Appendix 1. Some comments on this table are as follows:

The total area of fisheries habitat is estimated as the sum of the first five land-cover types plus all other land-cover classes 'inside the flood', an area of 197,737 km^2 or about 31% of the area of the LMB. Of this, 58,017 km^2 or 29% is within the major flood zone so most of fisheries habitat lies outside the major flood zone and 92% of that area is classed as rice fields.

Some issues with the GIS data include the following:

1. The areas estimated for rice fields are about 50% larger on average than the reported harvested areas of rice (see Appendix 1). This apparent discrepancy arises because each year a proportion of rice fields are not planted, some planted areas are not harvested and because the dominant rice-field class includes smaller patches of habitat such as other wetland crops, small ponds and canals, houses and garden plots, small patches of swamp and other vegetation. An overestimation of total habitat area that could result from including all 'rice fields' is probably offset by the underestimation of fisheries habitat within other classes as discussed below. In any case, calculations of yield (Section 4) are based on surveys of catches over large areas of the landscape, not from rice fields *per se*.
2. Flooded forest/grassland/shrub habitats were classified as such only in Cambodia, where comparison with Google Earth images shows a reasonable correspondence, except for some places where the forest has been recently cleared for rice fields. In the other LMB countries, this habitat would be mainly within the flood zone in land classed as forest (or 'forest and other' in Thailand).
3. Natural swamps: this habitat is not recognised as such in Thailand and Viet Nam, where any remnant swamps are probably included in the rice fields or forest classes.
4. Aquaculture is not discriminated in Cambodia or Lao PDR, where individual operations are based on small ponds or cages which would tend to fall within the rice-field class. The area devoted to aquaculture within Viet Nam is about 74% of the official area for 2000 quoted by Truong *et al.*, (2008)[4] and the area in Thailand is also likely to be an underestimate, in both cases because small operations are not discriminated.
5. Large permanent standing waterbodies including man-made lakes appear to be accurately digitised. But smaller waterbodies less than a few hectares are not delineated, and smaller rivers, streams and canals are either not delineated or are partly or inconsistently shown, generally being blended in with dominant land-cover classes. In order to partly check the accuracy of the GIS data, the surface area of artificial reservoirs was compared with that estimated from the GIS data set. The reservoirs were chosen on the basis that they spanned a wide range in sizes, data were available, they had not been modified since the GIS data

[4] Delta total of 3,656 km^2 x LMB proportion of 0.86 = 3144 km^2 for the LMB part of the Delta

were acquired and they were readily identifiable in the GIS data sets. Table 3 shows that the surface areas indicated by the GIS data were on average (arithmetic) about 79% of the full supply level (FSL) area. The actual mean surface area of reservoirs is significantly less than the FSL due to seasonal drawdown, so the GIS data overestimates the mean surface area of reservoirs. However, published yield-per-unit-area data for reservoirs (Section 4) are usually expressed relative to the area at FSL. Therefore yield estimates based on the GIS data would tend to be conservative (i.e. are likely to be underestimates).

Table 3 *Comparison of design full supply level (FSL) area of some reservoirs with that estimated from GIS data*

Country	Dam name	Year completed	River system	Inundated area at FSL (km^2)	Area in land cover GIS (km^2)	Ratio
Thailand	Nam Pra Phloeng	1968	Pra Phloeng	19.0	5.2	27.4%
Thailand	Chulaphorn	1972	Phrom	12.0	9.0	75.0%
Lao PDR	Nam Leuk	2000	Leuk	12.8	11.0	86.3%
Thailand	Kwan Phayao	1941	Ing	23.5	19.2	81.7%
Thailand	Nam Pung	1966	Pung	21.6	20.4	94.6%
Lao PDR	Houay Ho	1999	Se Kong	42.0	27.2	64.7%
Thailand	Huai Luang	1973	Huai Luang	31.0	32.8	105.8%
Thailand	Nam Un	1973	Un	85.0	74.0	87.0%
Thailand	Nong Han	1953	Kam	135.4	83.5	61.7%
Thailand	Sirindhorn	1971	Dom Noi	288.0	239.4	83.1%
Thailand	Lam Pao	1968	Pao	400.0	240.3	60.1%
Thailand	Ubolratana	1966	Pong	410.0	404.0	98.5%
Lao PDR	Nam Ngum 1	1971/84	Ngum	470.0	473.4	100.7%

It should be noted that any errors in the estimates of the area of waterbodies within the major flood zone are not consequential because these are included within the flooded area.

The GIS-based estimates for areas of other 'permanent' waterbodies (river channels, canals etc.) cannot be compared with their actual area because data are lacking. However, the area of the Tonle Sap-Great Lake has been estimated from modelling by the MRC as varying between 2,061 km^2 and 15,278 km^2 over the period 1997-2007, with mean minimum level of 2,232 km^2 and mean maximum level of 13,240 km^2. The GIS estimated area was 2,433 km^2 or 1.09 times the mean minimum level. Consistent with this information, it appears from visual inspection that the GIS data represent images that are close to the minimum dry-season levels, so the estimate of the extent of the waterbodies that are digitised is generally less than their mean extent. Dry-season satellite images are more likely to have been used for the GIS as they are more likely to have been cloud free. When we consider that small waterbodies are not digitised at all, there is a significant underestimation of the mean area of permanent surface waters outside the major flood zone.

The major flood zone

The major flood zone. During the wet season, the Mekong in Cambodia connects with extensive floodplains, which grade into rainfed rice fields in the foreground where water cannot be seen because it is covered by rice plants

Recession rice fields in the major flood zone near the Songkhram River, Thailand. Barriers are 'drowned out' allowing migration by aquatic animals.

The rainfed zone

The rainfed zone showing typical wet-season rainfed rice fields near Siem Reap. The paddies connect to many permanent ponds which form the main refuges from where fish and OAAs colonise the rice fields.

Rainfed rice fields near Vientiane, with a large permanent refuge pond in the foreground and aquaculture ponds on the left

Rainfed habitats

Throughout the rainfed environment, there are many barriers which restrict migration by aquatic animals, and water is often shallow. Amphibious animals are favoured in this environment.

Rainfed habitats

Close-up of a typical rainfed rice field near Vientiane connecting to a small permanent pond, a source of colonising fish and OAAs.

Fishing in rainfed rice fields near Vientiane. Water running beneath the plants is channelled through traps in the foreground.

Permanent Waterbodies

Permanent waterbodies outside the major flood and rainfed zones are mainly reservoirs, like this typical small irrigation reservoir, Nam Houm, in Lao PDR. Fish ponds can be seen downstream of the dam wall on the left.

In Thailand, several reservoirs have been developed specifically for fisheries – here the Nam Pan Reservoir in the Huai Luang catchment

Permanent Waterbodies

The Mekong River near Xayaburi in northern Lao PDR

In the Mekong Delta in Viet Nam, rice field – canal systems like this may be within the flood zone in the northern half of the delta or outside the flood zone (rainfed) in the southern half

3 Fisheries production and yield in the Lower Mekong Basin

3.1 Production and yield

3.1.1 Basic concepts of production and yield

Biological production is the rate at which biomass is produced per unit area (or volume) over a particular time interval, understood here to be net production, i.e. after subtracting respiration losses. Production is most correctly expressed in units of energy or mass of carbon, but it is generally more practically expressed as biomass produced per unit time. Biomass is most accurately expressed in terms of grams dry weight. But in applied field-based studies, it is common to see biomass expressed as wet (fresh) weight, and it should be understood that this practise may introduce significant errors caused by difference in water content.

Primary production typically refers to the biomass produced by plants as a result of photosynthesis, a process dependent on sunlight, nutrients and carbon dioxide[5]. Secondary production (consumption) refers to the biomass produced by animals feeding on plant material. Secondary production can also be considered to be the result of the action of a series of consumers – primary, secondary and so on – through a food chain, which is a simple and widely understood concept; examples of food chains with 2, 3 and 4 steps are shown in Figure 6.

5 **Quaternary consumer**			⇧ Humans
4 **Tertiary consumer**		⇧ Humans	⇧ Large fish
3 **Secondary consumer**	⇧ Humans	⇧ Fish	⇧ Small fish
2 **Primary consumer**	⇧ Fish	⇧ Insects & Shrimps	⇧ Zooplankton
1 **Primary producer**	⇧ Algae	⇧ Tree (leaves/detritus)	⇧ Phytoplankton

Figure 6 Example of a simplified aquatic food chain

At each step or trophic level, the loss of energy (and approximately of biomass) varies between about 50% and 90%, with higher efficiencies for transfer of animal foods (Odum, 1975). In practice, transfers are much more complex. For example, as a fish grows it may feed on foods of increasing size

[5] Primary production in anaerobic environments such as the deep sea may result from chemosynthesis by bacteria and similar organisms

such as zooplankton, small fish and then larger fish. Fish may eat many kinds of foods at both high and low trophic levels; many Mekong species are omnivorous, eating insects, fruits and fish if available. The flow of materials and energy may also spiral through the chain when, for example, a small fish formerly fed on shrimps dies and is then eaten by shrimps[6]. Diet also varies seasonally, with fish typically feeding intensely on flooded areas. The term 'food web' is often used by ecologists to take account of the complex multi-directional flows of food and energy.

Plants may be terrestrial, aquatic or semi-aquatic, and the quality of plant material as a food source varies greatly in terms of its composition and edibility. Once within an aquatic system, organic material is typically processed by shredding, grazing and filter feeding by aquatic organisms, with reaggregation of fine particles and conditioning by bacteria increasing the nutrient content of detrital aggregates. Within systems, there may be massive movements of organic material downstream, laterally (on and off floodplains, 'upstream' with flows into tributaries and tidal flows) and vertically (within the water column and sediments). The River Continuum Concept (RCC) and the Flood Pulse Concept (FPC) seek to provide a general conceptual framework for the flow of materials and energy through river-floodplain ecosystems (Junk *et al*., 1989; Junk and Wantzen, 2004). High primary productivity in one location may translate to high secondary productivity a great distance away. For example, a large quantity of detritus derived from plants throughout the catchment is progressively processed and transported to the Mekong Delta, providing the organic component of mud that nourishes many 'mud-eating' fishes such as mullets and scats as well as invertebrates such as polychaete worms, clams and shrimps. Apart from spatial separation, production and consumption are separated in time – full processing or organic carbon may take many years.

It is important to distinguish production from yield. Yield is the part of biological production that is removed each year by people[7], so it is a product of both productivity of the system and the efficiency of its harvest. Systems may be very biologically productive but provide no yield if they are not fished. Conversely, a system that is not particularly biologically productive may produce a relatively high yield under intensive fishing pressure. In practice, it is difficult to measure biological production from extensive waterbodies, particularly if they are strongly seasonal so most fisheries literature deals with yield. In enclosed waterbodies, catches reflect production in the system. But in river-floodplain systems (where migration is the norm), catches may reflect biological production of distant areas; i.e. fish and other aquatic animals may feed and grow in one area and be caught elsewhere or the food chain may be supported by production from elsewhere.

3.1.2 Production in wetlands

Wetlands include habitats which are among the most productive of plant biomass on Earth (Table 4). As well as large plants (macrophytes), macroscopic and microscopic algae add to the overall productivity. In flood zones, the biomass of phytoplankton may reach 600 kg/ha and algae that grow on the surfaces of larger plants (epiphytic algae) may comprise 17% of the total plant biomass (see Welcomme, 1985; Chapter 3). The biomass of algae in rice fields may reach 1.6 t/ha (Roger, 1989). As well as the biomass produced by aquatic plants or terrestrial plants that are flooded, a large quantity of

[6] This complexity is well understood by Mekong peoples. A Khmer proverb (applied to human affairs) states: 'when water rises, fish eat ants, when water falls, ants eat fish' (*teuk laeung trey see sromaoich teuk haoich sromaoich see trey*).

[7] It should be noted that economists usually refer to yield as 'production'.

organic material falls or is washed into streams and rivers each year from trees and other vegetation. Most of the plant biomass in waterbodies is, however, either not available (e.g. because it is harvested by people or is burnt off or decomposes) or is not processed by aquatic organisms (e.g. because it is not sufficiently nutritious or is in excess relative to the demand from primary consumer organisms).

If we assume (based on the data in Table 4) that LMB wetlands produce 10 – 20 t/ha/year of plant material and that 5 – 10% of the biomass is taken up by consumers and converted to animal biomass at a conversion efficiency of 10% (i.e. an overall efficiency of 0.5 – 1%), then secondary production (including all consumers) could be 50 – 200 kg/ha/year as dry weight or approximately 250 – 1,000 kg/ha/year as wet weight. This range provides some indication of the level of secondary production which might be expected and is not unreasonable given, for example, that the biomass of snails alone (common primary consumers) in rice fields may reach 1.6 t/ha (Roger, 1989).

