The Mekong River Commission

THE COUNCIL STUDY

STUDY ON THE SUSTAINABLE MANAGEMENT AND DEVELOPMENT OF THE MEKONG RIVER, INCLUDING IMPACTS OF MAINSTREAM HYDROPOWER PROJECTS

Biological Resource Assessment

Interim Technical Report 1

Volume 3: PRELIMINARY CALIBRATION REPORT

DRAFT I

December 2015

Contents

List of Figures

List of Tables

Acronyms and abbreviations

BDP	Basin Development Plan
BioRA	Biological Resource Assessment
CS	Calibration Scenario
DRIFT	Downstream Response to Imposed Flow Transformations
DSF	Decision Support Framework
DSMP	Discharge and Sediment Monitoring Project, coordinated by the MRC IKMP
DSS	Decision Support System
FA	Focus Area
HPP	Hydropower Plant
IBFM	Integrated Basin Flow Management
IKMP	Information and Knowledge Management Programme
ISIS	Hydrology, Hydaulics and Water Quality Modelling Programme
IUCN	International Union for Conservation of Nature
KCW	Knowledge Capture Workshop
LMB	Lower Mekong Basin
mamsl	metres above mean sea level
NMCs	National Member Countries
MRC	Mekong River Commission
MRCS	Mekong River Commission Secretariat
NB	*Nota bene* (note well)
OSP	Office of the Secretariat_Phnom Penh
OSV	Office of the Secretariat_Vientiane
PDR	People's Democratic Republic
Q	Discharge (m^3/s)
RC	Response Curve
RTWG	Regional Technical Working Group
SEA	Strategic Environmental Assessment
UMB	Upper Mekong Basin
WQ	Water Quality
WQMN	Water Quality Monitoring Network (The MRC-coordinated monthly monitoring program)
WUP-FIN	Water Utilisation Programme – Finland

1 Introduction

The Mekong River is the world's 12th longest river and the longest in south-eastern Asia, with an estimated length of 4 350 km. The river rises in the high plateau of Eastern Tibet and flows in a south-east direction through China, Myanmar, Lao PDR, Thailand, Cambodia and Viet Nam. It drains an area of 795 000 km², and discharges c. 457 km³ of water annually into the sea south-west of Ho Chi Minh City.

The Lower Mekong River (Figure 1.1) is about 3000 km long from the border between Lao PDR and Myanmar to the sea, and includes the Tonle Sap System and the Mekong Delta in southern Viet Nam. These two systems are unique features of the Lower Mekong Basin (LMB), which affect both how the system functions and how people depend on it. The Tonle Sap Great Lake is a shallow lake in western Cambodia that links to the Mekong River via the 150-km long Tonle Sap River. During the wet monsoon season of June to November, the high waters of the Mekong River reverse the flow of the Tonle Sap River and increase the size of the lake from 2 600 to 10 400 km^2. When the high waters of the Mekong River recede, the flow in the Tonle Sap River reverses again and drains the lake. This natural mechanism provides a unique and important balance to the Mekong River and ensures a flow of fresh water during the dry season into the Delta, which buffers the intrusion of salt water into the rich agricultural lands of the Delta (MRC 2006).

Kratie is generally regarded as the point in the Mekong system where the hydrology and hydrodynamics of the river change significantly. Upstream of this point, the river generally flows within a clearly identifiable mainstream channel. In all but the most extreme flood years, this channel contains the full discharge with only local over-bank natural storage. Downstream from Kratie, seasonal floodplain storage dominates the annual regime and there is considerable movement of water between channels and floodplains, the seasonal refilling of the Great Lake and the flow reversal in the Tonle Sap. There is extreme hydrodynamic complexity in both time and space and it becomes impossible to measure channel discharge. Water levels, not flow rates and volumes, determine the movement of water across the landscape, although water level is driven by discharge and volume.

Since its establishment in 1995, the Mekong River Commission (MRC) has been involved in the collection of data and the development of models, both conceptual and mathematical, aimed at improving and demonstrating the understanding of the functioning of the LMB aquatic ecosystems, and the links between the people and the river. The result is an enormous body of data, understanding of life-histories and system functioning, and resources such as maps and mathematical models.

The MRC has used these data and models to aid decision-making in the region as it pertains to the LMB through the analysis of possible changes to river resources, and knock-on effects on the people that depend on them, in response to actual and proposed water-resource developments in the basin at large. Studies that have addressed this include

- Integrated Basin Flow Management (IBFM; 2004-2006; MRCS 2006)
- Basin Development Plan (BDP; 2004-ongoing; MRC 2011)
- SEA (ICEM 2010).

Apart from IBFM, which was terminated before a planned 4th phase, the abovementioned studies did not include a systemic and systematic assessment of the impacts of developments on the river ecosystem or ecosystem services.

Figure 1.1 The Lower Mekong River Basin

This lack was identified as a data gap, *inter alia*, in the recent revision of the Basin Development Plan. Subsequently, at the 18th Council Meeting of the MRC[1], the National Member Countries' (NMCs) Prime Ministers agreed in principle to implement a study on sustainable management and development of the Mekong River including impact of mainstream hydropower projects, which addressed some of the existing data gaps. This agreement led to "The Council Study".

1.1 The Council Study

1.1.1 Aims

The Council Study focuses on sustainable management and development of the LMB[2]. It aims to address uncertainties in assessing the impact of different development opportunities in the Mekong River Basin and to provide recommendations to facilitate informed development planning in the mainstream of the LMB.

The developments opportunities to be analysed may be located on the mainstream Mekong River or in any of the tributaries in the LMB. The analysis of impacts of these on the river ecosystem and people will be limited to the mainstream Mekong and Tonle Sap Rivers, Tonle Sap Great Lake and the Mekong Delta.

The stated objectives of the Council Study are to:

- further develop a reliable scientific evidence of positive and negative environmental, social, and economic impacts of water resources developments;
- integrate the results into the MRC knowledge base to enhance the BDP process, and;
- promote capacity and ensure technology transfer to NMCs.

1.1.2 Organisation

The overall unified assessment framework of the Council Study is illustrated in Figure 1.2. The framework requires closely coordinating the activities of the various Thematic and Discipline Teams and successfully coordinating the technical inputs and integrating their outputs and deliverables. The Council Study is composed of six (6) Thematic Teams representing each development thematic area or sector, a cumulative assessment team, and five (5) cross-cutting Discipline Teams.

The Council Study major activities will be accomplished in the following general sequence.

Each Thematic Team formulates the water-resource development scenarios for each Thematic Area (Irrigation, Agriculture/Land Use, Hydropower, Flood Protection and Floodplain Management, Domestic and Industrial Water Use, and Navigation).

The Cumulative Assessment Team formulates the cumulative development scenarios in conjunction with the various Thematic Teams.

1 Held in Bali, Indonesia, November 2011
2 Impact area is Mekong Mainstream including a 15-km corridor area on both sides of the river and the Tonle Sap Great Lake and Delta floodplains.

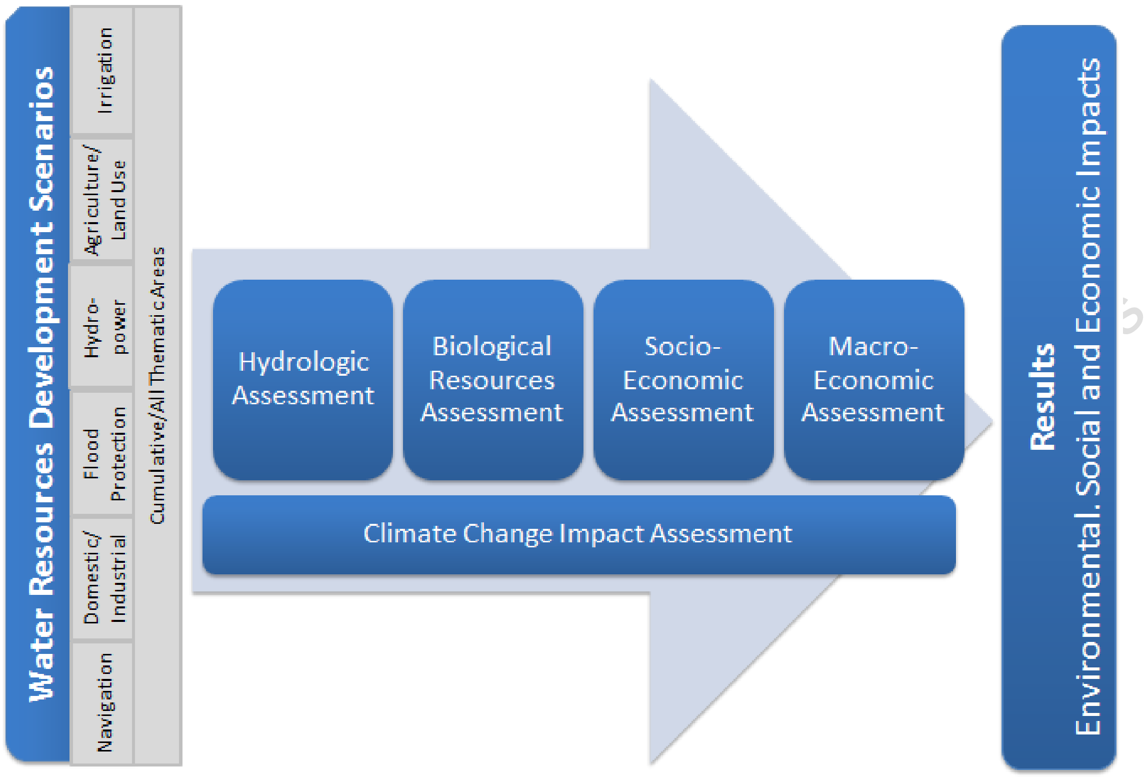


Figure 1.2 Council Study Assessment Framework

The Hydrologic Discipline Team through the use primarily of the MRC Decision Support Framework (DSF) and Water Utilisation Program (WUP-FIN) models assesses the changes in flow, sediment transport, and water quality as a result of the developments under reference and development scenarios.

The Biological Resource Discipline Team through the use of DRIFT assesses corresponding changes in the habitat, biodiversity, and other selected environmental indicators as a result of changes in flow, sediment transport, and water quality.

The Socio-Economic Discipline Team assesses corresponding changes in selected socio-economic indicators (i.e., livelihood, public health, and nutrition among others) as a result of changes in flow, sediment transport, water quality, and ecosystem.

The Macro-Economic Discipline Team assesses the macro-economic impact (including distributional analysis of benefits and costs amongst communities, livelihoods, countries, and people of different socio-economic strata) of the changes in flow, sediment transport, water quality, and ecosystem.

The Climate Change Discipline Team provides technical support to the Discipline Teams to account for climate change impacts.

The Thematic and Discipline Teams and the Cumulative Assessment Team in collaboration prepare reports to document the environmental and socio-economic impacts of developments under the six

(6) thematic areas or sectors separately and cumulatively, including recommendations on how to address the impacts, both in terms of generating new opportunities as well as prevention, mitigation or compensation options.

1.2 The Biological Resources Assessment

The objective of the Biological Resources Assessment (BioRA) is to provide clear and comparable information on the impacts of proposed thematic developments on the aquatic resources of Mekong River downstream of the China border, inclusive of the Tonle Sap Great Lake and the Mekong Delta.

The BioRA is under the management of the Fisheries Programme, MRCS, under the leadership of Dr So Nam.

Within BioRA, the DRIFT method (Brown *et al*. 2013) is being used to organise existing MRC data, information in the international scientific literature and expert opinion to provide a systemic and systematic picture for the LMB, Tonle Sap River, Tonle Sap Great Lake and the Mekong Delta ecosystems in terms of:

- their reference ecological integrity (health);
- possible future changes in integrity, as described through the evaluation of the water-resource development scenarios for each representative zone/site/area;
- predictions of change in abundance/area/concentration (relative to reference) for a wide range of ecosystem indicators.

The DRIFT process, as it is applied in BioRA, is discussed in various related BioRA documentation.

1.2.1 The BioRA process

The steps in the BioRA process are illustrated in Figure 1.3.

1.2.1.1 Step 1: Scenarios

In the Council Study, the scenarios will describe a range of potential water-resource developments in the Mekong Basin. Although the scenarios themselves are an integral part of the DRIFT process, scenario selection is not being undertaken by the BioRA Team. Several discussions have taken place with respect to the scenarios that will be developed. Currently, the NMCs have approved the concept of constructing Cumulative Scenarios to represent (RTWG4 Minutes):

- Early Development (up to 2007)
- Definite Future Development (up to 2020)
- Planned Development (up to 2040) combined with 2-3 climate change scenarios.

Following evaluation of these scenarios, then there may be additional Thematic Scenarios developed, such as:

- Exploratory Scenarios
- Alternative Plan Scenarios.

For these scenarios, change will be described relative to a Reference Scenario 2007, which was agreed by the NMCs in November 2015 (Small Technical Working Group Meeting; 12 November 2015; OSV, Vientiane, Lao PDR).

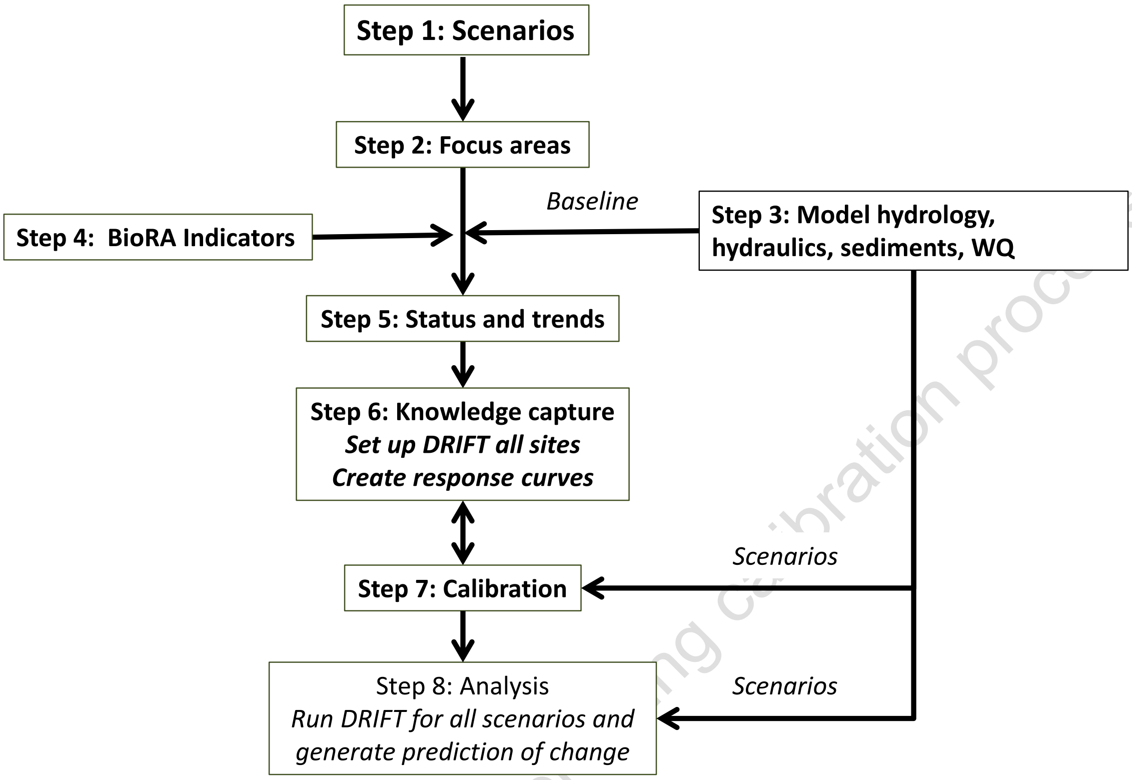


Figure 1.3 The steps in the BioRA process

1.2.1.2 Step 2: Focus areas

See Section 2.

