The role and significance of the flood pulse in the functioning and management of the Tonle Sap ecosystem, Cambodia

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27 March 2015

Presentation outline

1. The Tonle Sap ecosystem
2. The flood pulse concept
3. Evidence of Tonle Sap flood pulse
   - Water quality
   - The fish
4. Implications for management and conservation
5. Importance of Tonle Sap ecosystem
6. Threats to Tonle Sap ecosystem
7. Model for impact assessment
8. Conclusions

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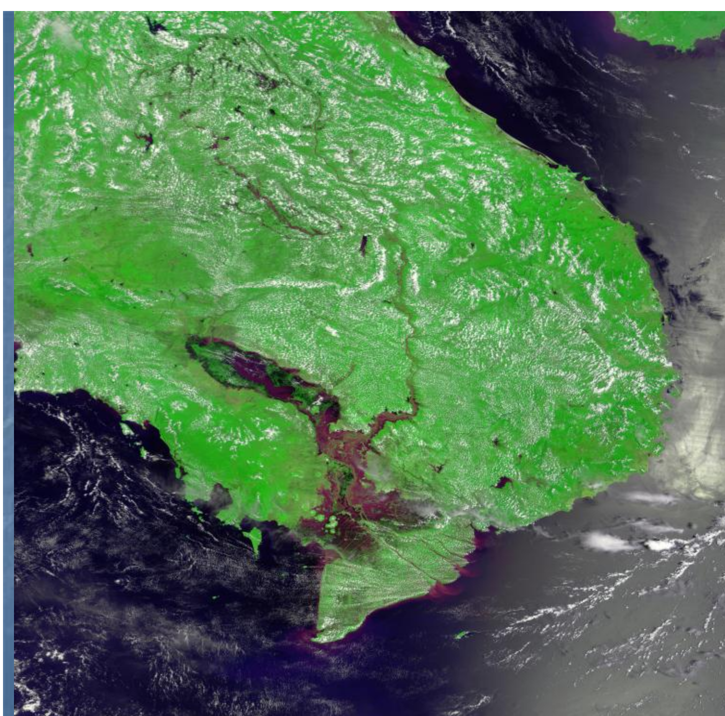