Table 4 *Indicative estimates of net primary production in wetlands*

Habitat	Production (t/ha/yr dry weight)	Source
Wetland habitats		
Typha swamps	25 – 30	Roggeri, 1995
Papyrus swamps	48 – 143	Roggeri, 1995
Mean swamp/marsh	20	Roggeri, 1995
Lakes and streams	5	Roggeri, 1995
Rice fields	24	Vromant and Chau, 2005
Reservoirs	4-8*	Thapanand *et al.*, 2009
Terrestrial habitats		
Sugar cane	63	Roggeri, 1995
Maize	60	Roggeri, 1995
Tropical rainforest	27.5	Roggeri, 1995
Temperate forest	10	Roggeri, 1995
Tropical grassland	7.5	Roggeri, 1995
Temperate grassland	7.5	Roggeri, 1995
Desert and scrub	0.2	Roggeri, 1995

* Reservoirs are Jasak Prolasid (Chao Phraya) and Ubolratana (Mekong); primary production is 42-44 t/ha as wet weight, estimated as 5-10% dry weight

3.1.3 Trophic level of fishery species

Many fishery species in the LMB eat some plant material, but most fishes consume a range of other foods if available. The most important species in river-floodplain fisheries are herbivores such as the algae-feeding carps *Henicorhynchus lobatus* and *H. siamensis* and omnivores including most cyprinids and pangasiid catfishes. Catches from swamps and rice fields are typically dominated by carnivores such as snakeheads and walking catfishes.

The average number of steps in the food chain is defined as an organism's trophic level. The trophic level of fish or other animals may be inferred from anatomy and by examining stomach contents. However, changes in diet with age, different rates of digestion of different foods, the complexity of food webs, and the spatial and temporal separation of different elements of the food web all constrain the usefulness of direct dietary examination. Local ecological knowledge can identify some key sources of primary production such as riparian plants which, when inundated during flooding, provide food for many fish (Baird, 2007) but cannot clarify the integrated contribution of different kinds of foods. Stable Isotope Analysis (SIA) is being increasingly used to estimate the proportion that different types of primary production (e.g. algae, grasses, higher terrestrial plants) have contributed to the biomass of an organism and to estimate its trophic level. SIA of the most abundant fishes from several South American rivers (Jepsen and Winemiller, 2002) showed that herbivorous fishes had a trophic level of approximately two (i.e. there is just one step in the chain), as would be expected because they feed exclusively on vegetation, including algae. The majority of the studied fishes' average trophic level was between two and three, i.e. their diet included vegetation as well as some organisms that consumed vegetation, and in some cases a smaller proportion of organisms at higher trophic levels. The highest trophic level was 3.9 for one species of piscivore. A study of a pond in the Mekong system found a maximum of four steps for the animals at the highest level, swamp eels and snakes (Kupfer *et al.*, 2006).

In Thailand, detailed studies of food chains and productivity have been carried out in Ubolratana Reservoir in the Mekong Basin and in Jasak Prolasid Reservoir in the Chao Phraya Basin (Thapanand *et al.*, 2009). These studies show that the weighted average trophic level of all species in catches was 2.6 in Ubolratana and 2.4 in Jasak Prolasid; i.e. the 'average' fisheries species was dependent mainly on direct consumption of vegetation, principally phytoplankton or detritus. Interestingly, there was a very low efficiency of transfer (0.1 – 0.2%) of primary production through to catches, suggesting that there is a large excess production of plant material which may be unavailable or not nutritious, or perhaps that the fishery is under exploited.

3.2 Fisheries yield at a landscape scale in the Lower Mekong Basin

The aquatic productivity of the Mekong system as a whole depends upon the extent, duration and depth of inundation by water, as well as other factors such as the quality of the inundated habitat, the quality of water (for example, its content of nutrients) and the amount and quality of inundated terrestrial organic material. Although some permanent water is necessary for the long-term survival of most of the aquatic species that are large enough to be caught in fisheries, temporary seasonal waterbodies are more extensive than permanent waterbodies in monsoonal systems such as the Mekong. Fishery species (fish and other aquatic animals) move into seasonal wetlands for feeding, reproduction or both. Some species of fish such as walking catfish (*Clarias* spp.), Asian swamp eels (*Monopterus albus*) and some amphibians can aestivate[8] in dried mud, and many invertebrates either aestivate or survive as eggs. Apart from the direct access to seasonal wetlands, flooding or inundation conditions water with nutrients, organic detritus and food organisms that later flow into permanent waterbodies, so raising their productivity.

Seasonal inundation can be broadly categorised as caused by:

- **Flooding:** rivers rise and create continuous sheets of water which 'drown-out' barriers to aquatic animals, which can then move freely along rivers and across floodplains. Flooding

[8] To aestivate means to survive by reducing metabolic rate. Many aquatic animals also protect themselves from desiccation, adults by secreting slime or as eggs with thickened membranes.

occurs each year along all major rivers as they rise in response to the monsoon rains. On floodplains, most agriculture is based on dry-season 'recession' rice, planted as the flood recedes in paddies which have been constructed to retard the recession of the water.

- **'Rainfed' inundation:** rainfall and local diversions of watercourses inundate vast areas of land in paddy rice fields, mostly to depths of 30 – 50 cm. Rainfed rice paddies are those that are developed on formerly forested land above floodplains. During the wet season, much of the rainfed landscape is underwater, although much is not visible when covered by rice plants and appears as vegetation in remote-sensing images. Most barriers are not drowned-out and along drainage lines numerous fishing gears usually restrict any movement of animals.

The boundaries of each zone may be poorly defined, and the actual extent of each zone varies from year to year. However, the maximum extent of the flood can be used to set the upper limit for the major flood zone, which includes all large floodplains and associated large rivers.

As well as the natural flooding or rainfed inundation, irrigation is applied to both zones in various ways. In the dry-season, parts of both floodplains and rainfed areas are irrigated to produce a second crop, using water that has been retained in reservoirs, or directly by pumping from rivers or canals. Wet-season irrigation typically supplements local rainfall in rainfed areas. Most rice in Cambodia, Lao PDR and Thailand is grown during the wet season and is rainfed on land surrounding the major floodplains, with only about 11 – 12% based on irrigation (MRC, 2010; Table 4.3.1). The Mekong Delta in Viet Nam produces more rice than the rest of the LMB combined (MRC, 2010; Table 4.3.2 and Figure 4.3.1) through intensive production. Most of the northern half of the delta in Viet Nam floods each year, the basis for the first rice crop, and almost all is irrigated by pumping from canals to produce a second or third crop. The southern half of the delta is rainfed, but virtually all land is also irrigated for a second crop. Other wetland crops (including lotus, morning glory and rushes) are grown in both flooded and rainfed zones, but they cannot be discriminated using GIS data over large scales from rice.

River-floodplain systems (within the major flood zone) are generally acknowledged to be significant for fisheries in the LMB. But it is important to recognise that most of the area of seasonal waterbodies comprises anthropogenic rainfed rice-field habitats, which support a very large but under-acknowledged harvest of aquatic animals. In this respect, the Mekong Basin is similar to many other large river basins in monsoonal tropical Asia but differs from river basins in other regions, where rainfed rice farming is absent or not extensive.

The typical development of rural landscapes in the LMB is summarised in Figures 1 to 3, based on descriptions in Floch *et al*. (2007), Fox and Ledgerwood (1999), Hayao and Keisuke (2003), Higuchi *et al.* (2004), Kummu (2003), Matsumoto *et al.* (2005), Stark (2006) and van Liere (1980), supplemented by field observations in various locations and interpretations of land-cover changes from Google Earth. The diagrams present schematic views of a basic pattern which could represent land-cover development at a local scale (small streams) to regional scale (major tributaries such as the Mun-Chi system). The process of domestication of the landscape—including forest clearance, conversion to paddies, and local storage and diversion of water—began long ago but accelerated after the 1960s in Thailand, in the 1980s in Cambodia and is continuing in Lao PDR.

Where landscapes are moderately populated and not highly modified, rainfed rice-field expansion may cause limited effects on river-floodplain fisheries; this is the situation on many tributaries in Cambodia and Lao PDR. Where the landscape is fully populated and highly modified (as is typical in northeast Thailand), rainfed rice fields expand well up slopes, diluting the available water and leading to shallower depths and deprivation of the downstream watercourses. Development also involves construction of storage reservoirs that redistribute water to the dry season, and modification of floodplain waterbodies for off-river storage. In the highly developed state, there is a major impact on biodiversity, but development of floodplain reservoirs, eutrophication stocking and the introduction of some exotics probably maintains a high fisheries production in former floodplains. There is significant amount of water spread through the agricultural landscape during the dry season, which would tend to compensate for the loss of river-floodplain fisheries. However, there has been no proper accounting of these gains and losses in the basin.

3.3 Habitats and areal yield estimates from the Lower Mekong Basin

3.3.1 Yield from the major flood zone (river-floodplain habitats)

The flow of the Mekong River and its tributaries is highly seasonal, with most discharge during the wet season. Although storage in reservoirs and abstraction for irrigation are significant in Thailand and some tributaries in Lao PDR, the river system is relatively unregulated overall with a fairly predictable monotonic flood pulse each year as exemplified in Figure 7.

Much of Cambodia and virtually the entire Mekong Delta in Viet Nam are flat and low-lying, so the annual river-associated floods cover most of the land classed as wetlands (Table 2). Floods are quite predictable from year to year and much of the flooded area is deeper than 2 metres. The Great Lake increases in depth by up to about 8 metres, and much of the floodplain is covered by several metres of floodwater for 3-4 months each year. The lower LMB floodplains are often considered to support the most productive fisheries (e.g. Lamberts, 2006 and Zalinge *et al.*, 2004). In Lao PDR and Thailand, flooding is less predictable and of more limited extent and duration. As a result of storage in reservoirs, many rivers in Thailand now flood significantly only in the wettest years.

In its natural state, the entire lowland river–floodplain system could be regarded as a single ecological unit under the flood pulse concept (Junk *et al.*, 1989; Junk and Wantzen, 2004). Flooding transfers nutrients and organic detritus from the rivers to their floodplains, wets soil which releases mineralised nutrients that support primary production, and inundates terrestrial vegetation, fruits, detritus and terrestrial animals (such as insects and other arthropods) that provide food for fish. Many species of migratory ‘white fishes’ move onto flooded areas to feed, whereas black (floodplain-resident) or grey (locally-migrating) fishes both feed and spawn on the floodplain. White-fish fry from spawning upstream in rivers typically arrive as drift in the rising floodwaters (Chea *et al.*, 2003; Nguyen *et al.*, 2008; Nguyen *et al.*, 2006 and Thach *et al.*, 2006).

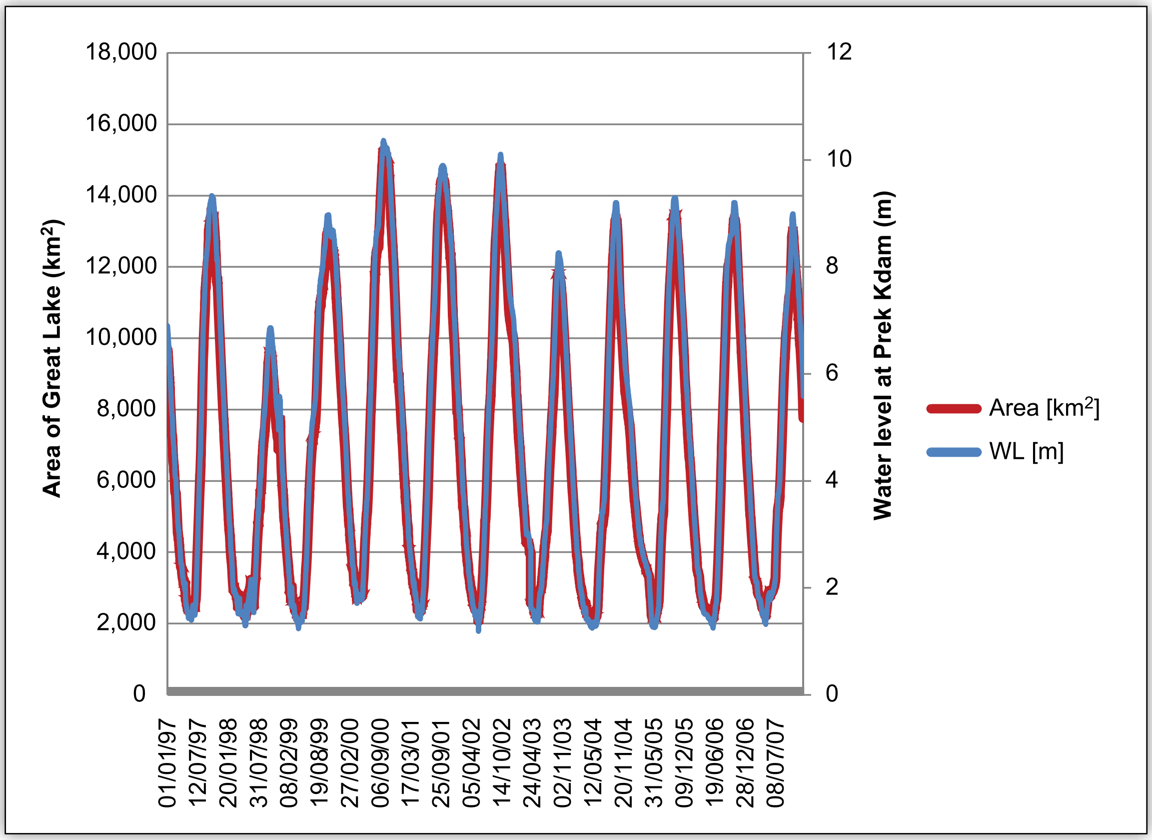

Figure 7 The annual flood of the Tonle Sap-Great Lake

Note that the rise in water level is almost linearly related to the increase in surface area The maximum extent of the Great Lake and its floodplains varies from 9,637 – 15,278 km^2 (1.6x) between wet (2000) and dry (1998) years.