1.2.1.3 Step 3: Model hydrology, hydraulics, sediments, WQ

Model hydrology, hydraulics, sediments and water quality, is the responsibility of the Hydrologic Assessment Group under the leadership of the Information and Knowledge Management Programme (IKMP). The modelling is being done using the MRC DSF, plus allied models such as the WUP-FIN suite of models.

For BioRA hydrology, hydraulics, sediments and water quality data are required for each focus area for reference and each scenario to be assessed. The basic requirement for DRIFT is to obtain daily (or, in the case of hydropower plant (HPP) schemes that generate power at peak times each day, sub-daily) sequences for a consecutive run of as many years as possible.

The first time-series required are continuous records of reference flows for each focus area over the agreed hydrological period. Thereafter, two other sets of simulated time series over the same period are needed:

- a series of 'calibration' scenarios that represent extreme period (floods and droughts) for the system (see Section 4.3);
- any chosen water-resource development scenarios.

The hydrological, hydraulic and proposed water quality modelling underpinning the Council Study is described in detail in Draft Working Paper: Council Study Impact Modelling (April 2015.)

1.2.1.4 Step 4: Select DRIFT indicators

The specialist team proposes indicators that represent each of the disciplines included in the assessment.

The indicators used in BioRA are described and reasons for their selection provided in the BioRA Interim Technical Report: Specialists' Report. See also Section 3.

1.2.1.5 Step 5: Status and trends

The objective of the status and trends assessments is to:

- describe the present ecological status of the Lower Mekong River;
- describe the past ecological status of the Lower Mekong River – both as a reference point from which to make predictions and to establish trends that can be used later on in the analyses;
- describe the future ecological status of the Lower Mekong River in the absence of the water-resource developments included in scenarios (these are referred to as exogenous baselines; see MRC 2015).

The results of the Status and Trends Assessment are provided in the BioRA Interim Technical Report: Specialists' Report.

1.2.1.6 Step 6: Knowledge Capture

In Knowledge Capture, the specialist teams will construct a response curve for each of the links delineated for each indicator using the DRIFT software. To do this, the data collected and the understanding developed by MRC and other organisations over the last two decades will be augmented with life-history information for key species, expert opinion and will be underpinned by the hydrological, hydraulic, sediment and water quality modelling by IKMP. The bulk of the response curve construction was done at the Knowledge Capture Workshop (KCW; Appendix B, this report).

1.2.1.7 Step 7: Calibration

In calibration the aim is to match DRIFT outputs with measured data and/or local knowledge. To facilitate this process, as series of calibration data sets are prepared for use. Typically these include representatives of period of extreme floods or drought. The bulk of the calibration was done in a workshop attended by the full team of BioRA specialists (Appendix B; this report).

1.2.1.8 Step 8: Analysis

Using the modelled times series of changes in flow, sediment and water quality for each of the development scenarios, DRIFT describes the present situation in terms of the flow regime and the river ecosystem and predicts how these could change with the presence of the proposed developments and the expected changes in flow, sediment and water quality.

The present and future situations are described using flow and ecosystem indicators developed in Step 4, each of which has some relationship to the flow and sediment regime of the river (although this might be indirectly through another indicator).

For each scenario, the predicted changes in the river represented are provided as:

1. estimated mean percentage change from Preliminary Reference in the abundance or area key indicators;
2. time-series of abundance, area or concentration of key indicators under the flow regime resulting from each scenario;
3. Overall Ecosystem Integrity (ecosystem condition).

The outputs for individual indicators will be combined to create the composite indicators in the MRC Indicator Framework.

1.2.2 Variations in the BioRA process

The BioRA discipline team was one of the first full teams appointed in the Council Study. Initially it was intended that BioRA take 16-18 months, with a target completion date of 29 February 2016. To accomplish this, the BioRA DSS would have needed to be populated and calibrated, and ready for scenario evaluation, by mid-December 2015. From the outset it was recognised that the nature of the work and its deliverables were dependent on the input data generated by the thematic and other discipline teams, and agreed that the original BioRA timelines would be followed as far as was possible and thereafter adjusted to accommodate the different start dates of the other Council Study teams.

In the event, there were two main obstacles to the BioRA DSS being populated and calibrated, and ready for scenario evaluation by mid-December 2015, both of which were linked to later starts of other teams and processes. These were:

- lack of clarity on the Reference Scenario;
- deferment of the approval of the modelling approach to be used by IKMP, and hence in the appointment of additional modellers to assist with the modelling.

The first of these, lack of clarity on the Reference Scenario, meant that the set-up, population and calibration of the DSS done to date had to use a Preliminary Reference Scenario. The Reference Scenario was subsequently identified as Reference Scenario 2007 in November 2015 (Small Technical Working Group Meeting; 12 November 2015; OSV, Vientiane, Lao PDR), which meant that the hydrological data used for the Preliminary Reference Scenario are in fact identical to those for Reference Scenario 2007.

The second of these had several implications for BioRA:

1. No modelled sediment and water quality time-series were available, and the Preliminary Reference Scenario data set relied on measured data for these parameters (see Section 4.2.3).
2. The data for Tonle Sap Great Lake were delayed and only became available after the KCW, which meant that the response curves were populated remotely rather than at the KCW, and as a result calibration is still incomplete.
3. Model outputs for the Delta are only expected in early 2016, and so the Delta is not yet included in the DSS.

Consequently:

- the BioRA DSS has been populated and partially calibrated for FA1 – FA7 (see Section 2);
- these will be completed in 2016 when the model outputs become available;
- the DSS may need to be recalibrated once the sediment and water quality modelling outputs for Reference Scenario 2007 become available.

Thus, although considerable progress has been made, the BioRA DSS cannot yet ready be used to evaluate of the Council Study Cumulative and Thematic Scenarios.

1.2.3 The BioRA team

1.2.3.1 Management and DRIFT DSS

The BioRA management team members are listed in Table 1.1.

Table 1.1 BioRA management team

Role	Name
BioRA Lead/MRC-FP Programme Coordinator	Dr So Nam
Council Study Coordinator	Dr Henry Manguerra
Council Study Adviser	Dr Vitoon Viriyasakultorn
BioRA Team Technical Lead	Prof. Cate Brown
DRIFT DSS Manager	Dr Alison Joubert
Council Study Administrative Assistant	Ms Manothone Vorabouth
MRC-FP International Technical Adviser	Mr. Peter Degen
MRC-FP Capture Fisheries Specialist	Mr. Ngor Peng Bun

1.2.3.2 BioRA lead specialists

The lead specialists on the BioRA team are listed in Table 1.2.

Table 1.2 BioRA lead specialists

Discipline	Name	Country
Geomorphology and Water Quality Lead Specialist	Dr Lois Koehnken	Australia/USA
Tonle Sap Processes Specialist	Dr Dirk Lamberts	Belgium
Vegetation Lead Specialist	Dr Andrew MacDonald	USA
Delta Macrophyte Specialist	Dr Nguyen Thi Ngoc Anh	Viet Nam
Delta Microalgae Specialist	Duong Thi Hoang Oanh	Viet Nam
Macroinvertebrate Lead Specialist	Dr Ian Campbell	Australia
Fish Lead Specialist	Prof. Ian Cowx	England
Fish Delta Specialist	Dr Kenzo Utsugi	Japan
MRC Fish Specialist	Dr Chavalit Vidthayanon	Thailand
MRC Fish Specialist	Mr Ngor Peng Bun	Cambodia
Herpetology Lead Specialist	Dr Hoang Minh Duc	Viet Nam
Bird and Mammal Lead Specialist	Anthony Stones	England

1.2.3.3 BioRA national specialists

The incorporation of the national specialists in the BioRA Team serves four main purposes:

1. to source in-country information, and ensure its consideration in BioRA;
2. to bring additional first-hand knowledge of the ecosystems into the assessments;
3. to contribute towards development of the relationships (response curves) developed for indicators and in so doing provide Member Country review of the thinking under-pinning the assessment;
4. to address one of the main objectives for the Council Study, viz. promote capacity and ensure technology transfer to NMCs.

The national specialists assigned to the BioRA team are listed in Table 1.3. The selection of candidates was based on short-lists provided by the NMCs.

Table 1.3 BioRA national specialists

Country	Name	Discipline
Cambodia	Geomorphology	Toch Sophon
	Biodiversity, excl. fish	Pich Sereywath
	Fish	Dr Chea Tharith
Lao PDR	Geomorphology	Dr Bounheng Soutichak
	Vegetation	Thananh Khotpathoom
	Fauna, excl. fish	Dr Phaivanh Phiapalath
	Fish	Dr Kaviphone Phouthavong
Thailand	Geomorphology	Dr Idsariya Wudtisin
	Fish	Chaiwut Grudpun
Viet Nam	Biodiversity, excl. fish	Dr Luu Hong Truong
	Fish	Vu Vi An

1.3 Purpose of this document

This document is part of Deliverable 5 of BioRA (Table 1.4). It is Interim Technical Report 1: Volume 3 - Preliminary Calibration Report.

This report describes the data used for the preliminary calibration scenarios and presents the results obtained, with explanations. It is intended to serve two main purposes:

1. To show the format of the standard DRIFT DSS results as a basis for discussion on the preferred format of BioRA results.
2. To illustrate how the DSS reacts to hypothetical scenarios in order to facilitate review and testing of outcomes prior to evaluation of the Council Study cumulative and thematic scenarios (Minutes of RTWG 5).

As discussed in Section 1.2.2, Interim Technical Report 1 excludes BioRA FA4, 6 and 8.

Volume 3 should be read in tandem with:

- Volume 1 - The Specialists' Report, which provides the information underlying the Response Curves, and other information, used in the DSS.
- Volume 2 - Guide to viewing and updating the BioRA DSS.

Please note: This is a discussion document. Calibration of the DSS is not complete. This document in itself represents a vital resource in the final process of calibration, as it is the first time all the results have been documented for analysis and revision, and the response curves will more than likely be adjusted on the basis of some of the data presented here. The idea is to check and recheck the outputs of the DSS using hypothetical calibration scenarios, and through this process to reach agreement that the DSS predictions for these are reasonable and, more importantly, explainable before using it to make predictions for the Council Study cumulative and thematic development scenarios.

Table 1.4 BioRA deliverables

No.	Deliverables	Date completed
1	Presentations for a day-long session on DRIFT, plus an overview of available EF methods	November 2014
2	Progress Report: Indicator and Site Selection and Field Visit Report	April 2015
3	Progress Report: DSS Set-up Report	July 2015
4	Interim Technical Report 1: Volume 1 - Specialists' Report (preliminary calibration version)	December 2015
5a	Interim Technical Report 1: Volume 2 - Guide to viewing and updating the BioRA DSS (preliminary calibration version)	December 2015
	Interim Technical Report 1: Volume 3 - Preliminary Calibration Report	
5b	Populated and calibrated DRIFT DSS - *including* the Mekong Delta	
	Final Technical Report 1: Guide to viewing and updating the BioRA DSS	
	Final Technical Report 2: Specialists' Report	
6	Final Technical Report 3: Results for the cumulative and thematic scenarios	

2 BioRA focus areas

The BioRA focus areas are shown in Figure 2.1 and listed in Table 2.1. Details are provided in Progress Report 1: Indicators and focus areas.