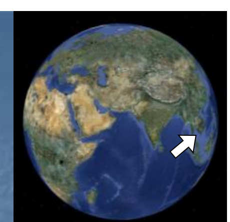

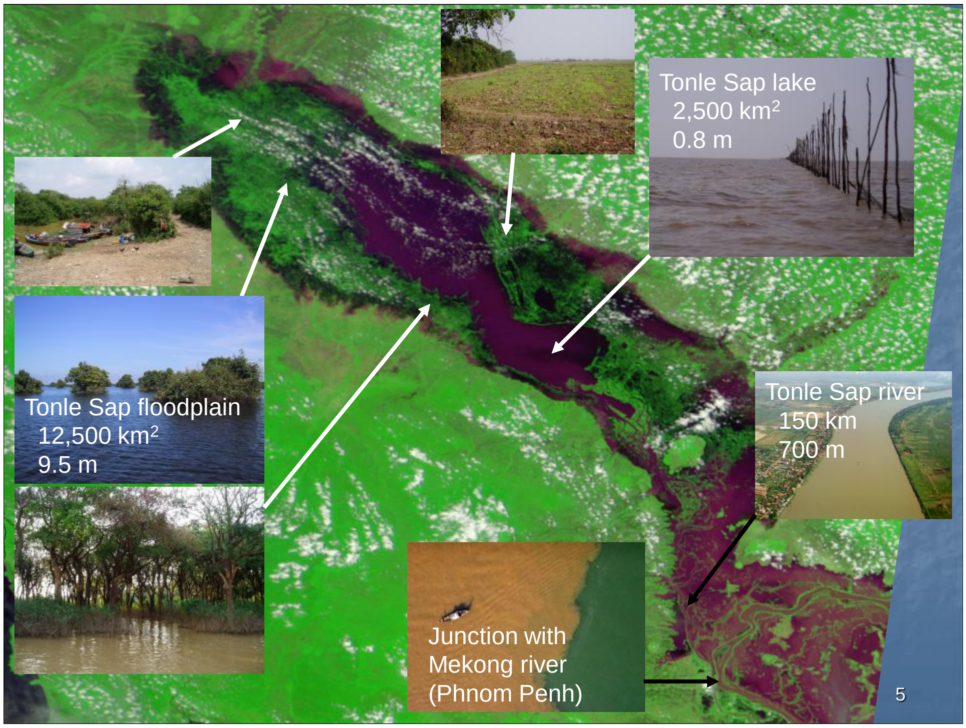
Tonle Sap lake
2,500 km²
0.8 m
Tonle Sap floodplain
12,500 km²
9.5 m
Tonle Sap river
150 km
700 m
Junction with
Mekong river
(Phnom Penh)
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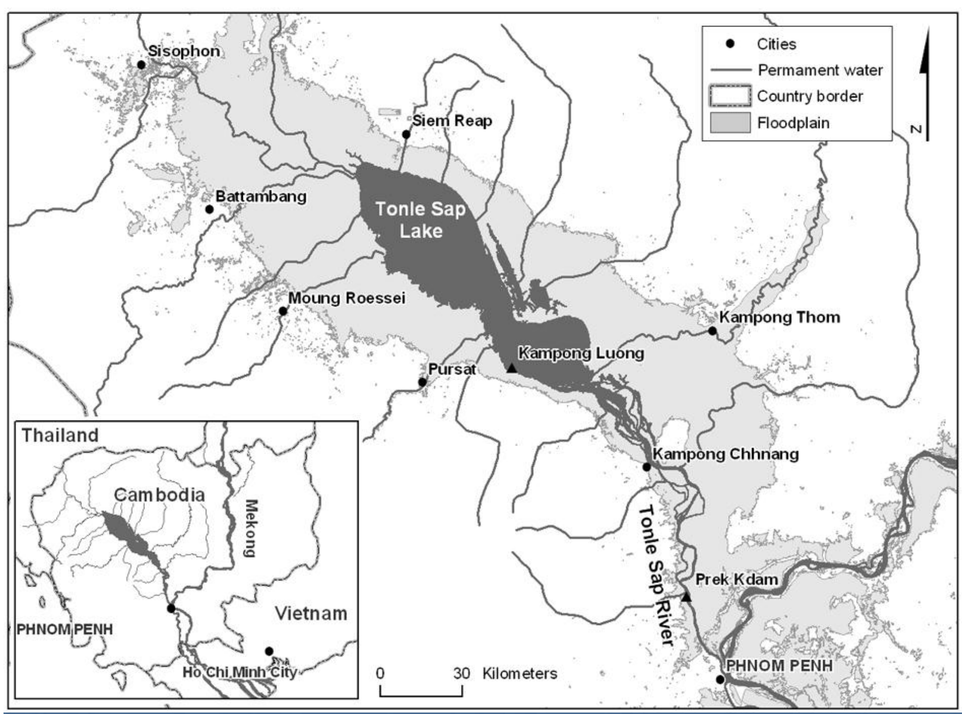
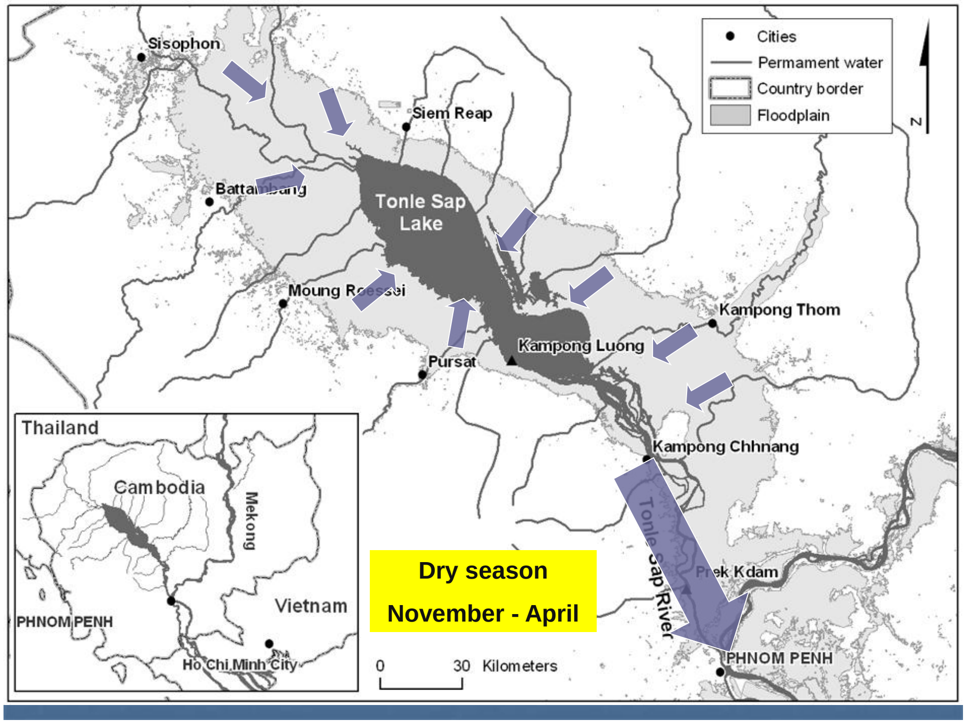