White fishes move off floodplains as water levels fall and then migrate via rivers to dry-season refuges, such as deep pools; along their migration routes they are heavily fished by large-scale commercial fisheries, as reflected in summary data for Cambodia by Zalinge and Nao (1999). Catches of small-scale fishers on floodplains may comprise mostly black or grey fishes, especially where there are significant floodplain waterbodies, e.g. Dubeau *et al*. (2001).

As discussed in detail by Hortle (2009), total catches (kg/ha/year) from floodplain systems are usually correlated with the size of the flood. In general, larger floods of longer duration allow more fish to survive and grow to a larger size, so flood amplitude and duration have a direct effect on available biomass and thereby fish catches, other factors being equal (Halls *et al.*, 2008). Other features of the flood pulse may affect productivity as discussed by Lamberts (2008). But there is no information which would allow a precise prediction of the importance for fisheries production of changes in the shape or timing of the flood pulse (Welcomme and Halls, 2004). Retention of water on floodplains during the dry season also enhances fish production. But the 'optimal' balance between wet and dry-season flows is unclear because production does not depend upon hydrology alone but also upon other factors such as nutrient release from exposed sediments during the flood pulse (Welcomme and Halls, 2004).

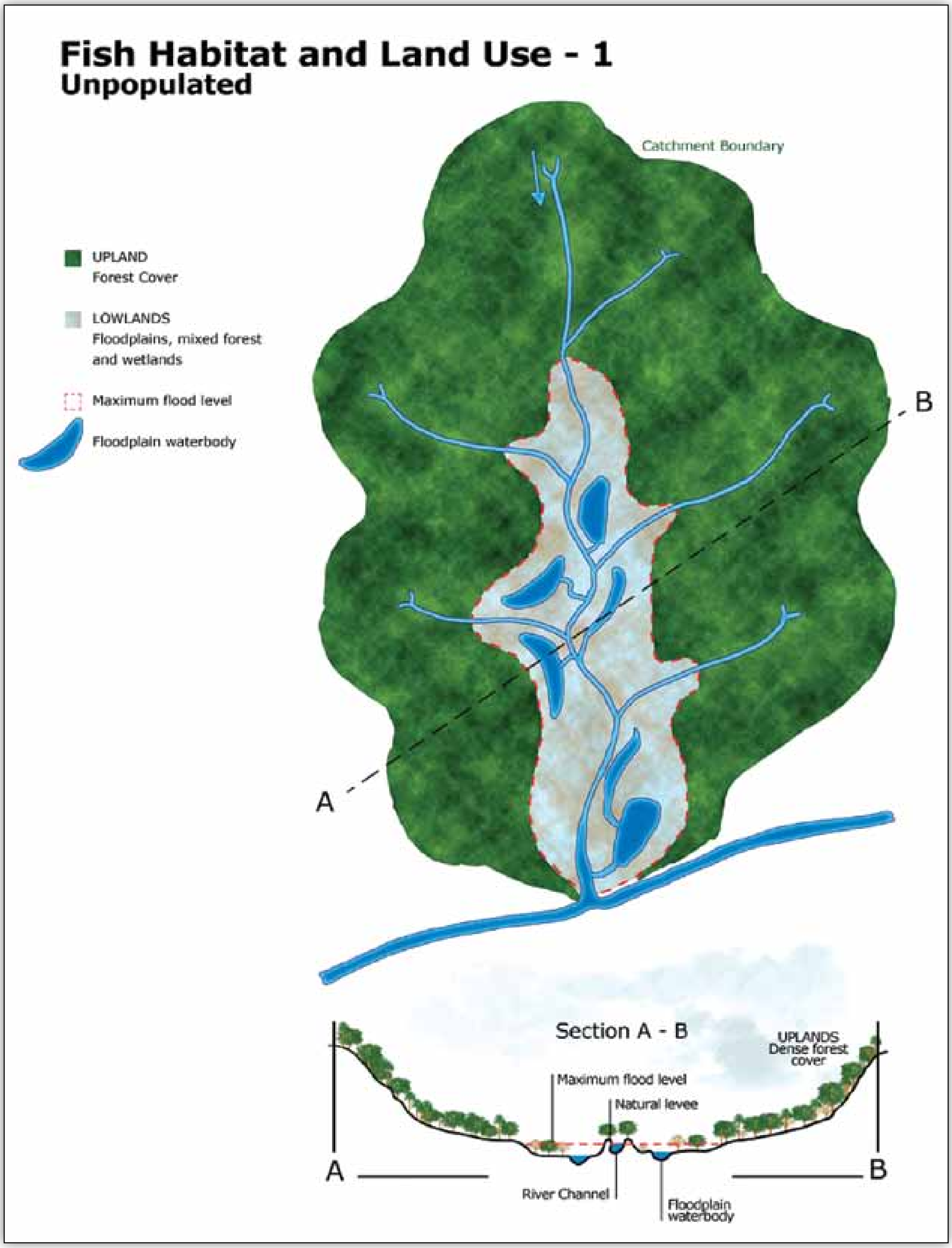

Figure 8 Schematic diagram of a hypothetical unpopulated river basin within the Mekong Basin

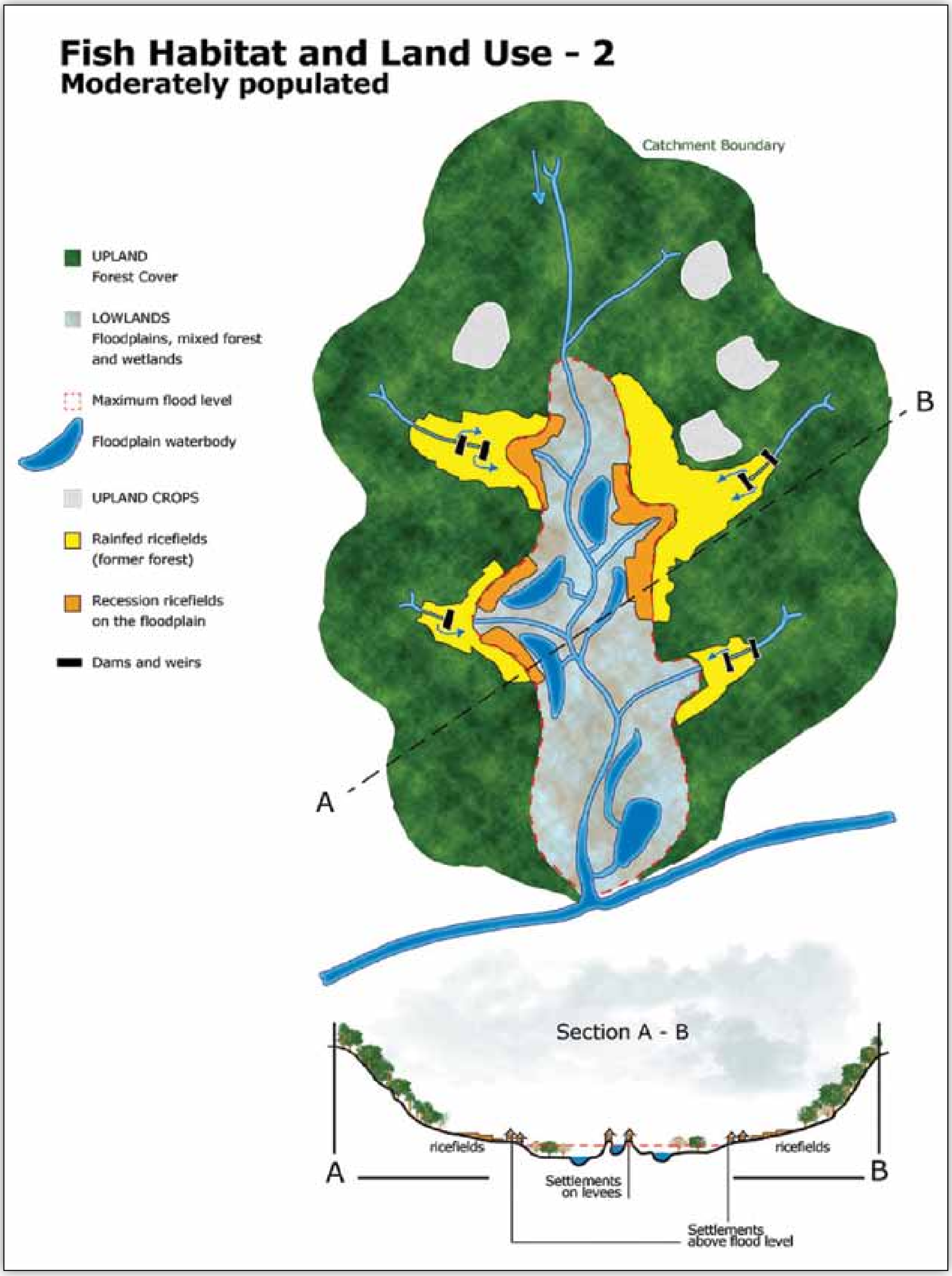

Figure 9 Schematic diagram of a moderately populated river basin within the Mekong Basin
New rainfed wetlands are developed on formerly forested land increasing total wetland area.

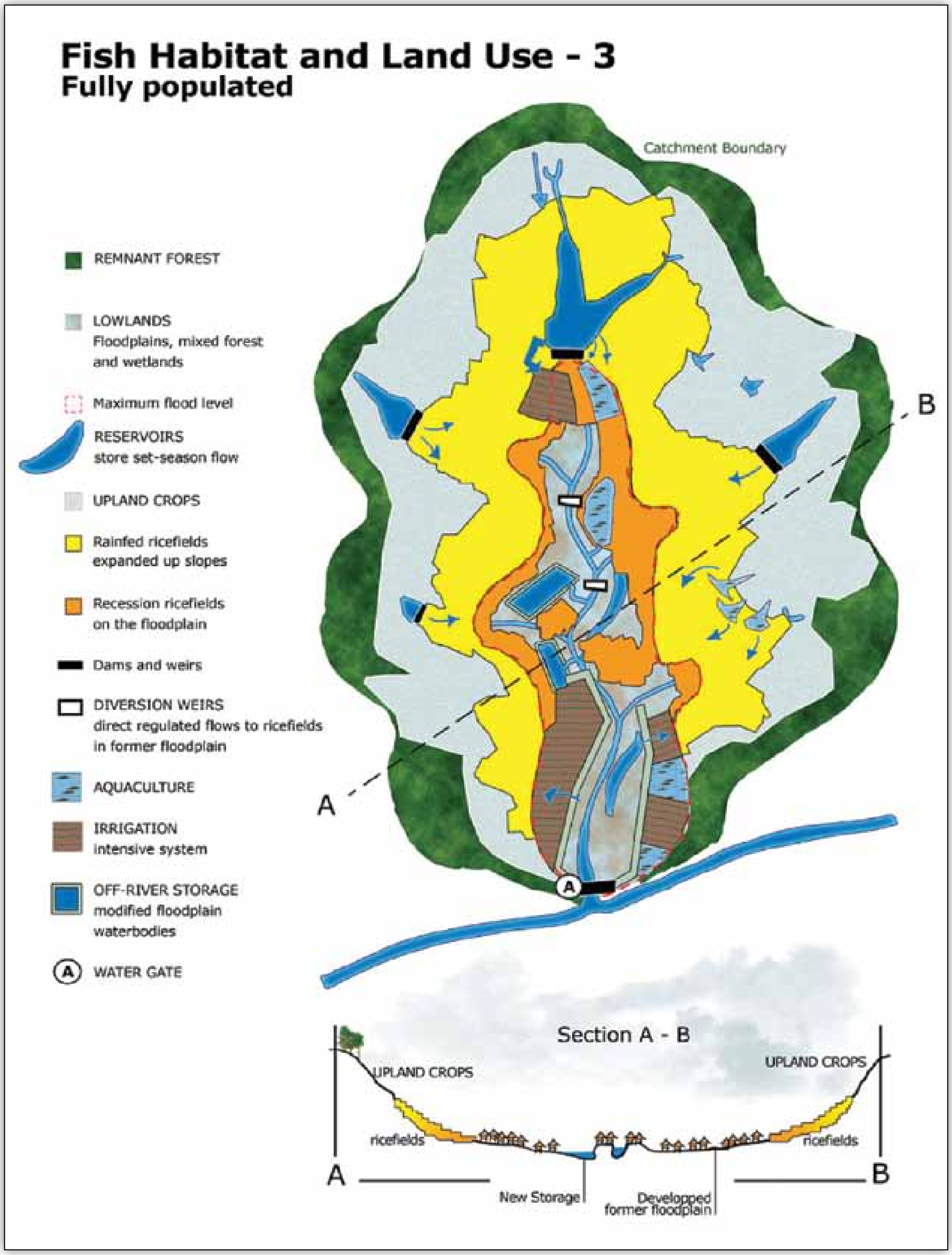

Figure 10 Schematic diagram of a fully populated river basin within the Mekong Basin

Rainfed and recession rice fields expand, rivers are heavily dammed and flooding reduced, irrigation is developed on both rainfed and floodplain lands and most of the basin is used for agriculture.