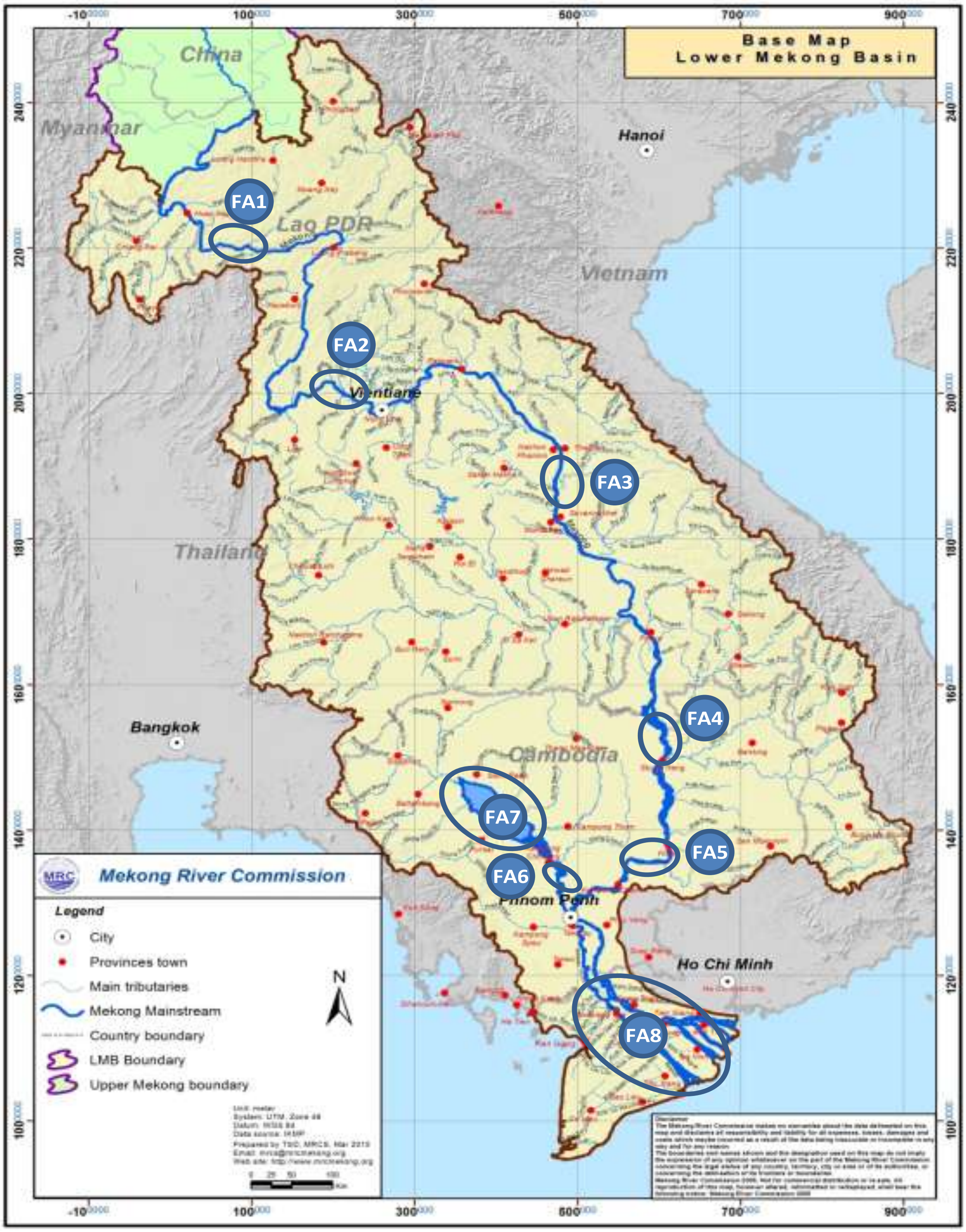


Figure 2.1 Preliminary BioRA focus areas

Table 2.1 Preliminary BioRA focus areas

Name	Description	Approximate coordinates	
		Upstream	Downstream
BioRA FA1	Mekong River upstream of Pak Beng	19°51'31.9" N 101°4'46.78" E	19°52'21.61" N 101°5'58.74"
BioRA FA2	Mekong River upstream of Vientiane	18°12'28.48" N 102°7'33.74" E	17°58'50.38" N 102°25'38.71"
BioRA FA3	Mekong River upstream of Se Bang Fai	17°12'23.87" N 104°48'21.92" E	16°49'14.27" N 104°44'47.51"
BioRA FA4	Mekong River upstream of Stung Treng	13°33'42.98" N 105°58'18.55" E	13°31'45.12" N 105°56'14.39"
BioRA FA5	Mekong River upstream of Kampong Cham	12°17'52.84" N 105°35'33.4" E	12°12'44.5" N 105°32'14.93"
BioRA FA6	Tonle Sap River at Prek Kdam	11°52'43.46" N 104°46'57.76" E	11°44'47.26" N 104°49'54.37"
BioRA FA7	Tonle Sap Great Lake	12°52'2.35" N[3] 104°5'1.18" E	
BioRA FA8	Mekong Delta	10°54'37.94" N 105°11'17.95" E	Coast[4]

3 Point in the lake.
4 There are nine distributary channels. Bassac arm: 9º34'14.70"N; 106º18'33.24"E.

3 BioRA indicators

The process for deciding on BioRA indicators is covered in Progress Report 1: Indicators and Focus Sites, and in Progress Report 2: DSS Set-up, and the supporting reasoning for the indicators chosen and their links is provided for each discipline in the Interim Technical Report 1: Volume 1 - Specialists' Report.

The BioRA indicators are provided as follows:

- modelled time-series indicators (Table 3.1);
- ecosystem indicators (Table 3.2).

Sixty six indicators were used in DRIFT, i.e., excluding those indicators generated by DSF.

Table 3.1 BioRA modelled time series indicators

Code	Indicator					
Hydrology						
MAR	All	Mean annual runoff				
Do	Dry season	Onset				
Dd		Duration				
Dq		Minimum 5-day discharge				
Ddv		Average daily volume				
DRange		Within-day range in discharge				
T1dv	Transition season 1	Average daily volume				
QmxiT1		Maximum instantaneous discharge				
dQiT1		Maximum rate of change in discharge				
T1Range		Within-day range in discharge				
Fo	Wet/flood season	Onset				
Fd		Duration				
Fq		Maximum 5-day discharge				
Fdv		Average daily volume				
Fv		Flood volume				
WRange		Within-day range in discharge				
T2dv	Transition season 2	Average daily volume				
T2Range		Within-day range in discharge				
Hydraulics			Season			
			Dry	T1	Wet	T2
avCV	Channel	Average velocity	X	X	X	X
maxCD		Maximum depth	X	X	X	X
minCD		Minimum depth	X	X	X	X
avCD		Average depth	X	X	X	X
SS		Shear stress	X	X	X	X
avWP		Wetted Perimeter	X	X	X	X
FpO	Floodplain[5]	Onset of inundation				

5 Including Tonle Sap Great Lake

Code	Indicator	
FpD		Duration of inundation
FPArea		Inundated area
avFpV		Average velocity
maxFpV		Maximum velocity
avFpD		Average depth
maxFpD		Maximum depth
minFpD		Minimum depth
Tonle Sap Great Lake modelled Indicators		
TLSwl	Water level	
TLSwd	Water depth	
TLSwa	Water area	
TLStp	Total production	
TLSpp	Periphyton production	
TLSphp	Phytoplankton production	
TLStpaq	Terrestrial production utilisation in aquatic phase	
TLSs	Sedimentation	
TLSo02	Area of oxygen vertical: 0-2 mg/l	
TLSo24	Area of oxygen vertical: 2-4 mg/l	
TLSo4u	Area of oxygen vertical: >4 mg/l	
TLSff	Area of flooded forest	
TLSfg	Area of flooded grassland	
TLShm	Area of herbaceous marsh	
TLSis	Area of isolated lakes in dry season	
Sediment		
SedConc	Sediment concentration	
SedGrain	Sediment grain-size distribution	
SedFpD	Floodplain deposition	
HSedOn	Onset of high sediment delivery at the beginning of the wet season	
HSedDur	Duration of high sediment delivery	
Water quality		
Salinity	Salinity/conductivity (extent of salinity intrusion)	
Temp	Temperature	
DO	Dissolved oxygen	
TOTN	Nitrogen species (Total Nitrogen, Nitrate + Nitrite, Ammonia)	
NO32	Nitrate + Nitrite	
TOTP	Phosphorus species (Total Phosphorus, Dissolved reactive phosphorus)	
PO4	Phosphate	
Si	Silica	
Pesti	Pesticides	
Herbi	Herbicides	

Table 3.2 BioRA ecosystem indicators showing applicable FAs for each

Indicator Groups		Taxa	Focus Areas							
			1	2	3	4	5	6	7	8
Geomorphology										
Channel	Erosion (bank / bed incision)	NA	■	■	■	■	■			
	Average bed sediment grain size in the dry season	NA	■	■	■	■	■			
	Availability exposed sandy habitat in the dry season	NA	■	■	■	■	■			
	Availability of inundated sandy in the dry season	NA	■	■	■	■	■			
	Availability of exposed rocky habitats in the dry season	NA	■	■	■	■	■			
	Availability of inundated rocky habitats in the dry season	NA	■	■	■	■	■			
	Depth of bedrock pools in the dry season	NA	■	■	■	■	■			
	Water clarity in the dry season	NA	■	■	■	■	■	■	■	■
Vegetation										
Channel	Riparian trees	NA	■	■	■	■				
	Extent of upper bank vegetation cover	NA	■	■	■	■				
	Extent of lower bank vegetation cover	NA	■	■	■	■				
	Extent of herbaceous marsh vegetation (submerged, floating and emergent)	NA		■	■					
	Weeds and grasses on sandbanks and sandbars	NA	■	■	■	■	■			
	Biomass of riparian vegetation	NA	■	■	■	■				
	Biomass of algae (periphyton, plankton, benthic)	NA	■	■	■	■	■	■	■	■
Floodplain	Extent of flooded forest	NA			■		■	■	■	■
	Extent of herbaceous marsh vegetation	NA			■		■	■	■	■
	Extent of grassland vegetation	NA			■		■	■	■	■
	Biomass of riparian/aquatic vegetation	NA			■		■	■	■	■
	Biomass of algae (periphyton, plankton, benthic)	NA			■		■	■	■	■
	Extent of invasive riparian plant cover	*Mimosa pigra*			■		■	■	■	■
	Extent of floating and submerged invasive plant cover	Hyacinth			■	■	■	■	■	■
Macroinvertebrates										
Insects on stones		Heptageniid mayflies	■	■	■	■				
Insects on sand		Baetid mayflies	■	■	■	■	■	■		■
Burrowing mayflies		Palingeniid mayflies	■	■	■	■	■	■		
Snail abundance		NA	■	■	■	■	■	■	■	■
Diversity of snails		NA	■	■	■	■	■	■	■	■

Indicator Groups	Taxa	Focus Areas							
		1	2	3	4	5	6	7	8
Neotricula aperta abundance	*Neotricula aperta*								
Bivalves abundance	NA								
Polychaet worms	NA								
Shrimps and crabs	NA								
Littoral invertebrate diversity	NA								
Benthic invertebrate diversity	NA								
Zooplankton abundance	NA								
Zooplankton diversity	NA								
Composite: Benthic invertebrate abundance	NA								
Benthic invertebrate biomass	NA								
Composite: Emergence	NA								
Fish									
Rithron resident species	NA								
Main channel resident (long distant white) species	NA								
Main channel spawner (short distance white) species	NA								
Floodplain spawner (grey) species	NA								
Eurytopic (generalist) species	NA								
Floodplain resident (black)	NA								
Estuarine resident species	NA								
Anadromous species	NA								
Catadromous species	NA								
Marine visitor species	NA								
Non-native species	NA								
Composite: Fish biomass	NA								
Herpetofauna									
Ranid amphibians	*Rana nigrovittata*								
	Hoplobatrachus rugulosus								
Aquatic serpents	*Enhydris bocourti*								
	Cylindrophis ruffus								
Aquatic turtles	*Amyda cartilaginea*								
	Pelochelys cantorii								
	Malayemys subtrijuga								
Semi-aquatic turtles	*Cuora amboinensis*								
Amphibians for human use	NA								
Aquatic/semi-aquatic reptiles for human use	NA								

Indicator Groups	Taxa	Focus Areas							
		1	2	3	4	5	6	7	8
Species richness of riparian/floodplain amphibians	NA								
Species richness of riparian/floodplain reptiles	NA								
Birds									
Medium / large ground-nesting channel species	River tern								
	Lapwing								
Tree-nesting large waterbirds	White-shouldered ibis								
Bank-/hole-nesting species	Pied kingfisher								
	Blue-tailed bee-eater								
Flocking non-aerial passerine of tall graminoid beds	Baya weaver								
Large ground-nesting species of floodplain wetlands	Sarus crane								
	Bengal florican								
Large channel-using species that require bank-side forest	Lesser fish eagle								
	Grey-headed fish eagle								
Rocky-crevice nester in channels	Wire-tailed swallow								
Dense woody vegetation / water interface	Masked finfoot								
Small non-flocking land bird of seasonally-flooded vegetation	Jerdon's bushchat								
	Mekong wagtail								
	Manchurian reed warbler								
Mammals									
Irrawaddy dolphin	Mekong dolphin								
Otter spp.	Otters - all species								
Wetland ungulates	Hog deer								

Table 3.3 Relation to MRC Framework environmental indicators

Assessment indicators	Monitoring parameters	Units	Source	Relevant BioRA indicators
Wetland area	Flooded forest area (Total Mekong basin and Tonle Sap)	'000ha	BioRA	• Extent of flooded forest
	Flooded marshes (Total Mekong basin and Tonle Sap)	'000ha	BioRA	• Extent of herbaceous marsh vegetation
	Inundated grasslands (Total Mekong basin and Tonle Sap)	'000ha	BioRA	• Extent of grassland vegetation
	Inundated rice fields (Total Mekong basin and Tonle Sap)	'000ha	-	-
	Disconnected wetlands	'000ha	BioRA	• Extent of floodplain pools
River channel condition and habitats	Availability of sandbars	No.	BioRA	• Availability of exposed sandy habitats on bars and banks in the dry season
	Availability of rocky habitat including rapids	No.	BioRA	• Availability of inundated rocky habitats in the dry season
	Number of deep pools	No.	BioRA	• Depth of bedrock pools
	Percentage cover of riparian vegetation within river channels	%	BioRA	• Extent of upper bank vegetation cover • Extent of lower bank vegetation cover
	Total sediment extraction (by region)	tonnes / yr	NA: Included in CS data sets	
River bank erosion	Extent of bank erosion	'000 ha/yr	BioRA	• Erosion (bank / bed incision)
	Length of river banks at risk of bank erosion as a result of induced geomorphological changes	'000m	-	• Erosion (bank / bed incision)
Aquatic biodiversity	Migratory fish CPUE	Biomass, no.	BioRA	• Main channel resident (long distant white) species • Main channel spawner (short distance white) species • Floodplain spawner (grey) species • Anadromous species • Catadromous species
	Viable migratory fish routes	km	BioRA	See Connectivity
	Non-migratory fish CPUE	Biomass, no.	BioRA	• Eurytopic (generalist) species • Floodplain resident (black) • Non-native species

Assessment indicators	Monitoring parameters	Units	Source	Relevant BioRA indicators
	Other aquatic animals (OAA)	Biomass, no.	BioRA	• Composite invertebrate biomass • Ranid amphibians • Aquatic serpents • Semi-aquatic serpents • Aquatic turtles • Semi-aquatic turtles • Irrawaddy dolphin • Birds (all) • Otters • Ungulates
	Benthic and littoral invertebrates, zooplankton, diatoms	No./ location	BioRA	• Littoral invertebrate diversity • Benthic invertebrate diversity • Algal biomass
	Listed threatened species	No.	-	?
Ecologically significant areas (environmental hot spots)	Total number and area of ecologically significant areas	No; '000ha	-	-
	Proportion of ecologically significant areas protected	%	-	-

4 Input data used for preliminary setup and calibration

4.1 Introduction

The DRIFT DSS has been populated for BioRA. It was originally envisaged that three individual DRIFT DSSs would be set up: one for the Mekong and Tonle Sap rivers (FA1-6), one for the Tonle Sap Great Lake (FA7) and one for the Delta (FA8). Advances to the DSS software meant that this was unnecessary and all eight of the BioRA focus areas can now be contained within a single DSS.