Cities
Permament water
Country border
Floodplain
N
Sisophon
Siem Reap
Battambang
Tonle Sap
Lake
Moung Roessei
Kampong Thom
Kampong Luong
Pursat
Kampong Chhnang
Tonle Sap River
Prek Kdam
PHNOM PENH
0
30 Kilometers
Thailand
Cambodia
Mekong
Vietnam
PHNOM PENH
Ho Chi Minh City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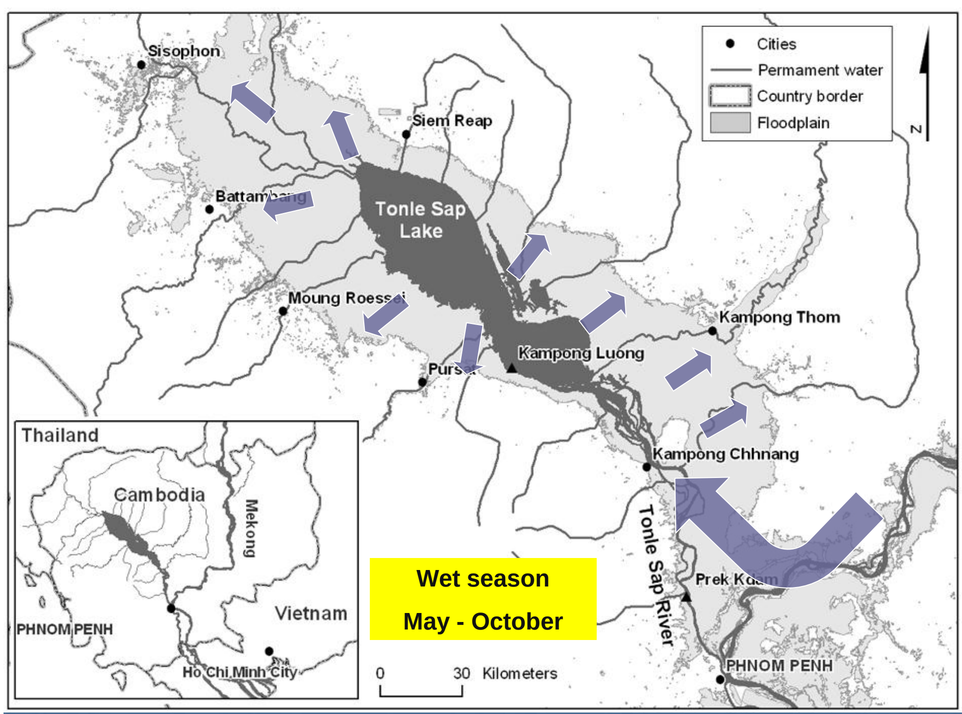
Cambodia
Mekong
Vietnam
PHNOM PENH
Ho Chi Minh City
0
30 Kilometers
Dry season
November - April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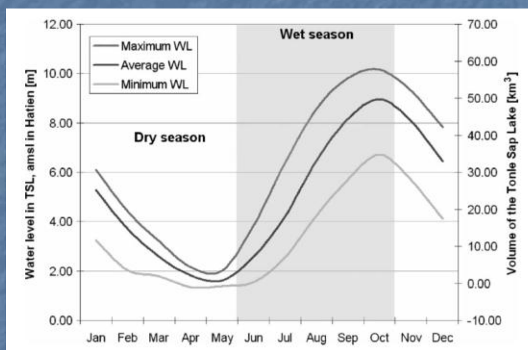
Cambodia
Mekong
Vietnam
PHNOM PENH
Ho Chi Minh City
0
30 Kilometers
Wet season
May - October