Yields from floodplains vary widely, with Halls *et al.* (2006) suggesting that catches are sustained around 100 – 150 kg/ha/year over a range of fishing effort, but much higher yields have been recorded; e.g. 574 kg/ha/year for wild fish (Ali, 1997) in Bangladesh, and even higher yields where floodplain waterbodies are stocked. The main environmental factors which lead to higher yields include:

1. open access from adjacent rivers;
2. deep and extended flooding;
3. the presence of floodplain waterbodies that persist through the dry season;
4. moderate to high fishing pressure;
5. stocking; and
6. additional inputs of nutrients from agricultural fertilisers or domestic wastewater.

In the Mekong, recession rice-farming may also be significant because paddy fields extend the coverage and duration of inundation (Matsumoto *et al.*, 2005). But there have been no specific studies of such effects on fisheries.

Four studies provide estimates of yield from floodplains in the Mekong system based on actual catch measurements. These are discussed in detail in Hortle (2009) and summarised in Table 5. Based on the LMB data and studies elsewhere (e.g. Bangladesh, Table 5), the yield from the major flood zone in the LMB is estimated to be in the range of 100 – 200 kg/ha/year. This estimate is conservative as it does not take into account the capture of fish and OAAs which, having fed on floodplains, are caught elsewhere. Yields are likely to be higher in more productive parts of the system in Cambodia and the upper parts of the Mekong Delta in Viet Nam, and lower where flooding is of relatively short duration and depth, such as in Lao PDR and Thailand.

In some river-floodplain locations, despite isolation from the sources of white fishes, very high yields have been observed. The highest yield estimate for floodplains in the LMB is for That Luang wetlands near Vientiane, Lao PDR. This system comprises a floodplain lake and associated marshes that have been isolated from the Mekong by levees; the wetlands are highly eutrophic as they receive urban wastewaters. Yield was estimated at 734 kg/ha/year, of which 65% was fish (Gerrard, 2004). Catches mainly comprised black fishes and tilapia, an exotic species that can feed on the abundant algae (Piyasiri and Perera, 2001). Hence any loss of productivity caused by isolation from the river system appears to have been more than offset by the effects of eutrophication and year-round availability of water. Other similar wetlands are found near many LMB towns or cities. Based on observations during field visits, they are apparently highly productive (e.g. Boeung Choeung Ek near Phnom Penh), but their yields have not been documented.

Although it is generally assumed that floodplains support much of the production of fishery species from river-floodplain habitats, there has been no attempt to estimate the relative importance of production within the main river channels compared with that in floodplains. Literature values for fish production in river channels elsewhere vary between 16 – 2,800 kg/ha/year (Welcomme, 1985 and Table 6.14). Among the most productive river systems is the Thames in the United Kingdom, where production of fish was estimated at 2,426 kg/ha/year, or 10 – 20 times the normal range from tropical floodplains. In that regulated river, stable water levels and high nutrient inputs favour plant growth, which would tend to compensate for the negative effects of fragmentation and loss of floodplains. The situation may be similar in some regulated rivers in the LMB, such as in the Pong River in northeast Thailand, where there is abundant plant growth (likely due to agricultural fertiliser runoff) and apparently high catches of fish and OAAs.

Table 5 *Estimates of yield from floodplains (from Hortle, 2009)*

Location	Habitats	Yield (kg/ha/ year)	Composition	Comment	Source
Tonle Sap, Cambodia	Mostly floodplain with recession rice, rainfed rice fields, permanent waterbodies about 5% of area	243 – 532	Fish and OAAs	Study area 8,252 ha, max flooded area 6,732 ha. Based on fisher logbooks plus commercial catches which were 4 – 9% of total	Dubeau *et al.* (2001)
Mekong Delta Floodplain, Viet Nam	Rice fields, deep water floodplain, acid soils	63	Fish 47%, OAAs 53%	Intensive monitoring at one site	De Graaf and Chinh (2000)
Mekong Delta Floodplain, Viet Nam	Rice fields, deep water floodplain, non-acid acid soils	119	Fish 89%, OAAs 11%	Intensive monitoring at one site	De Graaf and Chinh (2000)
Prey Veng, Cambodia	Floodplain-rice fields, single-crop, former forest	55	Fish	Underestimate: includes only commercial large and middle-scale catches in fishing lots, does not include artisanal catch	Troeung *et al.* (2003)
Prey Veng, Cambodia	Floodplain-degraded flooded forest 31% cover and rice fields, single crop	92	Fish		
Battambang, Cambodia	Floodplain-flooded forest	95	Fish		
Prey Nup, Cambodia (coastal)	Artificial deep floodplains behind polders	630	Fish	Extensive permanent waterbodies	Lim *et al.* (2005)
Floodplains, Bangladesh	Unregulated floodplains (8 studies)	24 – 574	Wild fish only	Intensively fished	Ali (1997) Tables 31 – 33
Floodplains, Bangladesh	Floodplain-natural	104 – 130	Fish	Intensively fished	Halls *et al.* (1999)
Tonle Sap System	Floodplain, total	230	Fish?	Crude estimate	Baran *et al.* (2001)
Tonle Sap Floodplain	Floodplain, total for 1995 – 99	139 – 190	Fish?	Crude estimate	Lieng and Zalinge (2001)

3.3.2 Yield from rainfed habitats

Outside the main floodplains (as defined by the Year 2000 flood), the lowland landscape comprises principally rainfed rice fields developed on formerly forested land. The term 'rainfed' refers to the main (wet-season) crop of rice in this zone that depends on inputs of water from direct rainfall and local diversions from small weirs across drainage lines and not major irrigation systems linked to large storage reservoirs. There are millions of small ponds and reservoirs within this environment which are not discriminated in the GIS and for which there are no accurate statistics.

The essential features of rainfed habitats are:

- They are primarily new aquatic habitats, created by the actions of people.
- Rainfed rice fields are typically shallow (30 – 50 cm deep).
- Small streams or rivers are usually highly modified with barriers to divert water laterally.
- There are many barriers that do not drown out during floods.
- Fishing gears typically block access for wholly aquatic species along drainage lines in many places.
- The main refuges are small ponds and other man-made waterbodies, such as canals, or remnant natural waterbodies including swamps and streams.

The main features of rice-field fisheries and the various studies in the LMB are reviewed in Hortle (2009). Most rural families in the LMB fish in and around rainfed rice fields, (Gregory *et al.*, 1996 and Hortle *et al*., 2008). Compared with rivers and streams, rice fields are rather extreme environments where water levels may fluctuate rapidly and water is often hot and deoxygenated. The few species that can tolerate such conditions may, however, grow rapidly and may be very abundant. Common fishes include air-breathing 'black fishes' such as striped snakehead (*Channa striata*), walking catfishes (*Clarias* spp.), climbing perch (*Anabas testudineus*), Asian swamp eels (*Monopterus albus*) and other animals such as snakes, crabs, shrimps, amphibians, molluscs and insects.

Data on yield-per-unit-area in the LMB and elsewhere are summarised in Table 6. Yields are favoured by inundation of rice fields to greater depths and for longer duration (see e.g. Khoa *et al.*, 2005) and where farmers maintain ponds as dry-season refuges (Angporn *et al.*, 1998). Small waterbodies including ponds and reservoirs up to about 100 ha in area are usually intimately connected with surrounding rice fields. Fish and fishers tend to move through the landscape; their yield cannot be separately accounted but is part of the 'rice-field landscape' yield. Small waterbodies are often stocked and also support feral fishes; i.e. stocked species or aquaculture escapees that have established wild breeding populations. As discussed below, small waterbodies may be very productive which may at least partly compensate for losses of fishery production in intensively farmed landscapes.

Expansion of the area of rainfed rice fields impacts river-floodplain fisheries by depriving them of water through the many small-scale diversions into fields. But losses to river fisheries may be compensated, to some degree, by additional catches of the more restricted suite of fish and OAAs from rice fields as well as capture in small reservoirs (Khoa *et al.*, 2005). The extent of compensation for any losses depends upon management: high pesticide use may support very limited fisheries, whereas rice-fish culture is likely to produce the highest yields.

Irrigation in the dry season is applied to an increasing proportion of the rainfed area to support a second crop of rice. The associated infrastructure creates refuges and dispersion channels for aquatic species, which may be fished throughout the year. Further intensification to a double-cropping rice system can be expected to create conditions which are less favourable for many aquatic organisms. For example, only seven fish species were present in an intensive rice-growing area in Malaysia. Nevertheless, fish yields remained high at 129 kg/ha/season with a maximum yield of 202 kg/ha/season (Ali, 1990).

The published data suggest that the yield of wild fish and OAAs from unstocked rainfed habitats may on average be 50 – 100 kg/ha/year. The more elevated and/or drier areas (such as in much of northeast Thailand) are probably relatively unproductive per unit area. But wetter low-lying areas would be relatively more productive, as they would include more permanent waterbodies and more waterbodies associated with irrigation, which would tend to raise the average yield.

Table 6 *Estimates of yields from rice fields or mixed habitats (from Hortle, 2009)*

Location	Habitats	Yield (kg/ha/year)	Composition	Comment	Source
Battambang, Cambodia	Rice fields, single crop rainfed, fertile land	119	Fish 77% OAAs 23%	Yields from 10 plots of 25 ha each, monitoring of all wet-season catches	Hortle *et al.* (2008)
Prey Veng, Cambodia	Rice fields, single crop rainfed, low yield	50 – 100	Fish, OAAs not assessed	Estimates based on catches, villages may not be representative, approximate area	Guttman (1999)
Svay Rieng, Cambodia	Rice fields, single crop rainfed, low yield	125	Fish 82% OAAs 18%	Estimates from 3 villages only and approximate areas	Gregory *et al.* (1996)
Mekong system, northeast Thailand	Rice fields, single crop rainfed	25 – 125	Fish, OAAs not assessed	Range from one study in Ban Khu Khat	Little *et al.* (1996)
Mekong system, northeast Thailand	Rice fields, single crop rainfed	209	Fish, OAAs not assessed	Mean with trap ponds, wild fish only, 16 – 20 farmers over two years	Middendorp (1992)
Mekong system, northeast Thailand	Rainfed and recession rice fields and floodplain	79	Fish and OAAs	Based on household survey of catches, consistent with consumption estimates	Hortle and Suntornratana (2008)
Near Penang, Malaysia	Rice fields, double-cropping Irrigated	129 (57 – 202)	Fish, OAAs not assessed	Double rice cropping, artisanal fishery	Tan *et al.* (1973)

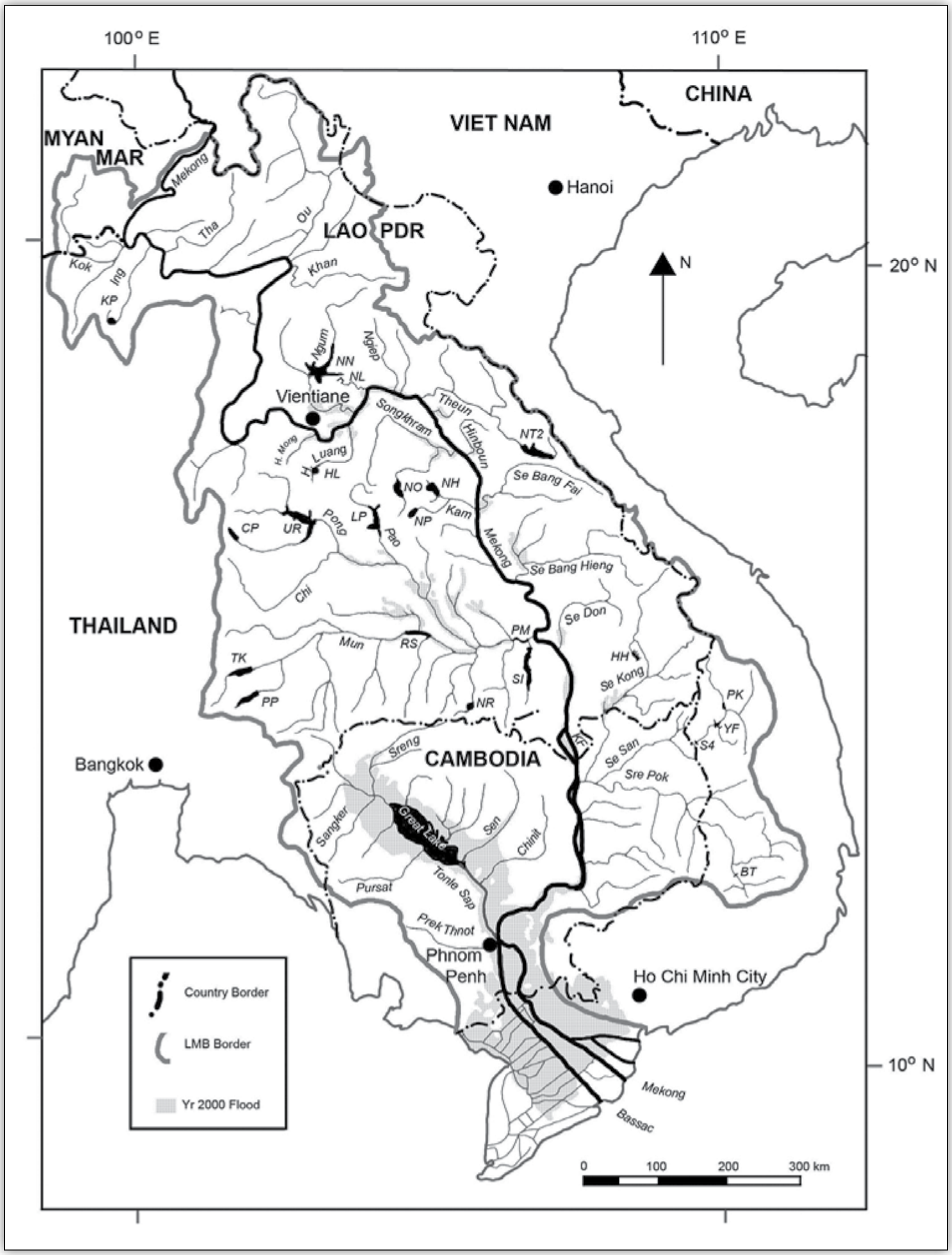

Figure 11 River systems, large reservoirs and flooded areas in the Lower Mekong Basin
Larger reservoirs present in 2010 are shown, abbreviated as in Table 7. KF = Khone Falls.