As discussed in Section 1.2.2, the preliminary setup and calibration of the BioRA DSS moved ahead of some of the other disciplines in the Council Study. This meant that not all of the modelled data required were available in time to be included in the preliminary calibration. This section outlines the data that were used for the Preliminary Reference Scenario and the Calibration Scenarios in the absence of the modelled data.

These data will be replaced with data sets modelled using the MRC DSF (and the DSS re-calibrated) as and when these become available.

Population of the DSS involved:

- detailing the project name, client and consultants involved in BioRA
- setting up the system description, including:
    - focus areas and 'Arcs' (river reaches) between focus areas;
    - photographs of focus areas.
- defining the BioRA indicators;
- linking each indicator to its driving indicators;
- importing the Preliminary Reference hydrological data for the focus areas, and calculating the seasonal flow indicators;
- importing the Preliminary Reference water quality, sediment and hydraulic data for the focus areas, and calculating the seasonal indicators for each;
- creating, and importing values for other indicators requested by the specialists (e.g. onset of the T1 season, the time at which sediment 'delivery' at a site has reached 20% of that year's annual sediment load), the time it takes to reach 80%, and calculating the seasonal indicators for each;
- generating the inputs to the response curves for population by the BioRA specialists;
- entering the preliminary response curves for each indicator;
- entering explanations of the response in each indicator to a change in each linked indicator;
- testing and adjusting these using a series of Preliminary Calibration Scenarios.

4.2 Preliminary Reference Scenario data sets

The source and parameters of the data used for the Preliminary Reference Scenario are described in Sections 4.2.1 to 4.2.6.

4.2.1 Hydrology (DSF)

The main driver indicator for the river focus areas was flow (m3/s), while depth / water level was used as the main driver for Tonle Sap River and Great Lake.

The hydrological time-series entered into the DSS were supplied by IKMP using the DSF models. The relevant parameters are:

- 1985-2008 climate (rainfall) data;
- 2007 level of infrastructure development;
- 2003 level of landuse;
- a daily time set.

4.2.1.1 Seasonal threshold values

Threshold values for defining the four seasons (Dry season (D), Transitional 1 (T1), Wet season (W), Transitional 2 (T2)) were set. The two threshold values required are the D/T1 threshold and the T1/W threshold. Parameters similar to those defined by Adamson (2007) were used to define the seasonal thresholds. For example, the T1/W threshold is the mean annual discharge and the first up-crossing above this value defines the start of the wet season (as per Adamson 2007).

Thus, for FA1, the mean annual discharge in the preliminary reference scenario is 3123 m^3/s, so the start of the wet season is the first up-crossing of 3123 m^3/s (Table 4.1). Thus, each year, when the (five-day average) discharge exceeds 3123 m^3/s for the first time, the wet season is deemed to have begun. For FA1, the start of the T1 season was set as the first up-crossing of 5.3 x the minimum dry season flow of 589.25 m^3/s, which is 2389 m^3/s. For each year, therefore, when the (five-day average) flow crosses 2389 m^3/s for the first time, the T1 season is considered to have begun.

Table 4.1 shows the main parameters and resulting thresholds for FA1 to FA7.

Table 4.1 Season threshold values and main hydrology calibration parameters for each site

Site	Multiple of min dry Q or depth (for D/T1)	Multiple of mean annual Q or depth (for T1/W)	Recession: Slope (days)*	D1/T1	T1/W (and W/T2)
FA1	5.3	1	0.7 (7)	2389.16 m^3/s	3122.79 m^3/s
FA2	4.2	1	0.7 (7)	2587.70 m^3/s	4661.56 m^3/s
FA3	4	1	0.7 (7)	3994.50 m^3/s	7854.41 m^3/s
FA4	4.3	1	0.7 (7)	5864.59 m^3/s	12372.58 m^3/s
FA5	4.3	1	0.7 (7)	6022.08 m^3/s	12307.49 m^3/s
FA6	1.2 (depth)	1.1	0.06 (8)	12.72 m	15.66 m
FA7	750 (depth)	1.3	0.7 (7)	2.12 m	4.24 m
FA8	Not done in 2015				

* The slope had little / no impact on season delineation except at FA6

4.2.2 Hydraulics (DSF)

The hydraulics data imported into the DSS were supplied by IKMP using a combination of the DSF models (ISIS-ID) and WUP-FIN models, with the exception of:

- FA4 (Stung Treng) for which neither DSF nor WUP-FIN models were available;
- FA6 (Prek Kdam) for which data were not received in time for inclusion;
- FA8 (Delta) for which the modelling is as yet incomplete.

The 1-dimensional ISIS (ISIS-1D) model was used to provide channel hydraulics at FA1 – 3, FA5 and FA6. The ISIS model provided daily time-series of:

- mean water stage and depth (by subtraction of bed elevation);
- mean water velocity in the channel;
- mean wetted perimeter.

For FA1 to FA5, a daily time-series of shear stress (SS) was calculate based on the slope (S) between the location of the cross-section and the nearest downstream cross-section, and depth at the cross-section (D) using the equation SS =10000 x S x D.

For the floodplains associated with FA3, FA5 and FA7, WUP-FIN models were used. These provided daily time-series of[6]:

- Flooded area
- Average depth
- Maximum depth
- Average velocity.

4.2.3 Water quality and suspended sediments

For water quality parameters, the time-series were derived using the results from the Water Quality Monitoring Network, for the period 1985 – 2008. In the case of suspended sediments, rating curves were constructed relating river discharge to either the total suspended solids results available in the WQMN or the historic depth integrated suspended sediment sample data (Table 4.2).

[6] Note: Once the full DSF modelling is available, the intention is to also use the WUP-Fin model to generate time-series of the following at FA7, but these were not available for the preliminary calibration, and so were not used:

- Total production (tnc/d)
- Periphyton production (tnc/d)
- Phytoplankton production (tnc/d)
- Terrestrial production utilisation in aquatic phase (tnc/d)
- Sedimentation (tn/d)
- Area of oxygen vertical average 0 - 2 mg/l
- Area of oxygen vertical average 2 - 4 mg/l
- Area of oxygen vertical average > 4 mg/l.

Table 4.2 Data sources used for the construction of the water quality time series used in initial population of DRIFT DSS

Focus Area	Daily Flows from DSF (1985 – 2008)	Monthly Water Quality	Sediment
FA1	Chiang Saen	Chiang Saen	Chiang Saen TSS[7]
FA2	Nong Khai	Vientiane	Nong Khai SSC[8]
FA3	Nakhon Phanom	Nakhon Phanom	Nakhon Phanom TSS
FA4	Pakse	Pakse	Pakse SSC
FA5	Kratie	Kampong Cham	Kampong Cham TSS
FA6	No data available. Preliminary Reference Scenario used 100%, i.e. 100% of reference median.		
FA7			

Note: The daily flow series used to derive Total Nutrients, TSS and SSC rating curves are based on those provided by the DSF models (Section 4.2.1).

One important difference between the modelled and measured water quality data is that, unlike the modelled data, the measured data display trends associated with water-resource and other developments in the basin between 1985 and 2008. These trends are most noticeable in the sediment supply (e.g., Figure 4.1) and nutrient data.

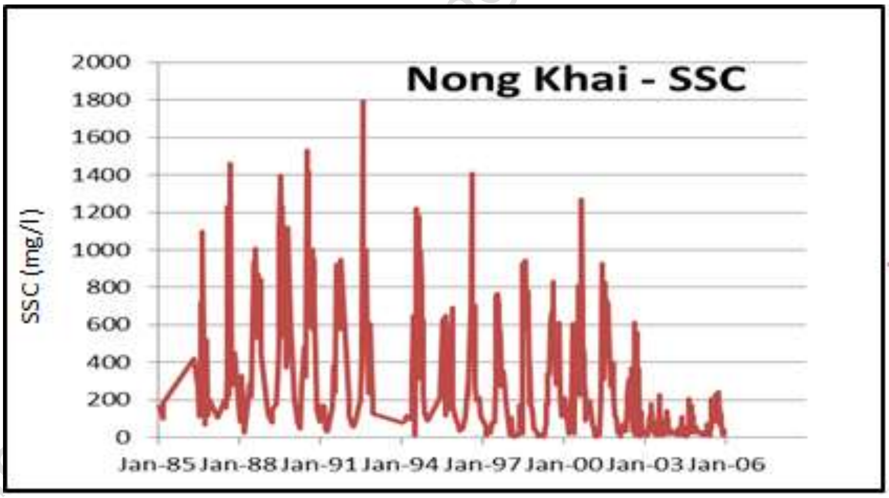


Figure 4.1 Suspended sediment concentrations measured at Nong Khai (1985-2008; HYMOS).

[7] TSS = Total suspended solids determined on surface grab sample under WQMN.
[8] SCC = Historic suspended sediment concentration determined from depth integrated samples. Data from MRC Master Catalogue.

4.2.4 Other external indicators

Time-series indicators, other than the main driver, from external models, or otherwise externally calculated, were imported into the DSS and analysed in the "*External indicators*" sub-section. A total of 40 input time-series were entered into the DSS, yielding a potential of 40 x 12 = 480 seasonal indicators (as min, ave, and max are calculated for each season). Only a relatively small subset of these (97) was actually used. Some of those not used in the current round of calibration, will be included in future rounds when e.g. sub-daily data is used for modelling hydropower scenarios, modelled water quality and sediment are available, and when scenarios of levels of exploitation are developed.

External data other than those listed for hydrology, hydraulics and water quality were:

- Sediment load.
- Onset of main sediment delivery (when it reaches 20% of total annual delivery).
- Duration of main sediment delivery (time to accumulate from 20% to 80% of total annual sediment delivery).
- Onset of the T1 and T2 seasons: these are not reported in the default DRIFT DSS, therefore it was calculated externally from the season start dates calculated by DRIFT.
- Within day ranges in flow: These are calculated within DRIFT DSS when sub-daily data is provided, but reported as 0 for daily data. Therefore, within day ranges were calculated externally by determining the change in flow from one day to the next, for each season (based on the season dates from DRIFT) and these values imported as external indicators.

4.2.5 Composite indicators

Composite indicators are aggregates of a number of other biophysical indicators (e.g. to estimate overall invertebrate biomass by aggregating the various invertebrate guilds). Composite indicators included in the BioRA DSS, and the indicators and weights used to calculate them, are shown in Table 4.3.

Table 4.3 Composite indicators in the BioRA DRIFT DSS, together with their weights

<table>
<tr><th>Comp: Benthic invertebrate biomass</th><th>FA1</th><th>FA2</th><th>FA3</th><th>FA4</th><th>FA5</th><th>FA6</th><th>FA7</th><th>FA8</th></tr>
<tr><td>Insects on stones</td><td>1</td><td>1</td><td>1</td><td rowspan="12">Not yet done</td><td>1</td><td>1</td><td rowspan="7">Used Benthic invertebrate abundance'</td><td rowspan="12">Not yet done</td></tr>
<tr><td>Insects on sand</td><td>1</td><td>1</td><td>1</td><td>1</td><td>n/a</td></tr>
<tr><td>Burrowing mayflies</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>Snail abundance</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>Bivalve abundance</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>Neotricula aperta (Schistosomiasis host)</td><td>n/a</td><td>n/a</td><td>1</td><td>1</td><td>n/a</td></tr>
<tr><td>Shrimps and crabs</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>Comp: Emergence</td><td>FA1</td><td>FA2</td><td>FA3</td><td>FA5</td><td>FA6</td><td>FA7</td></tr>
<tr><td>Insects on stones</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td rowspan="3">n/a</td></tr>
<tr><td>Insects on sand</td><td>1</td><td>1</td><td>1</td><td>1</td><td>n/a</td></tr>
<tr><td>Burrowing mayflies</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
</table>

Comp: Fish Biomass	FA1	FA2	FA3		FA5	FA6	FA7	
Rhithron resident	13	16	9		n/a	n/a	n/a	
Main channel resident (long distance white)	2	26	43		3	4	3	
Main channel spawner (short distance white)	57	43	38		15	26	20	
Floodplain spawner (grey)	n/a	n/a	2		16	22	19	
Eurytopic (generalist)	4	6	2		64	22	23	
Floodplain resident (black fish)	n/a	n/a	0.5		0.2	7	18	
Estuarine resident	n/a	n/a	n/a		n/a	n/a	n/a	
Anadromous	n/a	n/a	0.5		0.5	n/a	n/a	
Catadromous	n/a	n/a	n/a		0.5	n/a	n/a	
Marine visitor	n/a	n/a	n/a		n/a	n/a	n/a	
Non-native	23	8	5		0.5	2	4	

In addition, a number of composite indicators were created in order to model fish migration (see Section 4.2.6.

4.2.6 Connectivity

Fish migration can be affected by water resource developments, which interrupt the longitudinal connectivity of the river. These effects were modelled in the DRIFT DSS using the Connectivity Module in the BioRA DSS, which allows for the inclusion of virtual barriers between FAs as part of water-resource development scenarios. This requires that, for migrating fish guilds, fish abundance at one FA is dependent on 'receiving' fish from an upstream and/or downstream FA. This applies to both fish moving upstream (mainly adults heading to spawning grounds) and fish moving downstream (adults returning turning to feeding area and larvae/fry drifting downstream to those same areas).

For the Preliminary Reference Scenario connectivity between FAs was set at 100%. The modelled 'routes' for fish migration are illustrated in Figure 4.2 and Figure 4.3.

Of course, fish are not the only things affected by changes in longitudinal connectivity. Sediments, nutrients and seeds can also be affected. In BioRA, the issue of seed trapping in impoundments was not addressed. The issue of changes in sediment supply and nutrients as a result of impoundments is included and forms part of the IKMP modelling process, with the resultant (changed) sediment and nutrient time-series forming input to the BioRA DSS.