The hydrological cycle of the Tonle Sap



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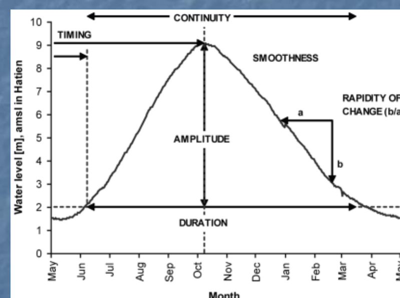
The Flood Pulse Concept

- Formulated by Junk, Bayley and Sparks in 1989
- Provides a comprehensive framework to describe the processes and dynamics of rivers and lakes with floodplains
- Thereby provides guidance for management and conservation
- A flood pulse is a regularly occurring flooding event, defined by a set of characteristics: frequency, duration, height, number of peaks etc.
- ‘Aquatic / Terrestrial Transition Zone’ (ATTZ)



Key flood pulse processes:

All occurring in the floodplain

- Sediments are deposited in floodplain during flooding
- Nutrients associated with sediments are mobilised by rooted terrestrial plants
- Terrestrial plant material, nutrients and energy, are transferred to the aquatic food webs during subsequent flooding

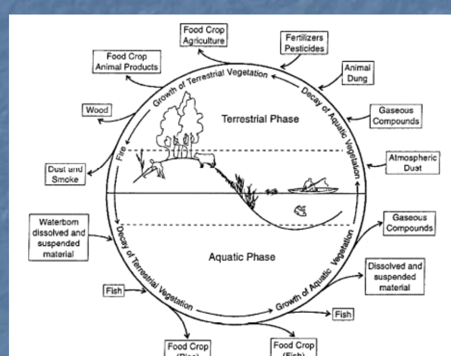


Fig. 1.2. Diagram of nutrient and energy cycles on floodplains. (Welcomme 1979, modified)

Flood-pulsed ecosystem productivity

- Combines aquatic and terrestrial production
- 2.5-4 times more productive (fish)
- Floodplain habitats creation
- Highly dynamic and stressful environment

- Flood pulse structures floodplain plant and animal communities
- Flood pulse requires adaptations
- Flood pulse provides opportunities

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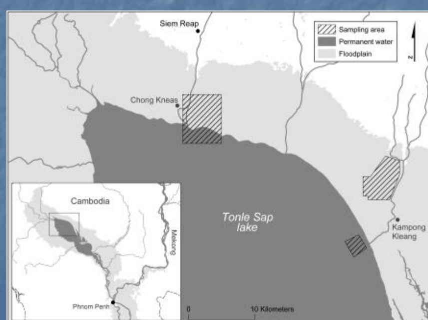
Sampling programme 1996-1997

- Two main locations in the Tonle Sap lake and floodplain
- Eight representative habitat types
- Seasonal and diurnal changes



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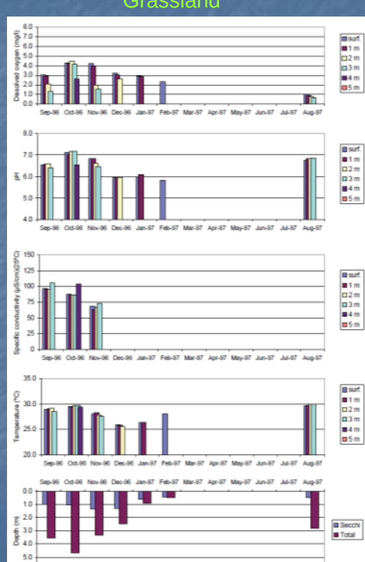
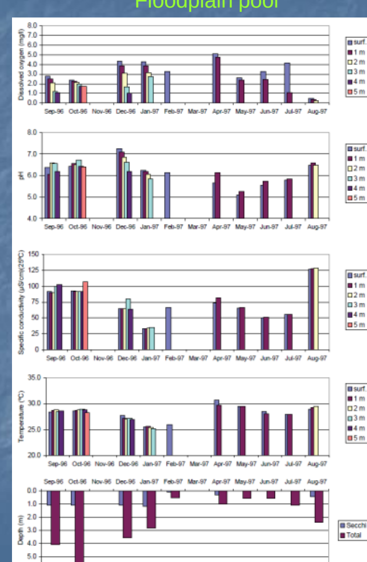
Seasonal variation in water quality