Table 7 *Some key features of the largest dams in the LMB in 2010, with existing Chinese Mekong dams shown for comparison.*
Showing only those where the reservoirs have surface area >20 km^2 or volume > 150 million m^3

Country	Dam name	Code	River system	Completed	Purpose	Elevation (masl)	Wall height (m)	Wall length (m)	Inundated area (km^2)	FSL Vol Mm^3	Mean Depth (m)	Catchment (km^2)	Inflow (m^3/s)
China	Xiaowan		Mekong	2010	Hydropower	1236	292	902	190	15,043	79.2	113,300	1,220
China	Manwan		Mekong	1996	Hydropower	994	132	418	24	920	39	114,500	1,230
China	Dachaoshan		Mekong	2003	Hydropower	906	111	460	83	940	11.4	121,000	1,340
Lao PDR	Houay Ho	HH	Se Kong	1999	Hydropower	883	79.5	400	42	620	14.8	192	9.5
Lao PDR	Nam Leuk	NL	Leuk	2000	Hydropower	405	45.5	800	13	185	14.5	274	16.4
Lao PDR	Nam Theun 2	NT2	Theun	2010	Multi	538	45	48	450	3,680	8.2	4,013	245.3
Lao PDR	Nam Ngum (1)	NN	Ngum	1971/84	Multi	212	75	468	370	7,000	18.9	8,460	427
Thailand	Nam Pung	NP	Pung	1966	Multi	284	41	1,720	22	165	7.7	296	4
Thailand	Lam Nam Rong	NR	Rong	1991	Irrigation	143	23.5	1,500	25	218	8.7	453	5
Thailand	Chulaphorn	CP	Phrom	1972	Multi	759	70	700	12	188	15.7	545	5
Thailand	Huai Luang	HL	Huai Luang	1973	Irrigation	198	12.5	1,400	31	113	3.6	666	Small
Thailand	Nam Pra Phloeng	PP	Pra Phloeng	1968	Irrigation	228	50	575	19	220	11.6	807	6
Thailand	Nam Un	NO	Oon	1973	Irrigation	178	29.5	3,300	85	520	6.1	1,100	12
Thailand	Kwan Phayao	KP	Ing	1941	Fisheries	405	5	10	24	11	0.5	1,161	Small
Thailand	Lam Ta Khong	TK	Ta Khong	1969/2001	Irrigation	277	40.3	527	44	445	10.1	1,430	8
Thailand	Nong Han	NH	Kam	1953	Fisheries	157	5	200	135	64	0.5	1,653	Small
Thailand	Sirindhorn	SI	DomNoi	1971	Multi	142	42	940	288	1,966	6.8	2,097	53
Thailand	Lam Pao	LP	Pao	1968	Irrigation	160	33	7,800	400	2,640	6.6	5,964	45
Thailand	Ubolratana	UR	Pong	1966	Multi	182	35.1	800	410	2,264	5.5	12,104	71
Thailand	Pak Mun	PM	Mun	1994	Multi	108	17	324	60	350	5.8	117,040	759
Thailand	Rasi Salai	RS	Mun	1994	Irrigation	117	9	nd	110	~440	~4	~48,000	~310
Viet Nam	Buon Tua Srah	BT	Sre Pok	2008?	Multi	488	83	1,035	37	787	21.2	2,930	100
Viet Nam	Plei Krong	PK	Se San	2006	Hydropower	570	71	495	53	1,049	19.7	3,216	128
Viet Nam	Yali Falls	YF	Se San	2000	Multi	515	69	1,190	53	1,037	19.5	7,455	270
Viet Nam	Se San 4	S4	Se San	2010	Hydropower	215	74	850	54	893	16.5	9,326	329

3.3.3 Yield from reservoirs

Many dams have been built in the LMB for various purposes and many more are under construction or planned. In the LMB in Thailand, Virapat and Mattson (2001) estimated there were 1,872 reservoirs (most used for storage of water for irrigation) in 1999 with a total FSL area of 2,120 km^2 which may be an underestimate because the combined area of the 13 largest Thai dams alone is 1,665 km^2 (Table 7). The 22 largest existing LMB reservoirs in 2010 had a combined surface area of 2,737 km^2 so the total area of LMB reservoirs (larger than 100 ha) is probably approaching 4,000 – 5,000 km^2. In the LMB, most of the larger dams are designed to create reservoirs that store wet-season flows for release during the dry season, reducing the flood pulse and impacting river-floodplain fisheries. By 2000, the effects of river regulation were evident in tributaries with large dams such as the Mun-Chi system in northeast Thailand and the Nam Ngum River in Lao PDR. But there had been little effect on the seasonal pattern of flows further downstream in the Mekong, which discharges about 475 km^3/year (MRC, 2005). By 2010, with about 40 km^3 of water stored in the 26 largest reservoirs (Table 7), the effects of river regulation were becoming evident in the Mekong mainstream as increased dry-season flows and slightly reduced wet-season flows.

The fisheries of LMB reservoirs are reviewed in Hortle (2009). While dams impact migratory species and reduce production from floodplains, up to about 100 fish species may persist in each reservoir. Production is often increased by stocking, particularly in smaller storages. Bernacsek (1997a, b) recorded 155 species occurring in reservoirs in the Mekong countries and Lagler (1976a) provided a detailed listing of those species which persisted in the larger Thai reservoirs (Lam Pao, Ubolratana and Sirindhon) and those which disappeared. Other factors being equal, it would be expected that the catch of reservoirs would increase initially and then decline over a period of years as the flooded terrestrial foods and detritus decay or are eaten and nutrients are gradually flushed from the reservoir. This pattern has often been reported or inferred. Several factors may, however, offset this decline. As people move into a catchment, farming intensifies and the supply of nutrients may increase. Over time, the natural fish community adjusts to the changed conditions, with some indigenous fish increasing in abundance and fish better adapted to impoundments being stocked or accidentally introduced, and fishing pressure increases. The long-term productivity from reservoirs is also favoured by the presence of large inflowing rivers which provide spawning habitats and an inflows of terrestrial detritus. Official catch data from reservoirs in the Lower Mekong Basin countries (summarised in Bernacsek, 1997) are based on surveys of landing sites so they cover part of the commercial catch only (Table 8). The neglect of artisanal (small-scale) catches in official figures leads to gross underestimates of yields so the generalisation that total fish catches typically decline may not apply in many cases. It should be noted that survey results are not comprehensive as they neglect most or all OAAs. Clams and shrimps may be particularly abundant in reservoirs; in Lam Pao, Suwannapeng (2007) recently estimated the standing crop of one clam species (*Corbicula* spp.) to be about 136 kg/ha, and the annual catch of this clam to be about 60 kg/ha/year, probably similar to the fish yield based on the similarity of this reservoir to Ubolratana. Accounting for the catches of OAAs could therefore double the estimates of total catches from some reservoirs.

Yield-per-unit-area tends to decline with size, as is evident from the data in Table 9 which is graphed in Figure 12. The general pattern of higher yields per unit area in smaller reservoirs is also well documented in other areas (e.g. Amarasinghe, 2006 and Nguyen, 2006). Smaller reservoirs are usually stocked and may support more productive fisheries because they have a greater length of shoreline relative to area, making them more accessible and fishable. They are also less likely to stratify and lock up nutrients, they tend to be eutrophic and the fish in small reservoirs are more easily caught, avoiding wastage of productivity in a large standing stock of fish that are not growing. Catches also appear to be correlated with the proportion of a reservoir that is 'drawn down' each year during the dry season (Nissanka, 2001), probably because nutrients are released from re-flooding of exposed shoreline sediments, as described for the flood pulse (Wantzen *et al.*, 2008). Most large reservoirs in the Mekong system are highly drawn down each year, a factor that could promote productivity and lead to relatively high yields.

An estimate of total catches of 25,428[9] tonnes/year from LMB Thai reservoirs by Virapat and Mattson (2001) equates to a yield of 120 kg/ha/year. But this is probably an underestimate as it is based on official data (see Table 8 and discussion above) and does not take into account the likely high yield from many smaller stocked reservoirs (Figure 12). Because the mean size of reservoirs in Thailand is much smaller than Nam Ngum or Nam Oon, yields per-unit-area are higher in smaller reservoirs. Taking into account the likely additional yield of OAAs, a reasonable estimate for the mean fisheries yield across all reservoirs is **200 kg/ha/year,** with a range (low-high) of 100 to 300 kg/ha/year. Reservoir yields in the LMB therefore appear to be quite significant and sustainable, and should be considered in any balanced assessment of dam impacts, which should also take into account that much of the yield is taken by the many unmonitored small-scale fishers.

Table 8 *Comparison of reservoir capture fishery yield data based on field surveys with 'official' data quoted by Bernacsek (1997)*

	This Report, Table 9				Bernacsek (1997)			
Reservoir	**Year(s) of survey**	**Area (km^2)**	**Fish catch (t/year)**	**Yield (kg/ha/year) (i)**	**Year(s) of survey**	**Catch (t/year)**	**Yield (kg/ha/year) (ii)**	**RATIO (II/I)**
Ubolratana (Thailand)	1992	410	3,714	59	1992	1,257	31	53%
Huai Luang (Thailand)	2000	31	781	252	1986	161	52	21%
Nam Ngum (Lao PDR)	1998	370	6,833	185	1996	694	19	10%
Nam Oon (Thailand)	2002?	85	1,032	121	1989	164	19	16%
Ea Kao (Viet Nam)	1997 – 1999	2.1	123	588	mean 1985 – 92	68	324	55%

Note: other aquatic animals are not included

[9] A figure of 240,000 tonnes per year from reservoirs quoted by Sverdrup-Jensen (2002) and others is apparently a misquote from Virapat and Mattson (2001). The origin of reservoir catches of 232,200 tonnes per year quoted by Zalinge *et al*. (2004) in Table 1 is not known, but would imply a mean yield of about 400 kg/ha/year.