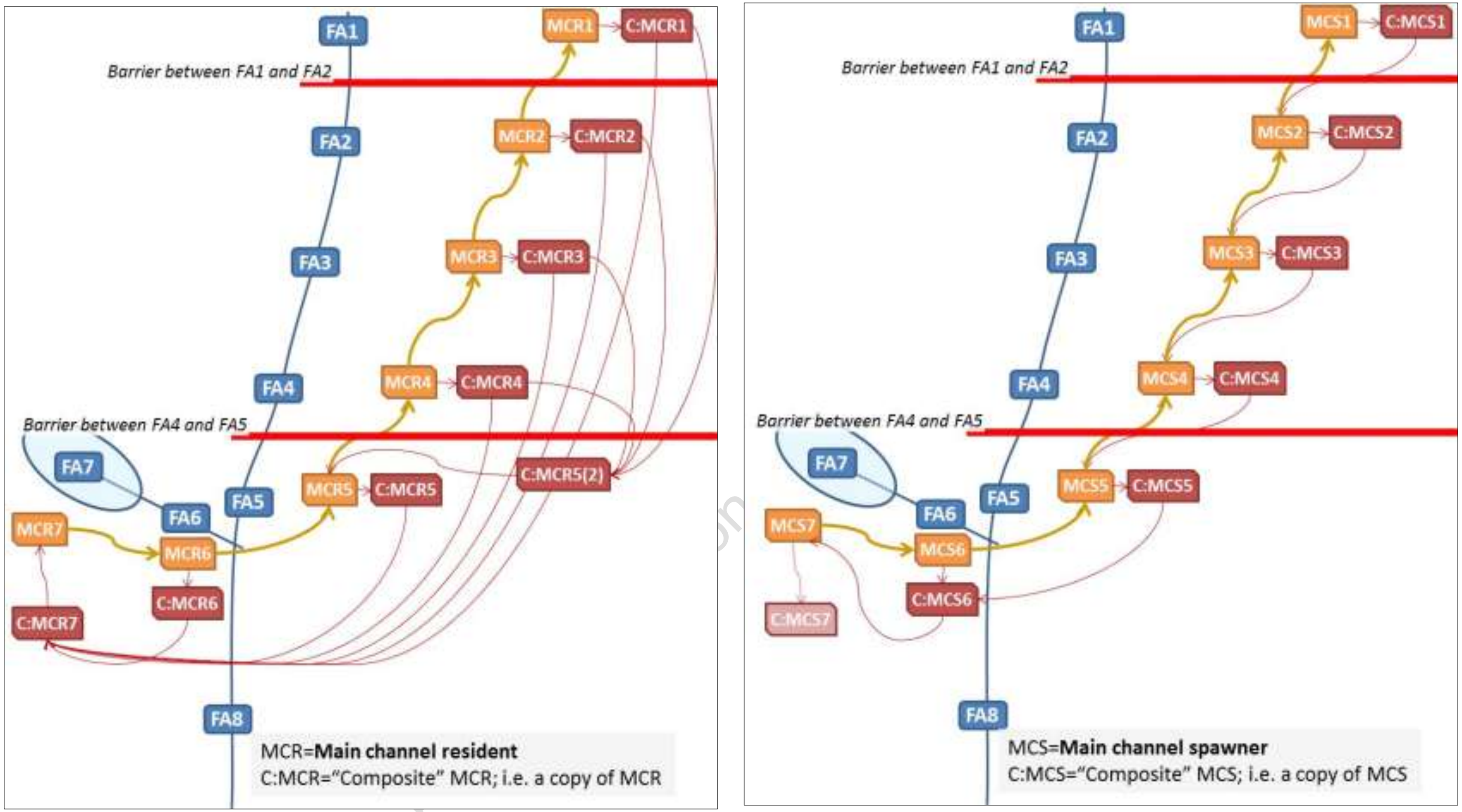


Figure 4.2 **Modelled fish migration routes for Main channel resident (left) and Main channel spawner (right)**

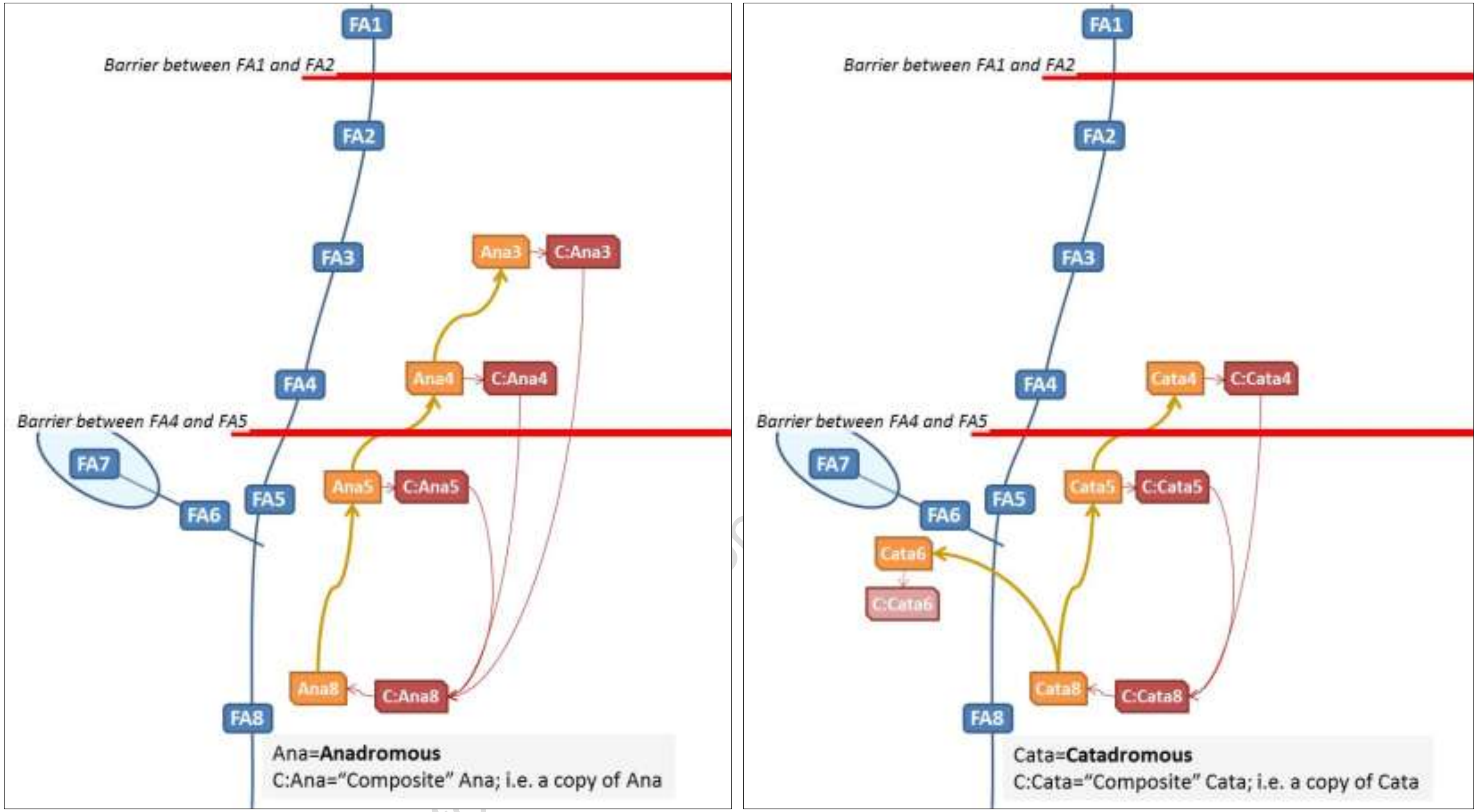


Figure 4.3 **Modelled migration routes for Anadromous (left) and Catadromous fish (right)**

4.3 Calibration Scenarios

As mentioned in Section 1.2.1.7, for calibration, a series of Calibration Scenario (CS) data sets were prepared for use. Typically calibration scenarios include representatives of periods of extreme floods or drought, but also extreme changes in sediment delivery, water quality and longitudinal connectivity. The CS data sets represent hypothetical and possibly unrealistic conditions in the system. Their sole use is as a calibration aid in the DRIFT DSS.

The CS data sets constructed were:

- CS 1: High dry season flow, low wet season flow
- CS 2: 6 dry years, followed by 6 wet years, etc.
- CS 3: A shortened wet season
- CS 4: Sediment supply at 75% of Preliminary Reference
- CS 5: Migration blocked between FA1 and FA2 ONLY
- CS 6: not used
- CS 7: Extreme dry year (1992 – 10%) repeated for whole sequence
- CS 8: Migration blocked between FA4 and 5 ONLY
- CS 9: Migration blocked between FA1 and 2 AND between FA4 and 5
- CS 10: Sediment supply at 25% of Preliminary Reference

CS1, CS2, CS3 and CS7 differ hydrologically from one another and from the Preliminary Reference Scenario, but are identical in terms connectivity. CS4, CS5, CS8, CS9 and CS10 are hydrologically the same as the Preliminary Reference Scenario, but differ in terms of either sediment supply (CS4 and 10) or longitudinal connectivity (CS5, 8 and 9). FA4, FA6, and FA7, only scenarios CS5, CS8 and CS9 have been entered. This was in order to facilitate the assessment of the effects of barriers to fish migration.

Note: There were no modelled calibration hydrology or hydraulic data available for FA7 (Tonle Sap Great Lake), and so the results for FA7 only cover CS5, CS8 and CS9.

4.3.1 CS1: High dry season flow, low wet season flow

CS1 was created by:

- Increasing daily flows in the dry season by an amount relative to the T1/W threshold (the smaller the flow, the larger the relative increase), and
- Decreasing daily wet season flows, by an amount proportional to their size relative to the T1/W threshold;
- Maintain the overall MAR of the Preliminary Reference scenario for each year.

Figure 4.4 shows the first six years of CS1 at FA3 as an example.

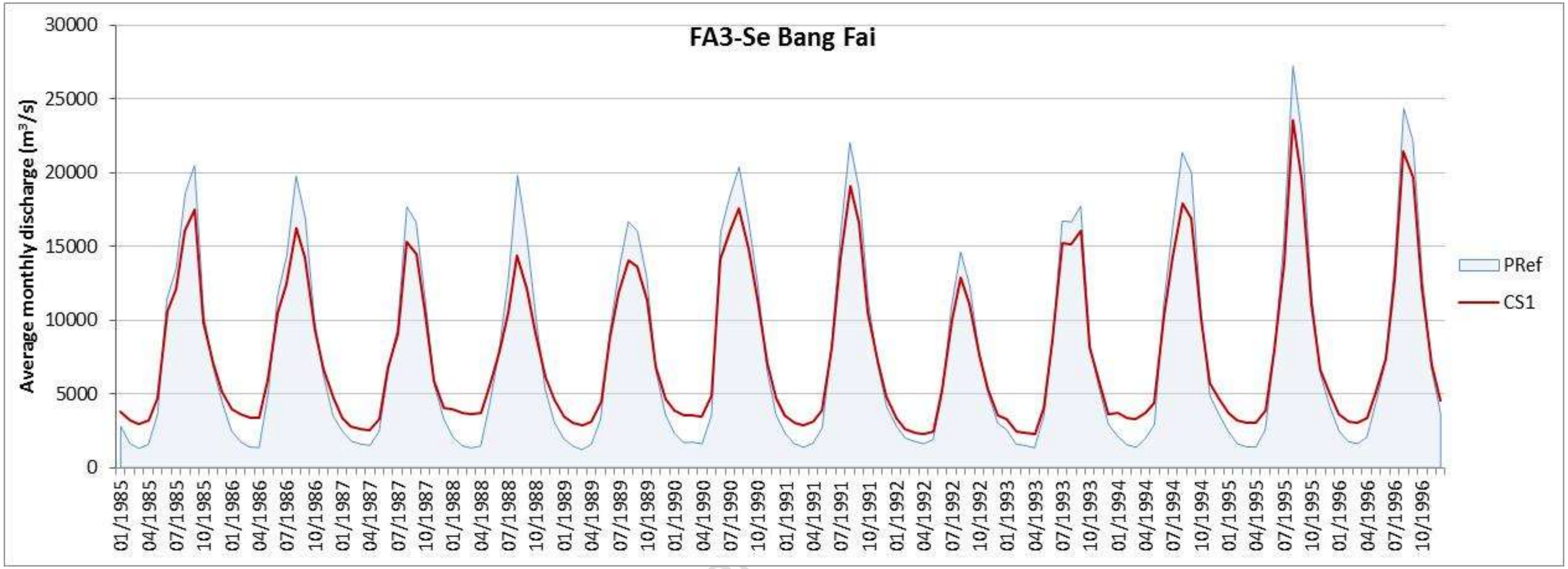


Figure 4.4 **The first twelve years of average monthly flows for CS1 at FA3 compared to Preliminary Reference**

Table 4.4 Values for the hydrological, hydraulic and connectivity indicators for CS1 relative to the Preliminary Reference Scenario.