Grassland



Floodplain pool



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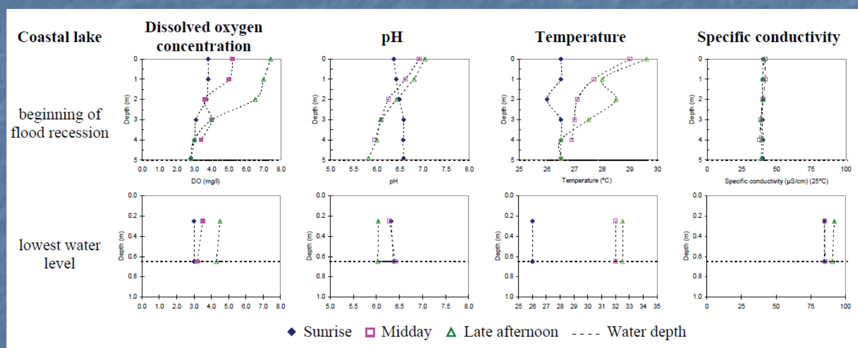
Diurnal variation in water quality



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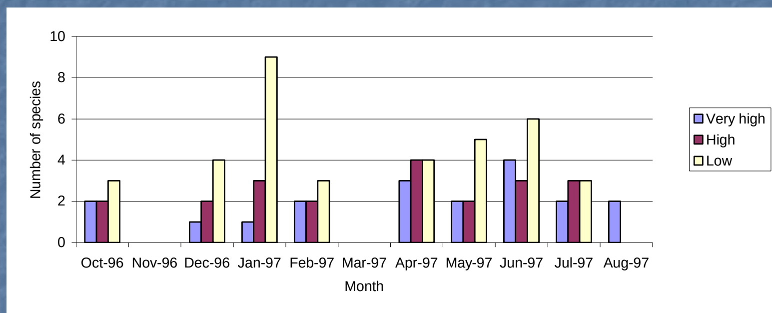
Catch composition in function of oxygen stress



Species composition (numbers) of floodplain pool catches in function of low dissolved oxygen concentrations resilience. Low: low resilience; High: high resilience; Very high: facultative air breathing

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Condition and reproduction in function of flood pulse

Henicorhynchus siamensis

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Condition and reproduction in function of flood pulse

Anematichthys apogon

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Management and conservation of flood-pulsed ecosystems

There is a solid body of evidence to support the assumption that the Tonle Sap ecosystem is a flood-pulsed ecosystem *sensu* Junk *et al*. (1989).

The productivity, integrity and diversity of flood-pulsed ecosystems are directly dependent on the flood pulse and its characteristics. As such, they are highly resilient to natural inter-annual variation but equally vulnerable to persistent changes to the hydrological cycle.

Management and conservation therefore have the greatest chance of being effective if based on a flood pulse perspective. The same applies to impact assessment.

Two examples:

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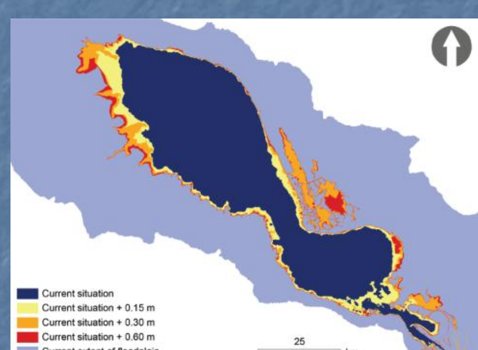
Management and conservation of flood-pulsed ecosystems

Example 1:

Small permanent rises in the dry season water level of the Tonle Sap lake would result in disproportionately large increase of the permanently flooded area, which would become unsuitable for rooted macrophytes.

A 10 cm increase would destroy 118 km^2 of the most productive floodplain vegetation.