Table 9 *Reliably estimated fisheries yields from LMB reservoirs.*
Many official data are not shown here as they underestimate yield by not including small-scale household or artisanal catches and OAAs

Waterbody	Location	Year constructed	Year(s) of Survey	Area (km²)	Mean Depth (m)	Catch (t/year)	Yield (kg/ha/year)	Species make-up	Dominant fishes	Source
Ho 31 Reservoir	Central Highlands (Viet Nam)	No data	1997 – 99	0.0537	1	6.1	1,139	99% stocked exotic	Silver carp, bighead carp, common carp, Indian carps	Tran *et al.* (2001)
Yang Re Reservoir	Central Highlands (Viet Nam)	1984	1997 – 99	0.56	6.1	32.2	575	87% stocked exotic	Silver carp, bighead carp, common carp, Indian carps	
Ea Kar Reservoir	Central Highlands (Viet Nam)	1978	1997 – 99	1.41	5.2	54.7	388	98% stocked exotic	Silver carp, bighead carp, common carp, Indian carps	
Ea Kao Reservoir	Central Highlands (Viet Nam)	1979	1997 – 99	2.1	5.1	123.5	588	77% stocked exotic	Silver carp, bighead carp, common carp, Indian carps	
Ea Soup Reservoir	Central Highlands (Viet Nam)	1980/2002	1997 – 99	2.4	6.1	51.4	214	98% self-recruiting indigenous	Indigenous fish	
Lak Lake	Central Highlands (Viet Nam)	Natural	1997 – 99	6.58	1	84.2	128	97% self-recruiting indigenous	Indigenous fish	
Kaeng La Wa Reservoir	Northeast Thailand	1983	2002?	19	1.4	512	269	Most self-recruiting	Carps, catfishes, snakeheads, Nile tilapia	Nachaipherm *et al.* (2003)
Huai Luang Reservoir	Northeast Thailand	1973	2000	31	3.6	781.15	252	Most self-recruiting	Nile tilapia 52%, carps, featherbacks	Nakkaew *et al.* (2002)
Nam Oon Reservoir	Northeast Thailand	1973	2002?	85	6.1	1,032	121	Most self-recruiting	Carps, catfishes, snakeheads	Nachaipherm *et al.* (2003)
Nam Ngum Reservoir	Lao PDR	1971/84	1998	370	18.9	6,833	185	All self-recruiting indigenous	*Clupeichthys aesarnensis* 28%, cyprinids	Mattson *et al.* (2001)
Ubolratana Reservoir	Northeast Thailand	1965	1992	410	16	2,435	59	97% self-recruiting indigenous	Cyprinids	Polprasith and Sirimongkonthaworn (1999)
16 village ponds	Thailand		1994 – 96	1.8 – 20 ha	~2		26–2,881, med. 652	Most stocked	Silver carp, bighead carp, common carp, Indian carps, silver barb, Nile tilapia	Lorenzen *et al.* 1998a
17 natural lakes and reservoirs	Lao PDR		1995 – 97	1 – 60 ha	39,569.00		60-690	Various	Stocked and indigenous	Lorenzen *et al.* 1998b
Huai Muk Reservoir	Northeast Thailand	No data	2002?	2	~1	13	65	Most self-recruiting	Carps, catfishes, snakeheads	Nachaipherm *et al.* (2003)

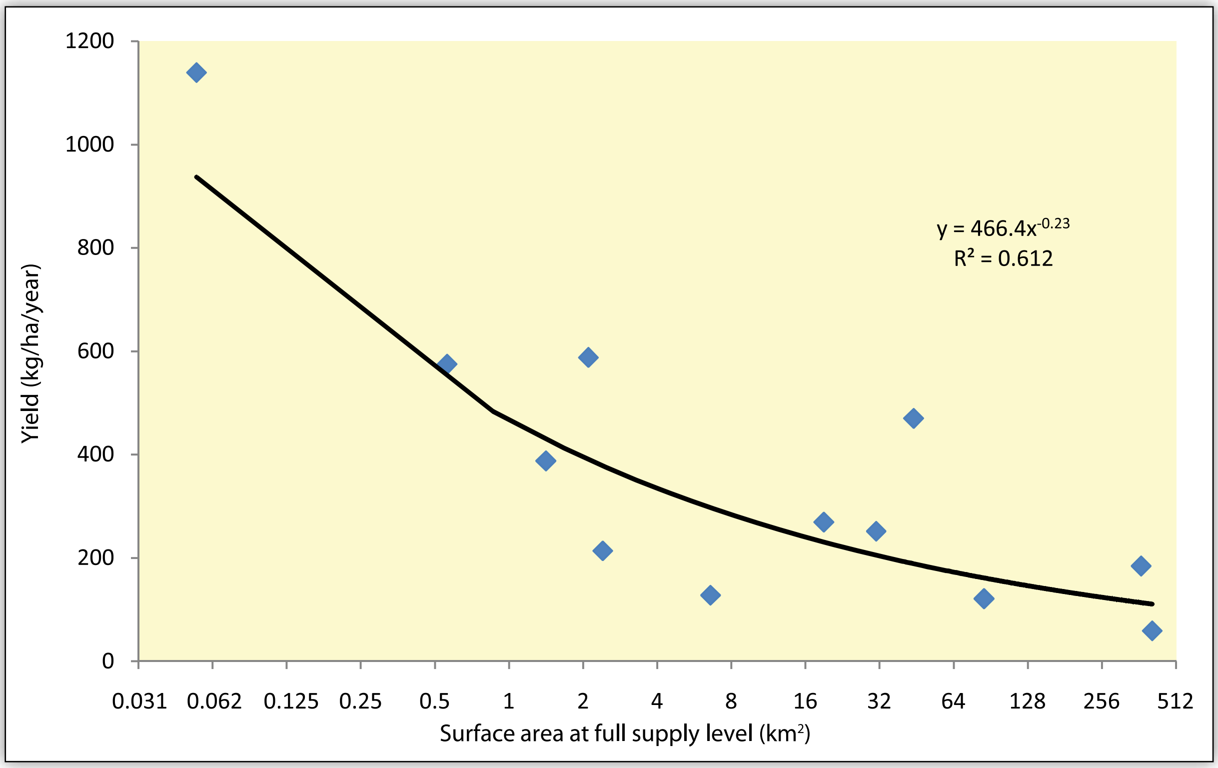

Figure 12 Relationship between yield-per-unit area and reservoir size for LMB reservoirs

Best-fit line and equation, based on Table 8, excluding ponds and Huai Muk which was heavily silted. For the four smallest reservoirs, the yield depends upon stocking; yields from the other reservoirs depend upon self-recruiting species (Table 9).

4 Total yield estimate from the Lower Mekong Basin – the ‘likely’ source of the yield

4.1 Approach

Given the limitations of the land cover and yield data, and considering the landscape-scale linkages in the system’s ecology and fishing effort, it is appropriate to estimate yield over broad categories of habitat. Table 10 presents a summary based on Table 2 that is derived from the land-cover data sets. As discussed above, estimates of yield from each habitat class vary from 50 – 300 kg/ha/year, a range that is consistent with potential secondary production of 250 – 1,000 kg/ha/year as discussed in Section 4.2, and taking into account the generally low trophic level for most fishery species (Section 4.3). Table 11 combines yield and habitat area estimates to show that the basin-wide yield is estimated to vary between 1.3 and 2.7 million tonnes per year, a figure which is consistent with the previous estimate of basin-wide consumption of wild-caught fish and OAAs of 2.37 million tonnes per year (Hortle, 2007). The range is also within that previously estimated based on the wetland data set of 0.7 – 2.9 million tonnes per year (Hortle, 2007). However, the analysis presented in this report is more soundly based and distinguishes the contribution from the main classes of habitat.

Table 10 *Major categories of LMB fisheries habitats and their area (km^2) based on Table 2*

Land-cover type	Cambodia	Lao PDR	Thailand	Viet Nam Delta	Viet Nam Highlands	Total LMB
1 Major flood zone: Permanent waterbodies including most major rivers, the Tonle Sap – Great Lake system, and seasonally flooded land; includes recession rice fields.	28,262	4,617	7,795	17,343		58,017
2 Rainfed zone: Mainly rice fields, other wetland crops and associated habitats not within the major flood zone. Most is former forest.	17,605	8,962	93,119	8,573	1,576	129,835
3 Large waterbodies: Including reservoirs outside the flood zone.	853	2,143	3,521	839	156	7,512
4 Aquaculture: Outside flood zone, not considered in yield figures			58	2,315		2,373
Total wetland area	**46,720**	**15,722**	**104,493**	**29,070**	**1,732**	**197,737**

Table 11 *Estimates of basin-wide yield and the estimated range of yields per unit area. Units are kt/year.*

Low-Yield estimate

Habitat	Cambodia	Lao PDR	Thailand	Viet Nam		Total LMB
				Delta	Highlands	
1 River-floodplain: Within the major flood zone @ 100 kg/ha/yr	283	46	78	173	0	580
2 Rainfed Outside the major flood zone @ 50 kg/ha/yr	88	45	466	43	8	649
3 Large waterbodies (mainly reservoirs) Outside the flood zone @ 100 kg/ha/yr	9	21	35	8	2	75
Total Low Estimate	**379**	**112**	**579**	**225**	**9**	**1,304**

Medium-yield estimate

Habitat	Cambodia	Lao PDR	Thailand	Viet Nam		Total LMB
				Delta	Highlands	
1 River-floodplain: Within the major flood zone @ 150 kg/ha/yr	424	69	117	260	0	870
2 Rainfed: Outside the major flood zone @ 75 kg/ha/yr	132	67	698	64	12	974
3 Large waterbodies: (mainly reservoirs) Outside the flood zone @ 200 kg/ha/yr	17	43	70	17	3	150
Total Low Estimate	**573**	**179**	**886**	**341**	**15**	**1,994**

High-yield estimate

Habitat	Cambodia	Lao PDR	Thailand	Viet Nam		Total LMB
				Delta	Highlands	
1 River-floodplain: Floodplain within the major flood zone @ 200 kg/ha/yr	565	92	156	347	0	1,160
2 Rainfed: Outside the major flood zone @ 100 kg/ha/yr	176	90	931	86	16	1,298
3 Large waterbodies: (mainly reservoirs) outside the flood zone @ 300 kg/ha/yr	26	64	106	25	5	225
Total High Estimate	**767**	**246**	**1,193**	**458**	**20**	**2,684**

4.2 Balancing consumption and yield data

As well as the overall range in estimated yields, it is useful to consider what might be the 'most likely' yield for each country and to balance this with the year 2000 consumption estimates. For the year 2000, the LMB consumption of all inland (fresh plus brackish fishery products) is assumed to be 2,560 kt/yr as fresh whole animal equivalent (FWAE) weights based on Table 24 of Hortle (2007).

Aquaculture is assumed to have been producing products that supported 10% of the total consumption (256 kt), based on the limited information reviewed in Hortle (2009 – Table 26). To determine the aquaculture contribution from each country, the following sources were used:

- **Cambodia:** FAO database figures were multiplied by two, based on field surveys showing that the official estimates are about half of the figures based on actual field survey (So and Haing, 2007). It is assumed that all production was consumed within the LMB;
- **Lao PDR:** FAO database. The figures may be underestimates, but it is assumed they are correct and the effect is minor in the overall figures. It is assumed that all production was consumed within the LMB;
- **Thailand:** Thai Department of Fisheries household survey data were used; these are based on household surveys so are considered relatively accurate; and
- **Viet Nam:** Survey data by RIA2 based on estimates by district officials were used. The total includes fresh and brackish water; 62% of the production quantity in 2000 was from fresh water. Figures for the LMB part of the total delta production were estimated pro-rata by multiplying by 85% (the proportion of the delta area within the LMB). Somewhat different figures have been published in various places; differences may be a result of variable conversion of products to fresh whole animal equivalent (FWAE) weights (e.g. one kg of fillets requires about 3 kg of whole fish).

Summing all aquaculture production provides an excess over the assumed aquaculture-derived consumption in 2000 of 181,903 tonnes which is assumed to have been exported from the LMB. As set out in Table 12 it was assumed that:

- there were no exports from Cambodia or Lao PDR;
- about 10% of the Thai production was exported from the LMB; and
- the balance was exported from the LMB portion of the Mekong Delta in Viet Nam.

Table 12 shows that under these assumptions about 16% of the Mekong Delta consumption in 2000 was supported by aquaculture.

Table 12 *Consumption and aquaculture data, inland fish and OAAs summarised for 2000*
Based on Hortle (2007) and data on aquaculture as discussed in the text. All units are kt/year.

Country	Consumption					Total inland aquaculture production (fresh plus brackish)	Aquaculture production consumed in the LMB	Capture fishery (fish plus OAAs)	Percent of fish and OAAs from the capture fishery
	Fresh Fish	Preserved Fish	Total Fish	OAAs	Fish plus OAAs				
Cambodia	313	169	482	105	587	29	29	558	95.1%
Lao PDR	85	83	168	41	209	42	42	166	79.8%
Thailand	479	241	721	191	911	57	51	861	94.4%
Viet Nam	479	213	692	161	853	315	134	719	84.3%
Delta	443	197	640	149	789	310	130	659	83.6%
Highlands	36	16	52	12	64	4	4	60	93.0%
Total	**1,356**	**706**	**2,062**	**498**	**2,560**	**442**	**256**	**2,304**	**90.0%**

Assuming the consumption and aquaculture data are correct, it would have been necessary for the capture fishery to provide 2,304,000 tonnes per year as FWAE weights in the year 2000. There are no data disaggregated by country which can be used to support any particular catch or yield estimate, so it is necessary to make assumptions on 'most likely' levels of yield within the ranges considered probable for each habitat zone. These are judged subjectively, based on available literature (as reviewed in part above) and field observations throughout the basin as discussed briefly below. They are provided here to illustrate the approach and to provide an order-of-magnitude accounting. The discussion refers to the situation in 2000.

Cambodia–most likely high yield. The country's extraordinary capture fisheries around the floodplains are associated with extensive deepwater flooding, with a high proportion of migratory white fishes in some commercial fisheries (Hortle *et al.*, 2004). As well as an intact flood pulse, most floodplains in 2000 were still well connected to river systems where fish migrate to rest in deep pools, and where many species spawn at the start of the wet season. The extensive rainfed rice fields are also mainly low lying and relatively deeply flooded. Pesticide use is generally still limited and there are good fishery yields even in drier areas. While declines in catches are often noted, these may be largely attributable to lower catch-per-fisher than to declining total catches.

Lao PDR–most likely high yield. The country has many small but intact floodplains, extensive areas of traditional deepwater rice cultivation which are in many cases connected to streams or swamps, with generally low pesticide use on rice fields and widespread moderate to high fishing pressure.