Calibration Scenario 1 - CS1		FA1		FA2		FA3		FA4		FA5		FA6		FA7	
Indicator	Units	PRef	Change	PRef	Change	PRef	Change	PRef	Change	PRef	Change	PRef	Change	PRef	Change
Mean annual runoff / depth	m^3/s	3096	0	4679	-4	7893	-15	12500	-	12383	-15	14	-	3	-
Dry onset	week	48.00	1.00	50.00	2.00	49.00	3.00	49.00	-	50.00	2.00	49.00	-	52.00	-
Dry duration	days	196.50	-26.00	167.50	-30.50	172.00	-29.00	175.00	-	173.00	-30.50	189.50	-	192.00	-
Dry Min 5day Q / depth	m^3/s	802	810	961	857	1273	1634	1788	-	1809	2613	11	-	0	-
Wet onset	week	25.50	0.00	25.00	0.00	24.00	0.00	24.50	-	25.00	0.00	31.00	-	33.00	-
Wet duration	days	143.00	0.00	148.00	0.00	142.50	0.00	135.50	-	137.50	0.00	127.50	-	137.50	-
Wet Max 5day Q / depth	m^3/s	11003	-3068	15508	-2452	25471	-4547	42350	-	38568	-6019	19	-	8	-
Flood volume	$10^6\ m^3$	69021	-10239	109007	-12350	194941	-24219	302808	-	298285	-43362	194	-	77	-
Dry ave daily vol	$10^6\ m^3$	116.47	49.46	129.05	58.21	183.02	102.65	265.38	-	271.74	169.84	1.05	-	0.08	-
T1 ave daily vol	$10^6\ m^3$	255.06	-15.80	317.14	-6.00	558.67	-30.82	800.03	-	815.90	-54.60	1.24	-	0.29	-
Wet ave daily vol	$10^6\ m^3$	488	-86	755	-86	1348	-172	2362	-	2276	-311	2	-	1	-
T2 ave daily vol	$10^6\ m^3$	226.93	1.67	287.90	10.37	490.29	-1.76	691.16	-	718.90	17.24	1.32	-	0.35	-
T1 onset	week	24.00	-2.50	21.00	-1.00	21.00	-1.00	22.00	-	22.00	-2.00	25.00	-	29.00	-
T2 onset	week	46.00	0.00	46.00	0.00	44.00	0.00	45.00	-	45.00	0.00	49.00	-	52.50	-
Dry: ave w/in day Range	m^3/s	33.08	-10.79	30.32	-5.77	42.27	-8.54	114.69	-	85.61	-23.67	0.04	-	0.03	-
T1: ave w/in day Range	m^3/s	197.71	-75.52	183.71	-33.59	319.21	-81.28	675.52	-	488.24	-115.07	0.08	-	0.08	-
T2: ave w/in day Range	m^3/s	64.80	-25.69	74.15	-14.04	130.34	-31.18	311.92	-	243.51	-62.24	0.06	-	0.06	-
D: ave Sediment conc	mg/l	109.94	0.00	98.36	0.00	99.36	0.00	20.72	-	30.63	-	-	-	-	-
T1: ave Sediment conc	mg/l	292.42	0.00	200.95	0.00	181.71	0.00	61.12	-	96.13	-	-	-	-	-
W: ave Sediment conc	mg/l	509.06	0.00	513.82	0.00	509.10	0.00	290.77	-	402.75	-	-	-	-	-
T2: ave Sediment conc	mg/l	214.44	0.00	188.14	0.00	219.02	0.00	70.82	-	96.26	-	-	-	-	-
W: ave Sediment Onset	week	30.00	0.00	31.00	-1.00	30.00	-0.50	31.00	-	32.00	-1.00	13.00	-	30.00	-
W: ave Sediment Duration	days	62.00	7.00	59.50	5.00	57.50	6.50	50.00	-	52.50	5.50	214.50	-	116.50	-
W: ave FP Onset inundation	week	-	-	-	-	21.50	0.50	-	-	22.00	0.00	-	-	-	-
W: ave FP Duration inundation	days	-	-	-	-	183.00	-1.00	-	-	186.50	-14.50	-	-	137.50	-
W: ave FP Area inundation	km^2	-	-	-	-	39.00	-25.22	0.02	-	305.12	-300.41	-	-	8102.05	-
Connectivity	%PRef	100	0	100	0	100	0	100	0	100	0	100	0	100	0

The main differences between CS1 and the Preliminary Reference Scenario are that CS1 has (using FA1 as an example):

- Dry season duration = 21 weeks shorter
- Dry Min 5day Q = c. 810 m^3/s higher
- Wet Max 5day Q = c. 310 m^3/s lower
- Flood volume = 11 000 x 10^6 m^3 less
- Wet average daily volume = 49 x 10^6 m^3 more
- Wet average daily volume = 86 x 10^6 m^3 lower.

4.3.2 CS2: Six dry years, followed by six wet years, etc.

CS2 was created by:

- Assessing each year to find those which had lower and higher than average MAR;
- Assessing each year to find those which had lower and higher than average dry and wet season depths;
- Selecting six years from the above which had low MAR and / or low dry season average depth and / or low wet season average depth;
- Selecting six years from those which had high MAR and / or high dry season average depth and / or high wet season average depth;
- Creating a sequence formed of the six dry years, followed by the six wet years, the set of twelve years being repeated to create 24 years;
- Figure 4.5 shows the first twelve years of CS2 at FA3 as an example.

The values for the hydrological, hydraulic and connectivity indicators for CS2 relative to the Preliminary Reference Scenario (PRef) are provided in Table 4.5. As the years are both drier and wetter, no overall pattern of indicator values being higher or lower than the Preliminary Reference Scenario was expected.

4.3.3 CS3: A shortened wet season

CS3 was created by:

- Assessing the duration of the wet season for all years, and choosing the year with the shortest or second shortest wet season, depending on the year. In general, if the shortest wet season coincided with the driest year in terms of MAR, then the second shortest was chosen.
- Figure 4.6 shows the first twelve years of CS3 at FA3 as an example.

The values for the hydrological, hydraulic and connectivity indicators for CS3 relative to the Preliminary Reference Scenario (PRef) are provided in Table 4.6. The main differences between CS3 and the Preliminary Reference Scenario are that CS3 has (using FA1 as an example):

- A shorter wet season, as expected: Wet duration = 40 days shorter,
- A lower flood volume : 18014 x 10^6 m^3 less,

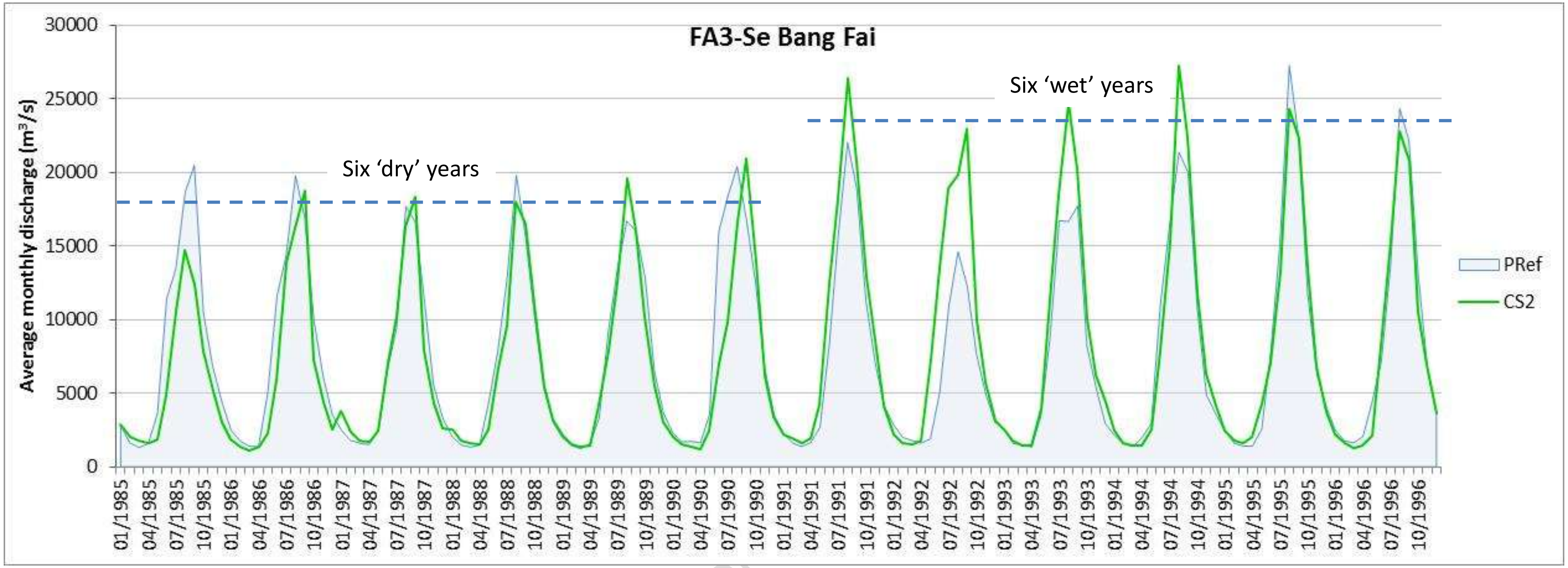


Figure 4.5 **The first twelve years of average monthly flows for CS2 at FA3 compared to Preliminary Reference**

Table 4.5 Values for the hydrological, hydraulic and connectivity indicators for CS2 relative to the Preliminary Reference Scenario.

Calibration Scenario 2 - CS2		FA1		FA2		FA3		FA4		FA5		FA6		FA7	
Indicator	Units	PRef	Change	PRef	Change	PRef	Change	PRef	Change	PRef	Change	PRef	Change	PRef	Change
Mean annual runoff / depth	m^3/s	3096	-108	4679	-150	7893	-220	12500	-213	12383	-367	14	-	3	-
Dry onset	week	48	0	50	0	49	0	49	0	50	-1	49	-	52	-
Dry duration	days	197	-5	168	-4	172	-3	175	-6	173	-9	190	-	192	-
Dry Min 5day Q / depth	m^3/s	802	23	961	-21	1273	77	1788	32	1809	60	11	-	0	-
Wet onset	week	26	0	25	0	24	1	25	0	25	-1	31	-	33	-
Wet duration	days	143	-1	148	0	143	-6	136	3	138	2	128	-	138	-
Wet Max 5day Q / depth	m^3/s	11003	-376	15508	445	25471	952	42350	-527	38568	-400	18.59	-	7.75	-
Flood volume	10^6 m^3	69021	-931	109007	-1070	194941	-11438	302808	-799	298285	-8693	193.55	-	77.19	-
Dry ave daily vol	10^6 m^3	116	0	129	-5	183	-2	265	-3	272	3	1	-	0	-
T1 ave daily vol	10^6 m^3	255	0	317	-15	559	-3	800	3	816	10	1	-	0	-
Wet ave daily vol	10^6 m^3	488	27	755	43	1348	47	2362	-313	2276	-233	2	-	1	-
T2 ave daily vol	10^6 m^3	227	0	288	14	490	3	691	7	719	-14	1	-	0	-
T1 onset	week	24	-1	21	1	21	1	22	-1	22	0	25	-	29	-
T2 onset	week	46	0	46	0	44	0	45	-1	45	0	49	-	53	-
Dry: ave w/in day Range	m^3/s	33	8	30	10	42	9	115	31	86	22	0	-	0	-
T1: ave w/in day Range	m^3/s	198	-82	184	-41	319	-109	676	6	488	-38	0	-	0	-
T2: ave w/in day Range	m^3/s	65	13	74	3	130	-10	312	12	244	22	0	-	0	-
D: ave Sediment conc	mg/l	110	4	98	-1	99	2	21	-	31	5	-	-	-	-
T1: ave Sediment conc	mg/l	292	-101	201	2	182	13	61	-	96	-8	-	-	-	-
W: ave Sediment conc	mg/l	509	10	514	0	509	-20	291	-	403	-43	-	-	-	-
T2: ave Sediment conc	mg/l	214	-10	188	-4	219	13	71	-	96	-2	-	-	-	-
W: ave Sediment Onset	week	30	0	31	-1	30	0	31	-	32	0	13	-	30	-
W: ave Sediment Duration	days	62	2	60	0	58	-3	50	-	53	5	215	-	117	-
W: ave FP Onset inundation	week	-	-	-	-	22	2	100	-	22	1	-	-	100	-
W: ave FP Duration inundation	days	-	-	-	-	183	-15	100	-	187	-21	-	-	138	-
W: ave FP Area inundation	km^2	-	-	-	-	39	12	0	-	305	-22	-	-	8102	-
Connectivity	%PRef	100	0	100	0	100	0	100	0	100	0	100	0	100	0

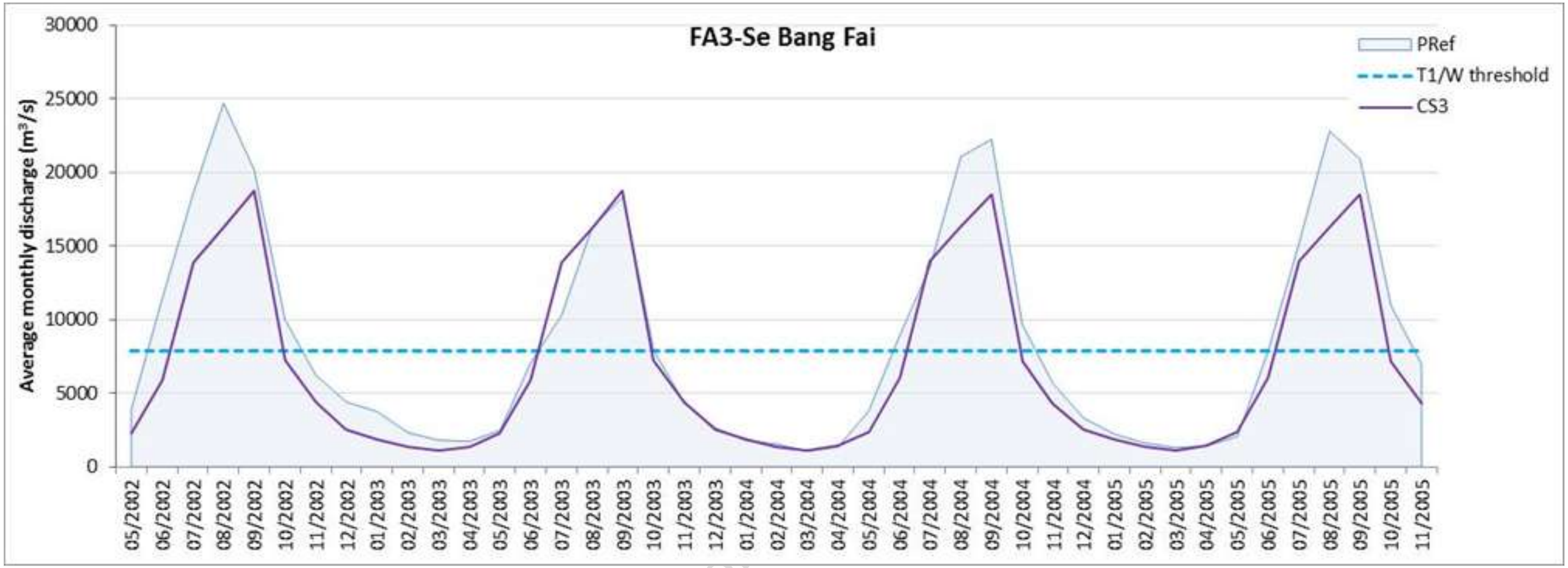


Figure 4.6 **The first twelve years of average monthly flows for CS3 at FA3 compared to Preliminary Reference**

Table 4.6 Values for the hydrological, hydraulic and connectivity indicators for CS3 relative to the Preliminary Reference Scenario (PRef)