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Management and conservation of flood-pulsed ecosystems

Example 2:
the Tonle Sap river fishery of *H. siamensis* in function of migration triggers: peak migration 3 days before full moon in December-March. If the flow direction in the Tonle Sap river has not yet reversed, this may lead to migration failure. Consequences?

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Tonle Sap is an exceptional ecosystem.

Biodiversity

- UNESCO Man and the Biosphere Reserve
- Ramsar site within its boundaries
- nine Important Bird Areas - BirdLife International
- world's largest exploitation of a single snake assemblage
- 18th largest lake on the planet
- pristine in comparison to the very few similar flood-pulsed lakes in the world:
  - lake Chad (West-Africa)
  - lake Bangweulu (Zambia)
  - lake Mweru (Zambia and Democratic Republic of Congo)
  - lake Dongting (China)
  - lake Poyang (China)
  - lake Peipus (Estonia and Russia).

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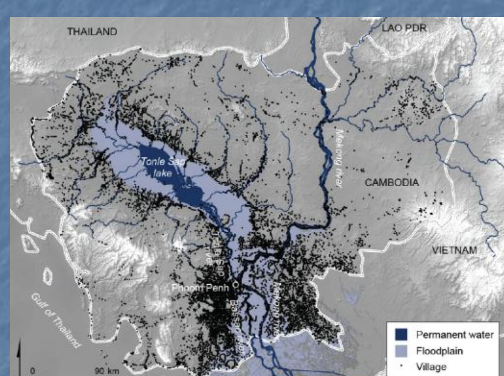
Tonle Sap is an exceptional ecosystem.

Social and economic importance

- 6 million – mostly poor – people live within 20 km from the floodplain
- food security and livelihood importance extends far beyond immediate influence zone
- importance reflected in the location of villages in Cambodia along the Tonle Sap floodplain and the rice-fertile Mekong delta
- no direct quantitative information on economic or social value



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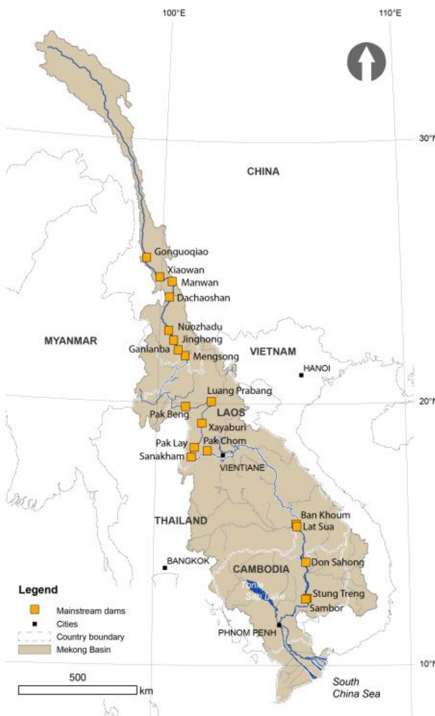

Most prominent direct threat to the integrity and productivity of the Tonle Sap ecosystem is hydropower development in the Mekong river basin. They will alter the flood pulse, trap sediments and block migration routes.

Other threats include land conversion, overfishing and the creation of obstacles to flooding.

Impact of climate change will be insignificant compared to the changes caused by hydropower development.

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A model for impact assessment

Considering
- the imminent threats to the system
- the insurmountable knowledge gaps

Modelling could be a powerful tool provided that
- it is tailored to Tonle Sap
- uses solid, relatively simple ecological concepts
- embraces the flood pulse concept
- uses data that can be easily collected
- generates outputs that are meaningful to potential information users (policy and decision makers)

An innovative four-dimensional integrated ecological-hydrodynamic model was developed in collaboration with Jorma Koponen

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A model for impact assessment