Thailand–most likely moderate yield. but high yield for reservoirs. By 2000, natural production had likely been impacted by the many barriers to migration formed by weirs and dams, reduction in the size of the flood pulse, and conversion to intensive shallow-water rice cropping with high pesticide use. Much anecdotal evidence suggests there is a decline in river fisheries that has been caused by habitat change. Based on household data (Piumsombun 2001 and Prapertchob *et al.,* 1989) consumption comprises about 60% black fishes, mainly snakeheads (*Channa* spp.) and walking catfish (*Clarias* spp.), or grey fishes, sedentary or short-distance migrators such as silver barb (*Barbonymus gonionotus*) or other generalist barbs which can live in reservoirs (Lagler, 1976b). Consistent with fragmentation of habitat, migratory white fishes account for 15% or less of consumption. Aquaculture production is now dominated by Nile tilapia (*Oreochromis niloticus*) and its hybrids.

Mekong Delta in Viet Nam–most likely medium yield. Although the delta is fragmented by small water gates and other barriers, most are opened or submerged during extensive and deep annual flooding of the northern half of the delta. The canal system forms a large permanent reservoir which supports capture fisheries. The delta is connected to floodplains and sources of fry from spawning in Cambodia, and catches include estuarine, catadromous and coastal fishes. Negative trends include intensification of rice cropping with high pesticide use and very heavy fishing pressure as well as use of illegal and destructive methods such as poisoning and electro-fishing. In Long An, catches mainly comprised black fishes such as snakeheads (*Channa* spp.), walking catfish (*Clarias* spp.), climbing perch (*Anabas testudineus*) and grey fishes such as featherbacks (*Notopteridae*) and catfishes (*Mystus* spp. and *Ompok* spp.). Migratory white fishes formed only 23% of catches, consistent with barrier effects and heavy fishing of migrations (Pham and Guttman, 1999).

Central Highlands in Viet Nam–most likely high yield. There is a relatively limited wetland area available in the Central Highlands in Viet Nam so many waterbodies are heavily stocked and rice fields and ponds in many places are also stocked. It should be noted that stocked fisheries are included in capture, not culture.

Table 13 *'Most-likely' yield estimate to match the consumption estimate.*
Consumption estimates for Year 2000 are from Table 10; yield from capture fisheries only.
All figures are 000 tonnes/year as FWAE weights. Note that there are some slight rounding errors.

Habitat	Cambodia (all habitats high yield)	Lao PDR (all habitats high yield)	Thailand (flood zone and rainfed medium yield, reservoirs high yield)	Mekong Delta in Viet Nam (all habitats medium yield)	Central Highlands in Viet Nam (all habitats high yield)	Total LMB
1 River-floodplain within the major flood zone	565	92	117	260	0	1,035
2 Rainfed outside the major flood zone	176	90	698	64	16	1,044
3 Large waterbodies (mainly reservoirs) outside the flood zone	26	64	106	25	5	226
Total Yield Estimate	**767**	**246**	**921**	**349**	**20**	**2,304**
Consumption Estimate Year 2000	558	166	861	659	60	2,304
Surplus/Deficit	209	80	61	- 310	- 39	0

Under the 'most-likely' yield estimate (Table 13), the LMB yield estimate balances fortuitously with the consumption estimate. The figures for each country are indicative and subject to possibly large errors. For example, the apparent excess yields in Lao PDR and Thailand may not be realistic. On the other hand, dispersal of aquatic organisms downstream would likely provide a very large net downstream transport of fish food organisms and small fish. The surplus yield in Cambodia would be consistent with the known migration of fish from the Cambodian floodplains to the other LMB countries, considering that the yield figures relate to the area where biological production originates (i.e. the area of habitat) rather than where catches are actually made. Exports from Cambodia to the other LMB countries are also significant and include dried and fermented fish products as well as fresh fish, but accurate data on quantities are not available.

Under this 'most-likely' estimate, the Mekong Delta in Viet Nam in 2000 was in deficit and it is assumed that this was made up by fish and OAAs from Cambodia, either as they migrated into the delta from productive floodplains upstream or as imports of preserved and fresh fish.

The Central Highlands in Viet Nam also appeared to be in deficit, which was likely to have been filled by imports from the delta, based on observations in markets during field visits.

Under this 'most likely' assessment, the yields from the major flood zone (river-floodplain habitats) and the rainfed zone are approximately equal (45% of the total) while large waterbodies (including reservoirs) produce about 10% of the total yield. These figures are considered to be based on reasonable working hypotheses and provide a basis for further work to better understand the capture fisheries yield and also to predict impacts of developments on fisheries.

The large and highly visible fisheries associated with deep flooding in Cambodia might lead some to question the finding that the total yield from rainfed habitats is similar to that from river-floodplain habitats of the major flood zone. If we apply the maximum areal yield to the major flood zone, and the minimum to the other zones, the major flood zone would then contribute about 61% of the LMB total, which would then be 1,885,000 tonnes per year. On the other hand, it may be that rainfed habitats are actually more productive, because rice fields and associated small waterbodies are accessible to most households and fished for a long period, but catches are less visible because they are so dispersed. If we assume a maximum level of yield from rainfed habitats and a minimum yield from the other classes, the total yield from rainfed habitats would be 1,954,000 tonnes per year, or 66% of the total. While it would be useful to get more precise estimates, they would not alter the finding that each of the two main classes of habitat makes a large absolute contribution to yield, justifying a proportional effort to conserving and enhancing their capture fisheries.

5 Conclusions

An analysis based on areas of broad habitat zones and possible range of yields per unit area provides estimates of fisheries yield from the Lower Mekong Basin in the range of 1.3 to 2.7 million tonnes per year. This range encompasses the estimate from consumption data for the year 2000 (2.3 million tonnes per year of fish and OAAs), and is also within the areal yield range estimated from the 'wetlands' data sets (Hortle, 2007).

A 'most likely' LMB yield estimate was made for each habitat zone in each country based on their areas and an assumed yield per unit area from each habitat zone. The 'most-likely' yield matches the consumption-based estimate (2.3 million tonnes per year), so it provides a basis for attributing yield to the different broad habitat zones. Under this working hypothesis of the LMB yield, equal proportions (45%) derive from river-floodplain habitats in the major flood zone (moderate-high yield over a moderate area) and from rice fields and associated habitats in the rainfed zone (low-moderate yield over a very large area), with a minor contribution (about 10%) from reservoirs and other large permanent waterbodies outside the major flood and rainfed zones. This breakdown highlights the main threats to fisheries and the opportunities for fisheries enhancement.

With regard to river-floodplain habitats within the major flood zone, reduced flooding and any measures which restrict access by aquatic animals to flooded areas or fragmented river systems are likely to reduce fisheries productivity. Planned hydroelectric dams are likely to impact the river-floodplain fisheries in many ways by preventing fish migration, for example, or by altering the flow regime and changing water quality. Opportunities to increase yield from floodplains include improving habitat management, controls on fishing in deep pools to protect broodstock, reinstating fish passage across the many existing barriers in the LMB, improving the design of water-management structures and creating refuges on floodplains.

The main threats to rainfed habitats arise from intensified agriculture, which entails planting high-yielding varieties typically associated with shallower water depths and accompanied by increasing use of pesticides. The resulting loss of fishery yield may more than offset the value of additional rice production. Within rice-field habitats, it should be possible to maintain or increase fishery yields by measures such as maintaining water depths, improving connectivity, developing refuge ponds and promoting integrated pest management to reduce pesticide use. Additional fisheries yield may also be supported by the additional habitats provided within irrigation storage and distribution systems such as canals and small waterbodies.

Reservoirs are well-defined habitats that have been a successful focus for co-management. Fisheries production can be enhanced by a range of measures including stocking, management of fishing pressure, catchment management to reduce sedimentation, protection of spawning streams and management of reservoir operations.

As landscapes and hydrological systems are increasingly modified, it is likely that the loss of yield from wild capture fisheries could be at least partly compensated for by better management of fisheries in the rainfed zone and in new waterbodies including reservoirs. In this regard, caution is required when predicting development impacts based on experiences from other regions, because the anthropogenic rainfed rice-field habitats that predominate in the Mekong Basin (and in other large river basins in tropical Asia) are absent or limited in extent elsewhere in the world. However, improving management of wild capture fisheries, including those within new or highly modified habitats, will require general improvements in governance and ownership as well as increased commitment to adaptive co-management.

Aquaculture is often promoted to replace lost production from capture fisheries. As currently practised, much aquaculture depends upon wild fisheries for provision of broodstock, wild-caught fry or 'trash fish' used in feed. If fish prices rise, then greater investments in aquaculture could decrease the dependence on capture fisheries. However, it should be noted that capture fisheries are based on 'free' production, their benefits can be obtained by poor people with limited investment, and measures to conserve and manage capture fisheries are likely to provide relatively high returns. By contrast, successful aquaculture requires access to land, water and capital as well as significant education and technical training, and may shift the burden of work onto women. Consequently, social inequalities may be exacerbated by policies that seek to replace capture fisheries by aquaculture. As well as considering the various socio-economic aspects, the negative environmental aspects of aquaculture should also be recognised—the potential for pollution, the spread of diseases, parasites and noxious species, and competition with the capture fishery which supports sustainable aquaculture by providing broodstock, fry and feed.

The yield estimates may be conservative for some habitats, and some wetlands may be not represented. There is no separate yield information for the estuarine zone, which is included mainly within waterbodies and rice-field classes. This could lead to an underestimate of its productivity. Because the GIS data does not resolve most of the smaller rivers and streams within land classed as forest or 'forest and other' outside the main flood zone, their possible yield is not included. This report also does not cover the coastal fisheries (nourished by the Mekong's plume) that were estimated to yield about 726,000 tonnes per year in 2004 (Truong *et al.*, 2008).

Despite its limitations, the analysis presented in this report provides a framework to guide further studies on habitat classification and fisheries yield per unit area. There is a long-standing need for a system to be set in place in each country to implement properly designed household surveys at regular intervals to determine the status and trends in yield and consumption basin-wide. Similarly, more estimates of yield-per-unit-area should be collected systematically in each of they key habitat zones to better understand their contribution to total catches and the important factors affecting production.

6 Recommendations

This brief review provides some indication of the relative importance of broad classes of habitat and the likely size of total system yield. Because of the shortcomings of the data, the conclusions are indicative and somewhat subjective. The report does, however, clarify an approach to assessment and shows what needs to be done to provide more certainty.

1. GIS data should be progressively improved and updated in terms of coverage, resolution, consistency and quality of documentation.
2. Estimates of yield-per-unit-area may not be representative or current. The fisheries yield-per-unit-area from the extensive rainfed areas in Lao PDR and northeast Thailand should be further investigated because of the large contribution they may be making to the total fisheries yield. Data are poor for river-floodplain habitats and catches from the full range of reservoir sizes and types should be assessed.
3. The relative contribution of black fishes and river-dependent fishes (including white fishes) from the different habitats should be further quantified.
4. Yield-per-unit-area from the estuarine zone should be investigated.
5. Fisheries management in any particular locality should take into account the relative importance of different types of productive wetland habitat.

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Appendix 1

Rice fields: the area classified as rice fields is generally larger than the maximum areas reported to be harvested. This discrepancy arises because each year a proportion of rice fields are not planted, some planted areas are not harvested and because the dominant rice-field class includes smaller patches of habitat such as small ponds and canals, houses and garden plots, and small patches of swamp and other vegetation. In the Central Highlands in Viet Nam, where rice fields occur in small patches among the major land-cover classes (forest and plantations), the rice-field areas are underestimated because they are blended into the dominant land-cover classes. To correct the highlands data, the rice-field harvested area was multiplied by the mean ratio for the other places (1.56) to increase the highland rice-field area to 1,576 km^2, with the additional area (996 km^2) subtracted from the area of forest.

Table A-1-1 *Comparison of rice-field habitat area with maximum reported planted area in the LMB*

Statistic	Cambodia	Lao PDR	Thailand	Viet Nam Delta	Viet Nam Highlands
Total 'rice fields' area (GIS)	28,482	10,624	98,252	20,158	580
Max. area harvested for rice	18,460	6,311	50,130	16,632	1,010
Ratio: rice-field area /area harvested	**1.37**	**1.68**	**1.96**	**1.21**	**0.43**

Note: areas planted with rice obtained from MRC (2003); Cambodia 2000, Lao PDR 1999, Northeast Thailand 2001, Viet Nam 1999. The LMB was estimated to cover 86% of the Mekong Delta in Viet Nam, where it was assumed that 2nd and 3rd crops were harvested from the same area as 'autumn paddy'. Northern Thailand harvested area was estimated at 2,000 km^2 based on Huke and Huke (1997) and adjusted pro-rata for the area in the LMB.

In Cambodia, some land classified as mangrove was added into the flooded forest category: 20 km^2 inside the flood zone and 1 km^2 outside the flood zone.

In Cambodia, 3,773 km^2 of land was classified as riparian forest; this land fringed rivers in forested areas and was added into the forest category.

In Cambodia, recession rice fields were separately categorised, 1,824 km^2 inside and 54 km^2 outside the flood. These were added to the rice-field class.

In the Central Highlands in Viet Nam, 223 km^2 of unclassified land was added into the total for field crops.

In the Mekong Delta in Viet Nam, rice fields were broken down as follows (areas are km^2):

Table A-1-2 *Land-cover area*

Land-cover type	Mekong Delta in Viet Nam	
	Inside the flood	Outside the flood
Rice fields - 'irrigated'	10,279	2,100
Rice fields - 'rainfed'	917	6,011
Rice fields with 'upland' crops	321	62
Rice fields with shrimp/fish ponds	**68**	**400**

These subcategories were combined as the rice-field class.