Calibration Scenario 2 - CS2		FA1		FA2		FA3		FA4		FA5		FA6		FA7	
Indicator	Units	PRef	Change	PRef	Change	PRef	Change	PRef	Change	PRef	Change	PRef	Change	PRef	Change
Mean annual runoff / depth	m^3/s	3096	-258	4679	-656	7893	-1443	12500	-2785	12383	-2544	14	-	3	-
Dry onset	week	48	0	50	-2	49	-2	49	0	50	-1	49	-	52	-
Dry duration	days	197	1	168	44	172	23	175	4	173	6	190	-	192	-
Dry Min 5day Q / depth	m^3/s	802	132	961	-203	1273	-215	1788	17	1809	16	11	-	0	-
Wet onset	week	26	4	25	3	24	3	25	3	25	3	31	-	33	-
Wet duration	days	143	-40	148	-40	143	-42	136	-26	138	-27	128	-	138	-
Wet Max 5day Q / depth	m^3/s	11003	-2831	15508	-2236	25471	21	42350	-5596	38568	-3815	18.59	-	7.75	-
Flood volume	10^6 m^3	69021	-18014	109007	-21414	194941	-58940	302808	-99931	298285	-94115	193.55	-	77.19	-
Dry ave daily vol	10^6 m^3	116	2	129	-7	183	-18	265	20	272	20	1	-	0	-
T1 ave daily vol	10^6 m^3	255	-39	317	-6	559	-11	800	-115	816	-119	1	-	0	-
Wet ave daily vol	10^6 m^3	488	7	755	56	1348	-1	2362	-518	2276	-437	2	-	1	-
T2 ave daily vol	10^6 m^3	227	36	288	4	490	2	691	-2	719	12	1	-	0	-
T1 onset	week	24	1	21	5	21	2	22	1	22	1	25	-	29	-
T2 onset	week	46	-1	46	-2	44	-3	45	-2	45	-1	49	-	53	-
Dry: ave w/in day Range	m^3/s	33	1	30	-4	42	-14	115	47	86	32	0	-	0	-
T1: ave w/in day Range	m^3/s	198	-117	184	-112	319	-160	676	-311	488	-232	0	-	0	-
T2: ave w/in day Range	m^3/s	65	84	74	-23	130	-49	312	33	244	35	0	-	0	-
D: ave Sediment conc	mg/l	110	5	98	-7	99	-15	21	-4	31	-1	-	-	-	-
T1: ave Sediment conc	mg/l	292	-126	201	-59	182	-44	61	-18	96	-40	-	-	-	-
W: ave Sediment conc	mg/l	509	-51	514	-124	509	41	291	-117	403	-185	-	-	-	-
T2: ave Sediment conc	mg/l	214	52	188	-85	219	-62	71	-32	96	-4	-	-	-	-
W: ave Sediment Onset	week	30	3	31	0	30	-1	31	-1	32	0	13	-	30	-
W: ave Sediment Duration	days	62	-8	60	1	58	-3	50	7	53	2	215	-	117	-
W: ave FP Onset inundation	week	-	-	-	-	22	-1	-	-	22	5	-	-	-	-
W: ave FP Duration inundation	days	-	-	-	-	183	24	-	-	187	-43	-	-	138	-
W: ave FP Area inundation	km^2	-	-	-	-	39	-15	0	39	305	-173	-	-	8102	-
Connectivity	%PRef	100	0	100	0	100	0	100	0	100	0	100	0	100	0

4.3.4 CS4: Sediment supply at 75% of Preliminary Reference

CS10 and the Preliminary Reference Scenario are identical in terms of their hydrology and connectivity. They differ in that CS10 has a 75% reduction in sediment supply at each FA (Table 4.7).

Table 4.7 Sediment concentration for CS4 relative to the Preliminary Reference Scenario

CS2		FA1		FA2		FA3		FA4		FA5	
Indicator	Units	PRef	Change	PRef	Change	PRef	Change	PRef	Change	PRef	Change
D: ave Sediment conc		110	-27	98	-25	99	-25	21	-5	31	-8
T1: ave Sediment conc		292	-73	201	-50	182	-45	61	-15	96	-24
W: ave Sediment conc		509	-127	514	-128	509	-127	291	-73	403	-101
T2: ave Sediment conc		214	-54	188	-47	219	-55	71	-18	96	-24

4.3.5 CS5: Migration blocked between FA1 and FA2 ONLY

CS5 and the Preliminary Reference Scenario are identical to one other in terms of their hydrology and sediment supply. They differ only in that CS5 has a virtual barrier across the channel between FA1 and FA2. This barrier is deemed to have reduced fish migration as follows:

- Upstream migration:
  - Main channel resident – 100% reduction
  - Main channel spawner – 80% reduction
  - Anadromous – 100% reduction
  - Catadromous – 100% reduction
- Downstream migration:
  - Main channel resident – 80% reduction
  - Main channel spawner – 80% reduction
  - Anadromous – 80% reduction
  - Catadromous – 80% reduction.

Note: These values can be adjusted to reflect migration aids, such as fish ladders, that may form part of actual water-resource developments. They were set at the values above purely to test the connectivity sequences and response curves in the DSS.

4.3.6 CS7: Extreme dry year (1992 – 10%) repeated for whole sequence

1992 was generally the year with the lowest MAR across all sites. CS7 was compiled by:

- Using daily flows from 1992 as a base, subtracting a 10% off each day, and repeating the sequence for 24 years.
- Figure 4.7 shows the first twelve years of CS3 at FA3 as an example.

The values for the hydrological, hydraulic and connectivity indicators for CS7 relative to the Preliminary Reference Scenario are provided in Table 4.8. The main differences between CS7 and the Preliminary Reference Scenario are that CS7 has (using FA1 as an example):

- A shorter wet season: Wet duration = 110 days shorter,
- A longer dry season: Dry duration = 123 days longer,
- A lower flood volume : 57606 x 10^6 m^3 less,

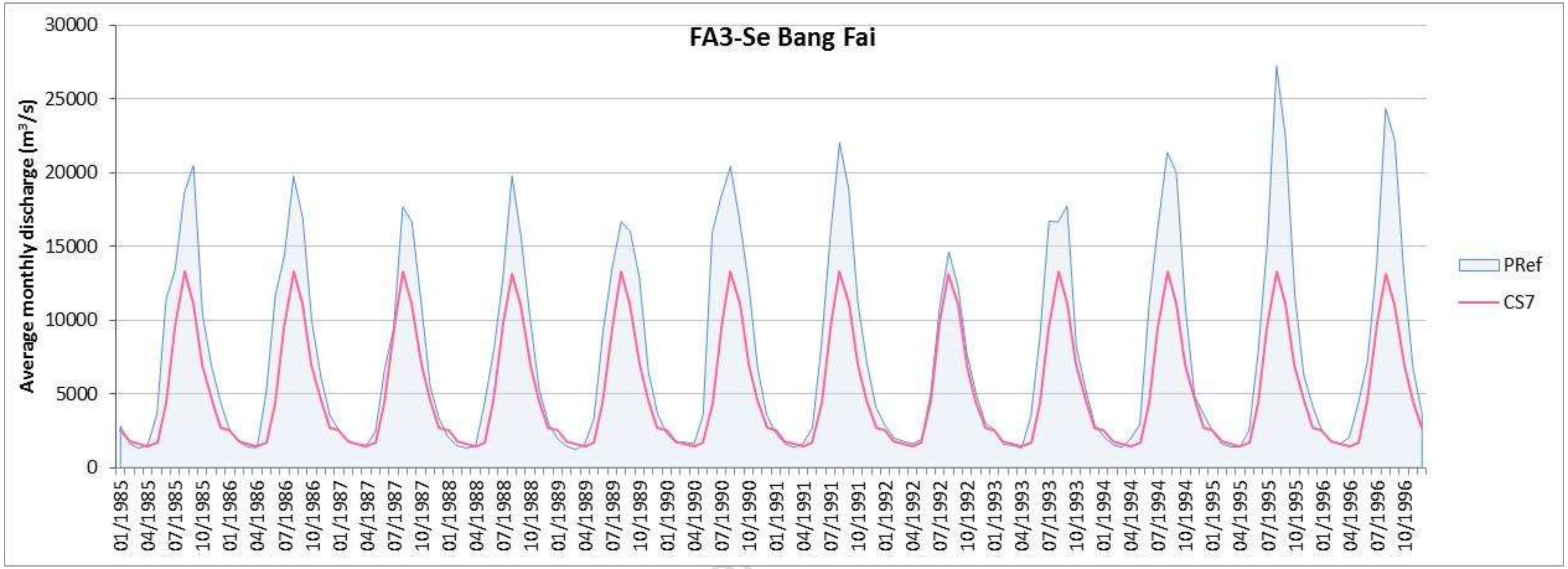


Figure 4.7 The first twelve years of average monthly flows for CS7 at FA3 compared to Preliminary Reference

Table 4.8 Values for the hydrological, hydraulic and connectivity indicators for CS7 relative to the Preliminary Reference Scenario (PRef)

		FA1		FA2		FA3		FA4		FA5		FA6		FA7	
Indicator	Units	PRef	Change	PRef	Change	PRef	Change	PRef	Change	PRef	Change	PRef	Change	PRef	Change
Mean annual runoff / depth	m^3/s	3096	-1019	4679	-1587	7893	-2710	12500	-3756	12383	-3460	14	-	3	-
Dry onset	week	48	-14	50	-3	49	-2	49	-2	50	-3	49	-	52	-
Dry duration	days	197	123	168	59	172	36	175	32	173	31	190	-	192	-
Dry Min 5day Q / depth	m^3/s	802	186	961	125	1273	96	1788	-282	1809	-306	11	-	0	-
Wet onset	week	26	4	25	3	24	4	25	5	25	4	31	-	33	-
Wet duration	days	143	-110	148	-55	143	-54	136	-45	138	-45	128	-	138	-
Wet Max 5day Q / depth	m^3/s	11003	-6277	15508	-7259	25471	-10912	42350	-9690	38568	-7248	18.59	-	7.75	-
Flood volume	$10^6\ m^3$	69021	-57606	109007	-60617	194941	-104466	302808	-130968	298285	-123157	193.55	-	77.19	-
Dry ave daily vol	$10^6\ m^3$	116	44	129	15	183	4	265	-15	272	-16	1	-	0	-
T1 ave daily vol	$10^6\ m^3$	255	2	317	88	559	-50	800	36	816	28	1	-	0	-
Wet ave daily vol	$10^6\ m^3$	488	-142	755	-235	1348	-331	2362	-474	2276	-393	2	-	1	-
T2 ave daily vol	$10^6\ m^3$	227	-16	288	70	490	13	691	40	719	43	1	-	0	-
T1 onset	week	24	4	21	0	21	7	22	2	22	3	25	-	29	-
T2 onset	week	46	-12	46	0	44	-10	45	-3	45	-2	49	-	53	-
Dry: ave w/in day Range	m^3/s	33	7	30	1	42	-13	115	-32	86	-26	0	-	0	-
T1: ave w/in day Range	m^3/s	198	-148	184	-139	319	-217	676	-316	488	-219	0	-	0	-
T2: ave w/in day Range	m^3/s	65	19	74	3	130	5	312	-133	244	-80	0	-	0	-
D: ave Sediment conc	mg/l	110	10	98	18	99	0	21	-3	31	-1	-	-	-	-
T1: ave Sediment conc	mg/l	292	-160	201	-77	182	0	61	-28	96	-43	-	-	-	-
W: ave Sediment conc	mg/l	509	-216	514	-226	509	0	291	-111	403	-110	-	-	-	-
T2: ave Sediment conc	mg/l	214	-46	188	-24	219	0	71	-17	96	-18	-	-	-	-
W: ave Sediment Onset	week	30	-1	31	-2	30	0	31	1	32	1	13	-	30	-
W: ave Sediment Duration	days	62	38	60	34	58	3	50	-2	53	-8	215	-	117	-
W: ave FP Onset inundation	week	-	-	-	-	22	3	100	0	22	2	-	-	-	-
W: ave FP Duration inundation	days	-	-	-	-	183	-26	100	0	187	-24	-	-	138	-
W: ave FP Area inundation	km^2	-	-	-	-	39	-36	0	0	305	-107	-	-	8102	-
Connectivity	%PRef	100	0	100	0	100	0	100	0	100	0	100	-	100	-

4.3.7 CS8: Migration blocked between FA4 and 5 ONLY

CS8 and the Preliminary Reference Scenario are identical to one other in terms of their hydrology and sediment supply. They differ only in that CS8 has a virtual barrier across the channel between FA4 and FA5. This barrier is deemed to have reduced fish migration as follows:

- Upstream migration:
  - Main channel resident – 100% reduction
  - Main channel spawner – 80% reduction
  - Anadromous – 100% reduction
  - Catadromous – 100% reduction
- Downstream migration:
  - Main channel resident – 80% reduction
  - Main channel spawner – 80% reduction
  - Anadromous – 80% reduction
  - Catadromous – 80% reduction

Note: These values can be adjusted to reflect migration aids, such as fish ladders, that may form part of actual water-resource developments. They were set at the values above purely to test the connectivity sequences and response curves in the DSS.

4.3.8 CS9: Migration blocked between FA1 and 2 AND between FA4 and 5

CS9 and the Preliminary Reference Scenario are identical to one other in terms of their hydrology and sediment supply. They differ only in that CS9 is modelled to have two barriers to fish migration, one between FA1 and FA2, and one between FA4 and FA5. Four guilds were affected by these barriers, viz., Main channel resident (long distance white), Main channel spawner (short distance white), Catadromous, and Anadromous. Fish migration was reduced as follows.

- Upstream migration:
  - Main channel resident – 100% reduction
  - Main channel spawner – 100% reduction
  - Anadromous – 100% reduction
  - Catadromous – 100% reduction
- Downstream migration:
  - Main channel resident – 80% reduction
  - Main channel spawner – 80% reduction
  - Anadromous – 80% reduction
  - Catadromous – 80% reduction

Note: These values can be adjusted to reflect migration aids, such as fish ladders, that may form part of actual water-resource developments. They were set at the values above purely to test the connectivity sequences and response curves in the DSS.

4.3.9 CS10: Sediment supply at 25% of Preliminary Reference

CS10 and the Preliminary Reference Scenario are identical to one other in terms of their hydrology and connectivity. They differ only in that CS10 has a 75% reduction in sediment supply at every FA (Table 4.8).

Table 4.9 Values for the hydrological, hydraulic and connectivity indicators for CS10 relative to the Preliminary Reference Scenario (PRef)

CS7		FA1		FA2		FA3		FA4		FA5	
Indicator	Units	PRef	Change	PRef	Change	PRef	Change	PRef	Change	PRef	Change
T2: ave w/in day Range		110	-82	98	-74	99	-75	21	-16	31	-23
D: ave Sediment conc		292	-219	201	-151	182	-136	61	-46	96	-72
T1: ave Sediment conc		509	-382	514	-385	509	-382	291	-218	403	-302
W: ave Sediment conc		214	-161	188	-141	219	-164	71	-53	96	-72

5 Calibration results per FA

This section provides results for individual FAs produced by the DRIFT DSS for the hypothetical calibration scenarios outlined in Section 4.3. This allows evaluation of DSS outputs to see if the predictions at each FA appear reasonable and are explainable in terms of ecosystem functioning.