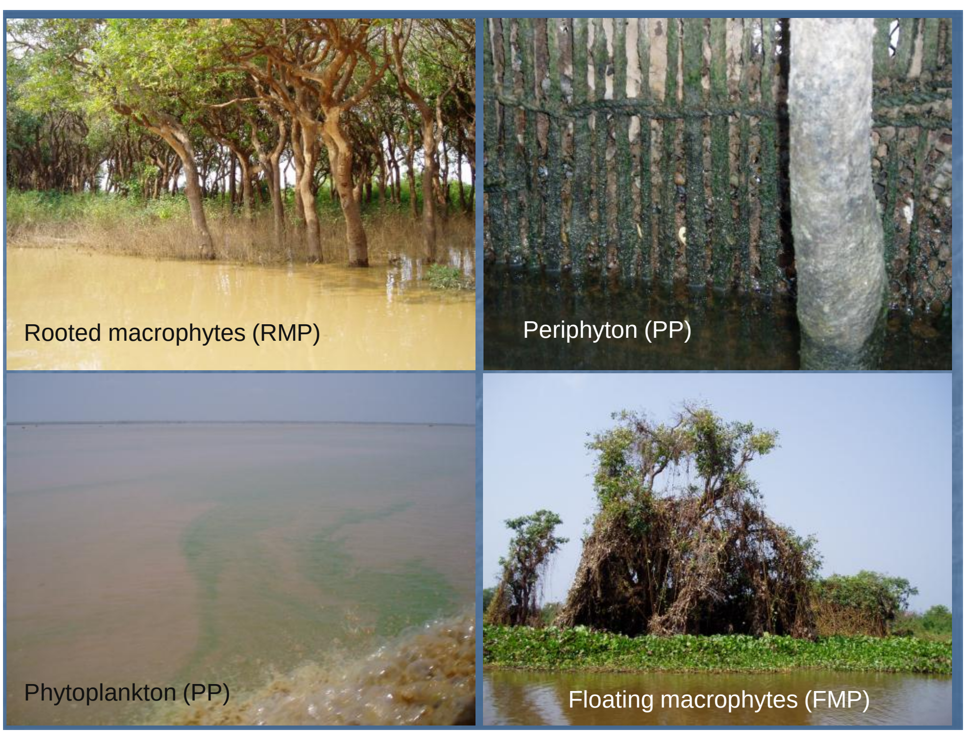
Model focus is the *production potential* of the Tonle Sap ecosystem

- its fisheries production cannot be modelled (ever)
- its primary production potential, and thereby the food base for secondary production (including fish) can be modelled

Based on hydrodynamic modelling of the euphotic volume, the primary production potential is calculated

- spatially explicit – 1 km^2 grid cells
- quantitative where possible
- qualitative where the present knowledge and data would not permit quantification or would introduce voiding uncertainties

There are 4 main primary producer groups in the Tonle Sap ecosystem:



A model for impact assessment

For each primary producer group in the Tonle Sap ecosystem, the primary production (PP) potential is calculated, for each grid cell, based on 2 kinds of factors:

Intrinsic productivity rates (PPY)
(g C / reference unit . time)

Environmental parameters:
- euphotic volume
- flooded area
- surface area index
- exposure time

No data on any PPY rates currently exist specific for Tonle Sap, but these can readily be established

A model for impact assessment

For the whole ecosystem, the Secondary Production Basis (SPB) is obtained as follows:

$$SPB = PP_{PF} + PP_{PP} + PP_{RMP}.f_T + PP_{FMP}.f'_T + OM_{EXO}$$

with f_T and f'_T transferability factors to the aquatic phase
and OM_{EXO} exogenous organic matter imported into the ecosystem

Some modelling results

Environmental factors

Table 6.2. Results of hydrodynamic modelling for current conditions and under modified flow conditions in the fictitious development scenario.

	1997		1998		2000	
Modelling outcomes	**Current**	**Scenario**	**Current**	**Scenario**	**Current**	**Scenario**
Euphotic volume.hours (km^3.h)	19,664	41,363	17,082	32,044	23,696	38,290
Floodplain area flooded (km^2)	9,901	9,153	6,618	5,646	11,258	8,848
Total number of non-flooded days area (km^2.days) in flooded floodplain*	1,826,047	1,560,344	1,196,316	571,487	1,871,811	1,033,333
Average number of dry days in flooded area	184	170	181	101	166	117
Permanent lake area (km^2)	2,499	2,519	2,483	2,504	2,503	2,517
Grid area not flooded (km^2)	38,754	39,482	42,053	43,004	37,392	39,789