Appendix 2

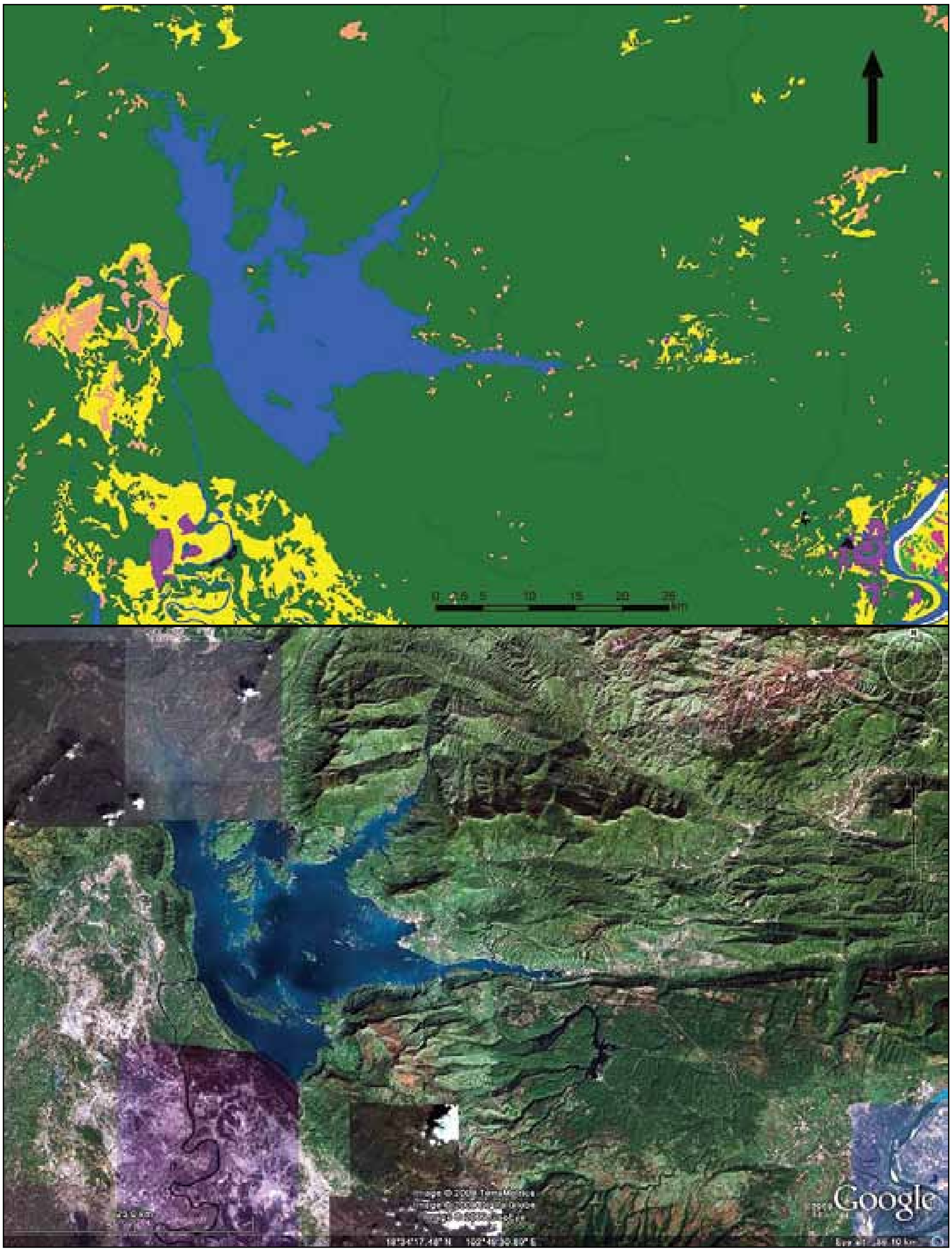

Figure A-2-1 Nam Ngum Reservoir, Lao PDR. The land-cover GIS data accurately show the extent of the reservoir but most islands are not digitised, an error with is balanced by smoothing of small inlets. Most land appears to be correctly classed as either forest, rice fields, swidden agriculture or swamps. Only major rivers are digitised. Nam Leuk Reservoir (which diverts water into Nam Ngum) to the southeast of Nam Ngum is not shown because it began filling after 2000.

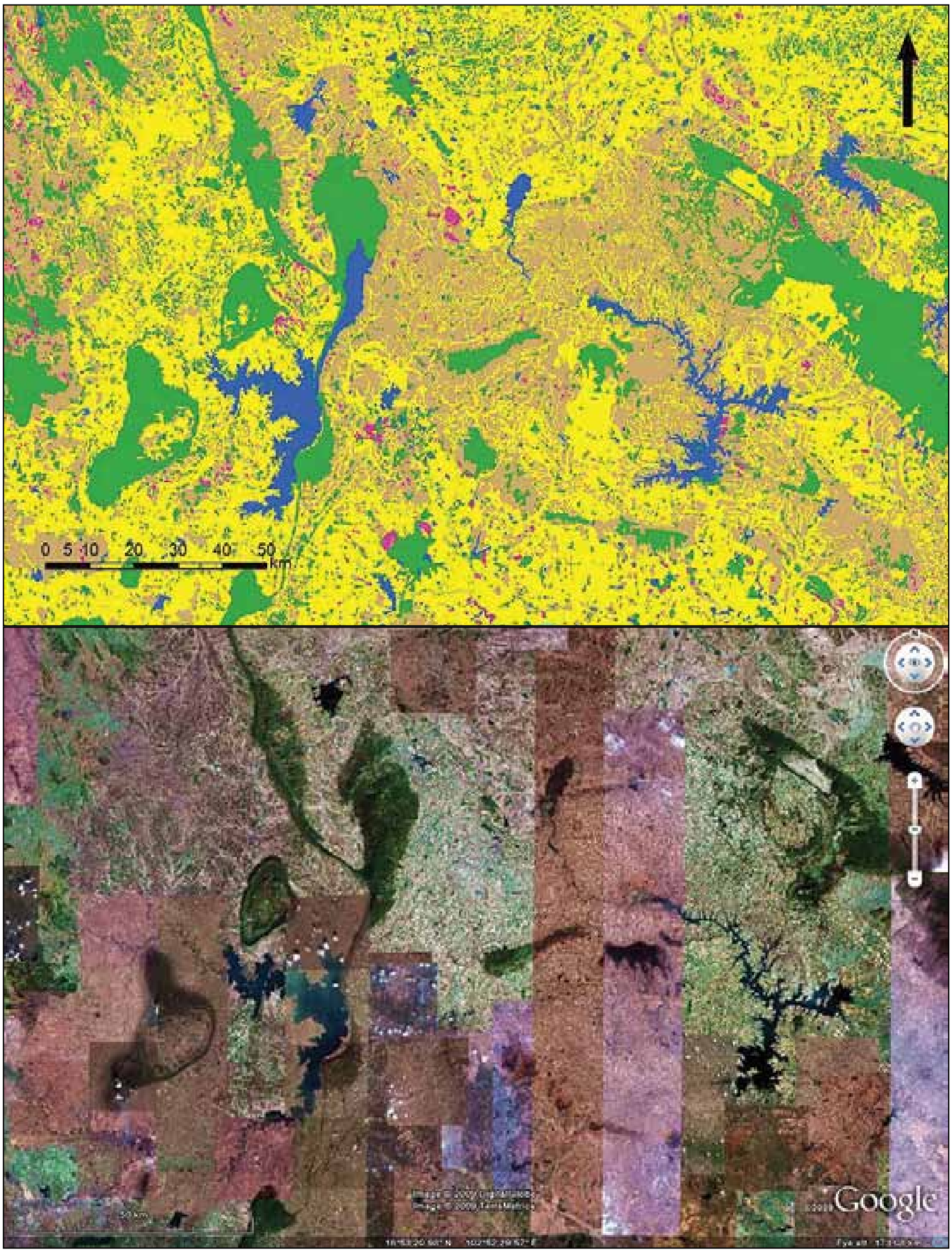

Figure A-2-2 Ubolratana Reservoir, northeast Thailand. In general, the major reservoirs are accurately digitised but part of a mountain range to the northeast of Ubolratana is incorrectly classed as part of the reservoir. The classification of rice fields, field crops and 'forest and other land' is very detailed and appears to be accurate, based on visual appraisal at higher resolutions. Few rivers or canals are shown; they are generally within the land classed as rice fields. Small urban centres are not separately digitised.

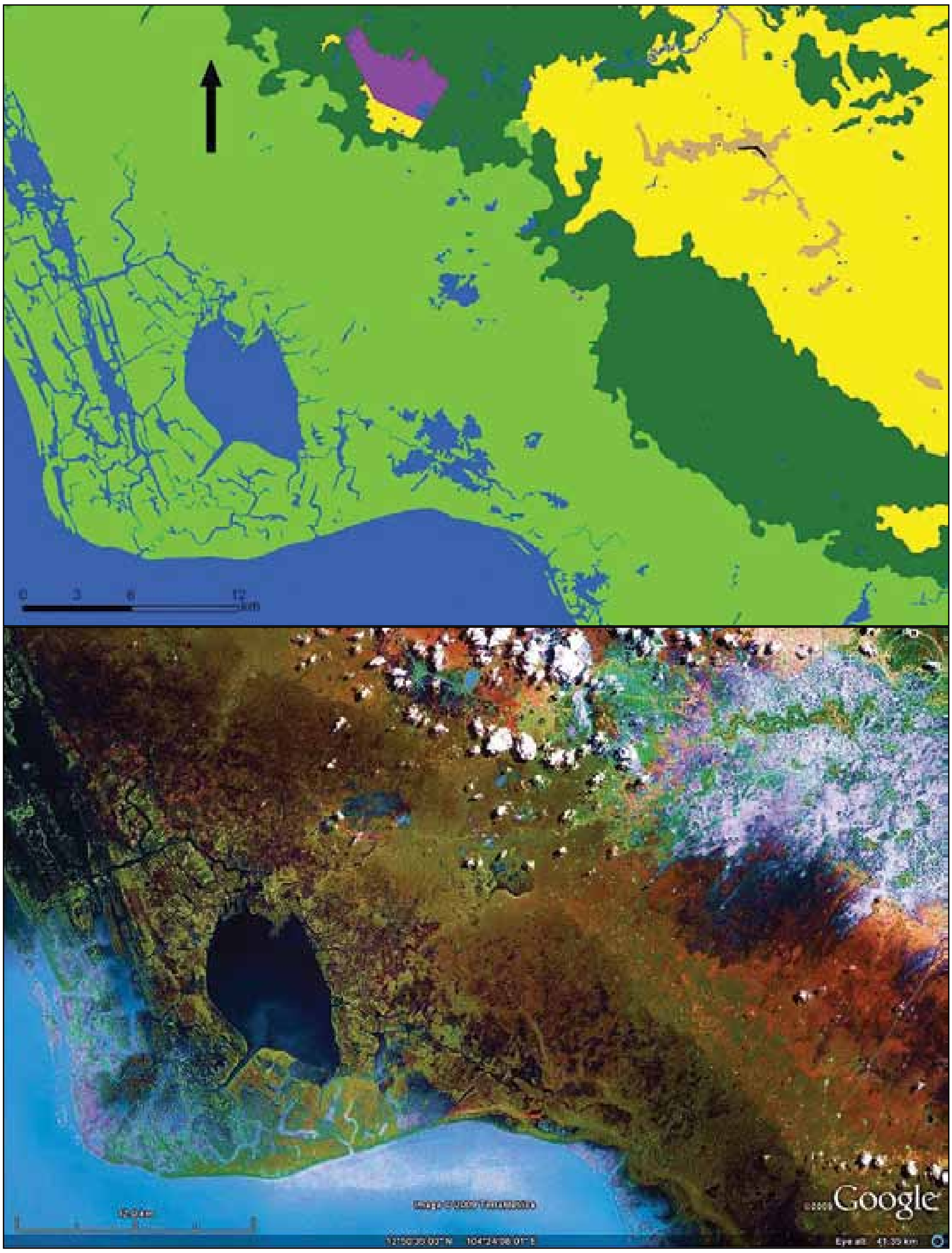

Figure A-2-3 Boeung Tonle Chhma, on the southeast side of the Tonle Sap-Great Lake. The Google Earth image shows the complexity of natural wetland habitats. The land-cover data appears to accurately follow the lake's dry-season shoreline. Most of the flood-zone wetlands are digitised and land-cover classes generally follow their appearance on the Google Earth image, except that rice fields are extending further into the forest (centre left). A swamp (upper centre) is accurately located but appears too large.

Figure A-2-4 Tra On, in the Mekong Delta in Viet Nam. The major river (Mekong) and islands are accurately digitised but many canals are not including the large canal which runs north of Tra On. The plantations of fruit trees are shown accurately on the islands but their area is overestimated along canals. The main town is shown as urban but the boundaries are not accurate and other urban areas are in linear strips along canals and are not separately digitised.

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