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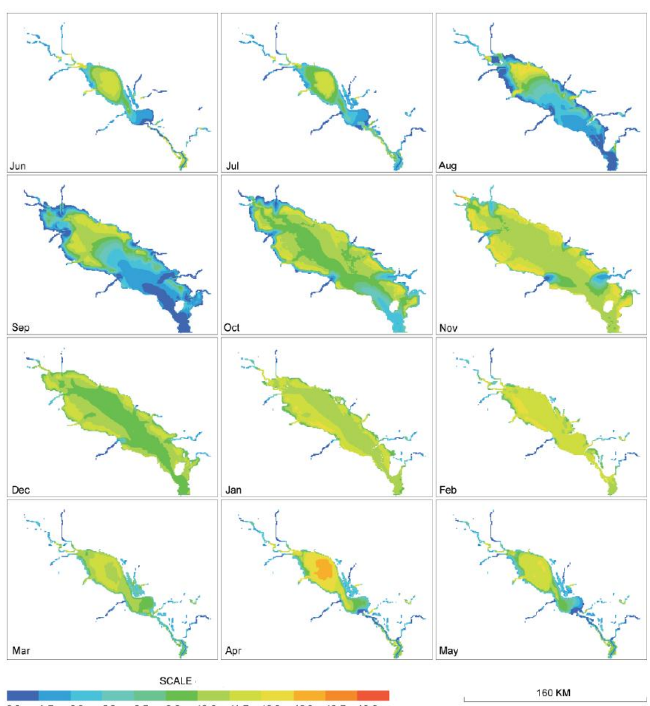
Monthly cumulative exposure time in the euphotic volume (10^{-2}.km^3.h)



Some modelling results

Production

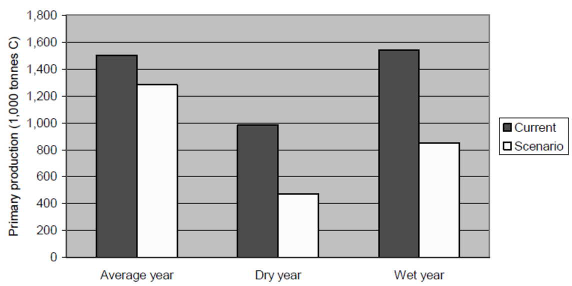
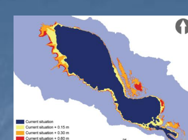


Figure 6.11. Primary production by rooted macrophytes in the flooded part of the floodplain for average, dry and wet years, current situation and scenario outcome.

Some modelling results



Production potential

Table 6.3. Primary production (biomass) by rooted macrophytes in the ecosystem in function of rising permanent water level, for a range of PPY_{RMP} values (2-12 tonnes biomass.ha^{-1}.year^{-1}).

Permanent lake level rise (cm)	RMP area loss (km^2)	PP_{RMP} (1,000 tonnes) 2	4	6	8	10	12	% PP_{RMP} loss
0	0	2,497	4,994	7,491	9,988	12,485	14,982	0.00
10	118	2,473	4,947	7,420	9,894	12,367	14,841	0.94
20	236	2,450	4,900	7,349	9,799	12,249	14,699	1.89
30	355	2,426	4,852	7,278	9,704	12,130	14,556	2.84
40	475	2,402	4,804	7,206	9,608	12,011	14,413	3.80
50	595	2,378	4,756	7,134	9,512	11,890	14,268	4.76
60	716	2,354	4,708	7,062	9,416	11,770	14,124	5.73
70	837	2,330	4,659	6,989	9,319	11,648	13,978	6.70
80	959	2,305	4,610	6,916	9,221	11,526	13,831	7.68
90	1,082	2,281	4,561	6,842	9,123	11,404	13,684	8.66

Model animations - Tonle Sap flow and water depth

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Conclusions

1. The Tonle Sap ecosystem is a flood-pulsed (*sensu* Junk *et al*.) lake-river based ecosystem.
2. Management and conservation of Tonle Sap ecosystem should be from a flood pulse perspective to be effective.
3. Flow alterations of the Mekong river have the potential to significantly erode the production basis for the Tonle Sap ecosystem.
4. Even in extremely data deficient systems, tailored modelling can generate essential management insights.
5. The prospects are bleak.
6. There is an extraordinarily high potential to rapidly fill major knowledge gaps.

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