The scores from all the response curves for any one indicator are combined in various ways, so that measures of change can be expressed as time-series per indicator, per discipline, or as overall ecosystem integrity. For the latter, results are provided on a scale of A to E, where A represented a pristine ecosystem and E a critically modified one with few, if any, intact ecosystem functions and thus of little value to people (Table 5.1). The reference ecological condition is taken from the Status and Trends assessment for each discipline presented in Interim Technical Report 1: Volume 1 - Specialists' Report.

Table 5.1 Definitions of Overall Ecological Integrity categories (after Kleynhans 1997)

A	Unmodified, natural	As close as possible to natural conditions.
B	Largely natural	Modified from the original natural condition but not sufficiently to have produced measurable change in the nature and functioning of the ecosystem/community.
C	Moderately modified	Changed from the original condition sufficiently to have measurably altered the nature and functioning of the ecosystem/community, although the difference may not be obvious to a casual observer.
D	Largely modified	Sufficiently altered from the original natural condition for obvious impacts on the nature and functioning of the ecosystem/community to have occurred.
E	Completely modified	Important aspects of the original nature and functioning of the ecosystem community are no longer present. The area is heavily negatively impacted by human interventions.

In this section the predicted changes in the aquatic ecosystem (river and floodplains) are evaluated per FA as:

1. estimated mean percentage change from Preliminary Reference Scenario[9] in the abundance, area or concentration of key indicators;
2. time-series of abundance, area or concentration of key indicators under the flow regime resulting from each calibration scenario;
3. Overall Ecological Integrity.

The predicted changes in the aquatic ecosystem per FA, i.e., the LMB picture for each CS, are presented in Section 5.

It is clear from the results that the magnitude of the change in indicators in response to flow and sediment changes as represented by the CSs increases down the biophysical hierarchy (Figure 5.1).

[9] Preliminary Reference ecological conditions are those measured in c. 2010-15.

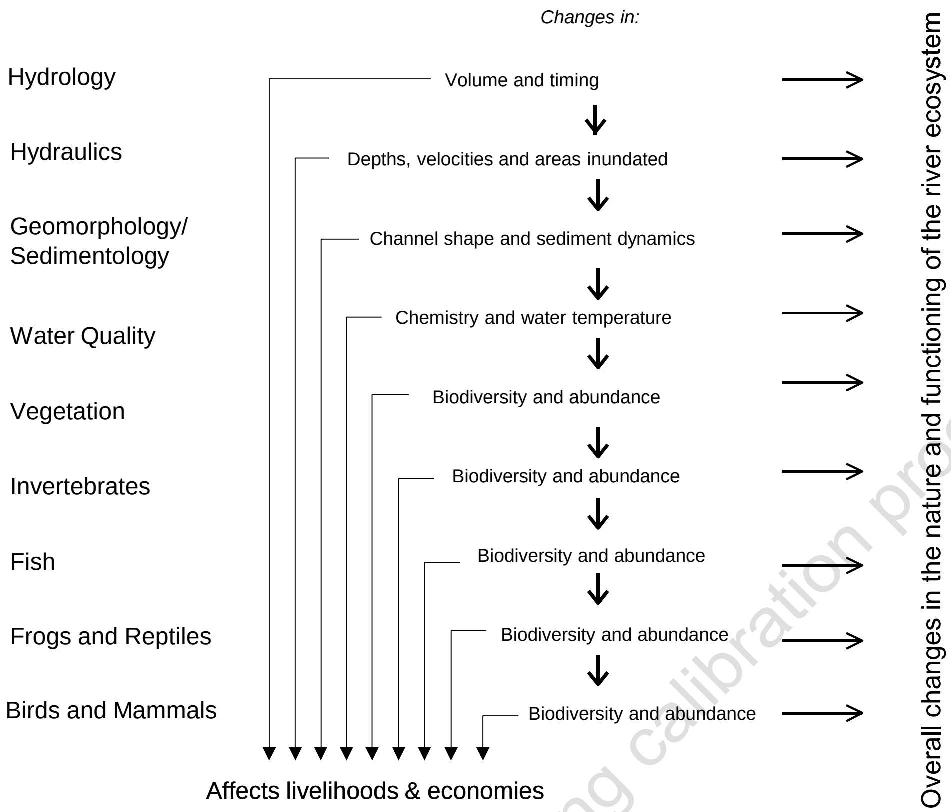


Figure 5.1 The knock-on effects of downstream change driven by manipulation of the flow regime[10]

This is to be expected because impacts at each level of the hierarchy can cause knock-on effects at the next level, in addition to any direct effects, which magnifies the impacts in the lower levels. For instance, impacts on fish are a result of direct flow and sediment effects, plus changes in water quality, habitat (geomorphology and vegetation) and food (vegetation and macroinvertebrates). This magnification does not always occur. Many birds, for instance, are not flow or river dependent and so both the direct effects and the indirect knock-on effects are offset by other factors and live history options. Similarly, semi-aquatic turtles, reptiles and amphibians are buffered by a lower dependence on the river than say fish.

5.1 Focus Area 1: Pak Beng

Focus Area 1: Pak Beng represents BioRA Zone 1, which extends from the Lao PDR-China border to just upstream of Pak Beng.

5.1.1 Characteristics of the flow regime of each calibration data set at FA1

The main characteristics of the flow regimes at FA1 associated with each of the calibration scenarios are summarised in Table 5.2.

[10] Feedback loops not included.

Table 5.2 Characteristics of the flow regime (median values) of each calibration data set at FA1 (Pak Beng) [11]

FA1-Pak Beng	Units	PRef	CS1	CS2	CS3	CS4	CS5	CS7	CS8	CS9	CS10
Mean annual runoff	m^3/s	3096	3096	2988	2838	3096	3096	2078	3096	3096	3096
Dry onset	week	48.0	49.0	48.0	48.0	48.0	48.0	34.0	48.0	48.0	48.0
Dry duration	days	196.5	170.5	192.0	197.0	196.5	196.5	319.0	196.5	196.5	196.5
Dry Min 5day Q	m^3/s	801.6	1611.9	824.6	933.5	801.6	801.6	987.8	801.6	801.6	801.6
Wet onset	week	25.5	25.5	25.5	29.0	25.5	25.5	29.0	25.5	25.5	25.5
Wet duration	days	143.0	143.0	142.5	103.0	143.0	143.0	33.0	143.0	143.0	143.0
Wet Max 5day Q	m^3/s	11003	7935	10627	8172	11003	11003	4726	11003	11003	11003
Flood volume	MCM	69021	58782	68090	51008	69021	69021	11415	69021	69021	69021
Dry ave daily vol	MCM	116.5	165.9	116.9	118.0	116.5	116.5	160.1	116.5	116.5	116.5
T1 ave daily vol	MCM	255.1	239.3	255.1	215.9	255.1	255.1	257.3	255.1	255.1	255.1
Wet ave daily vol	MCM	488.1	402.0	515.6	495.2	488.1	488.1	345.9	488.1	488.1	488.1
T2 ave daily vol	MCM	226.9	228.6	227.2	263.0	226.9	226.9	210.7	226.9	226.9	226.9
T1 onset	week	24.0	21.5	23.0	25.0	24.0	24.0	28.0	24.0	24.0	24.0
T2 onset	week	46.0	46.0	46.0	45.0	46.0	46.0	34.0	46.0	46.0	46.0
D: ave w/in day range	m^3/s	33.1	22.3	41.5	34.2	33.1	33.1	40.2	33.1	33.1	33.1
T1: ave w/in day range	m^3/s	197.7	122.2	116.1	80.5	197.7	197.7	49.7	197.7	197.7	197.7
T2: ave w/in day range	m^3/s	64.8	39.1	78.1	148.8	64.8	64.8	84.2	64.8	64.8	64.8
D: ave Ch Velocity	m/s	0.69	0.82	0.71	0.71	0.69	0.69	0.73	0.69	0.69	0.69
W: ave Ch Velocity	m/s	1.31	1.21	1.29	1.22	1.31	1.31	1.08	1.31	1.31	1.31
D: ave Ch Depth	m	12.3	13.8	12.5	12.5	12.3	12.3	12.7	12.3	12.3	12.3
Wet: ave Ch Depth	m	20.0	18.7	19.8	18.8	20.0	20.0	16.8	20.0	20.0	20.0
D: min Ch Depth	m	10.8	12.9	10.9	11.3	10.8	10.8	11.8	10.8	10.8	10.8
D: max Ch Depth	m	15.5	15.8	16.0	16.2	15.5	15.5	15.6	15.5	15.5	15.5
W: ave Wetted perimeter	m	350.7	347.6	350.4	347.3	350.7	350.7	341.9	350.7	350.7	350.7
D: ave Sediment conc	mg/l	109.9	109.9	114.3	115.2	82.5	109.9	120.3	109.9	109.9	27.5
T1: ave Sediment conc	mg/l	292.4	292.4	191.4	166.2	219.3	292.4	132.3	292.4	292.4	73.1
W: ave Sediment conc	mg/l	509.1	509.1	519.6	458.0	381.8	509.1	292.7	509.1	509.1	127.3
T2: ave Sediment conc	mg/l	214.4	214.4	204.2	266.6	160.8	214.4	168.8	214.4	214.4	53.6
D: ave Sediment load	t/ day	14115	18563	13777	14993	10586	14115	13990	14115	14115	3529
W: ave Sediment load	t/ day	284685	224359	303456	218974	213514	284685	86156	284685	284685	71171
T1: ave Sediment load	t/ day	73724	75004	35092	29411	55293	73724	14969	73724	73724	18431
T2: ave Sediment load	t/ day	48600	52624	46677	71574	36450	48600	29162	48600	48600	12150
W: ave Sediment grain-size	mm	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
W: ave Sediment Onset	week	30.0	30.0	30.0	33.0	30.0	30.0	29.0	30.0	30.0	30.0
W: ave Sediment Duration	days	62.0	69.0	64.0	54.0	62.0	62.0	100.0	62.0	62.0	62.0
D: ave Dissolved Oxygen	mg/l	8.39	8.39	8.63	8.15	8.39	8.39	8.76	8.39	8.39	8.39
D: ave Conductivity	mS/m	27.21	27.21	26.57	27.32	27.21	27.21	27.99	27.21	27.21	27.21
D: ave Total Nitrogen	mg/l	0.22	0.23	0.23	0.22	0.22	0.22	0.23	0.22	0.22	0.22
D: ave Total Phosphorous	mg/l	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
D: max Temperature	^oC	26.00	26.00	26.00	28.00	26.00	26.00	28.20	26.00	26.00	26.00

5.1.2 Mean percentage changes

The mean percentage changes (relative to Preliminary Reference Scenario) for the indicators in response to each CS at FA1 (Pak Beng) are given in Table 5.3.

[11] PRef = Preliminary Reference Scenario

Table 5.3 **The mean predicted percentage changes in abundance (relative to Preliminary Reference Scenario) at FA1 for the indicators for each CS.** Blue and green are changes that represent increases: green = 40-70%; blue = >70%. Orange and red are changes that represent decreases: orange = 40-70%; red = >70%. Preliminary reference, by definition, equals 100%.

Indicators	Calibration scenarios								
	CS1	CS2	CS3	CS4	CS5	CS7	CS8	CS9	CS10
Discipline : Geomorphology									
Erosion (bank / bed incision)	-4.9	0.7	-10.1	9.2	0.7	-8.7	0.7	0.7	36.4
Average bed sediment size - dry season	1.0	0.8	0.6	1.2	0.3	1.1	0.3	0.3	2.5
Availability exposed sandy habitat - dry season	7.9	-5.3	4.1	-4.5	0.2	4.8	0.2	0.2	-20.8
Availability inundated sandy habitat -dry season	1.9	0.4	2.3	-5.2	-2.0	-0.4	-2.0	-2.0	-15.4
Availability exposed rocky habitat -dry season	-1.0	-5.0	-7.3	7.2	1.0	-3.3	1.0	1.0	25.2
Availability inundated rocky habitat -dry season	3.2	2.8	0.8	-0.4	-1.6	-1.5	-1.6	-1.6	1.6
Depth of bedrock pools in dry season	-7.1	-0.3	-4.7	5.3	0.2	-7.7	0.2	0.2	12.3
Water clarity	1.2	27.5	38.9	16.4	1.2	53.6	1.2	1.2	242.4
Discipline : Vegetation									
C: Riparian trees	-19.0	-6.3	-0.1	-1.8	-1.8	-37.5	-1.8	-1.8	-1.8
C: Extent upper bank veg cover	-39.3	6.4	-42.8	4.1	1.0	-81.3	1.0	1.0	18.6
C: Extent lower bank veg cover	-79.2	-1.2	-10.9	3.5	-0.8	-3.7	-0.8	-0.8	19.8
C: Weeds, grasses on sandbanks and sandbars	-25.2	-5.1	-0.5	-1.6	-0.9	17.3	-0.9	-0.9	-4.3
C: Biomass riparian veg	-76.6	-4.1	-36.5	2.9	-2.0	-31.1	-2.0	-2.0	20.2
C: Biomass algae	-6.8	8.4	15.4	3.4	1.4	21.4	1.4	1.4	55.4
Discipline : Macro-invertebrates									
Insects on stones	-4.9	-0.5	1.4	-2.3	-1.9	1.7	-1.9	-1.9	6.6
Insects on sand	-1.9	1.3	3.9	-1.3	-1.1	3.5	-1.1	-1.1	11.5
Burrowing mayflies	-3.9	0.1	2.0	-1.4	-0.5	2.6	-0.5	-0.5	7.6
Snail abundance	6.9	3.5	3.6	0.8	0.3	10.6	0.3	0.3	12.1
Diversity of snails	-5.4	-0.8	1.2	-1.8	-1.0	2.0	-1.0	-1.0	3.6
Bivalves abundance	-9.1	0.9	4.8	-3.2	-0.1	4.4	-0.1	-0.1	12.0
Shrimps and crabs	-2.5	1.3	3.3	0.1	-0.4	5.0	-0.4	-0.4	11.4
Littoral invertebrate diversity	-5.6	-0.8	1.4	-1.9	-1.1	2.3	-1.1	-1.1	4.2
Benthic invertebrate diversity	-6.1	-1.4	-0.1	-2.9	-1.8	1.4	-1.8	-1.8	0.7
Zooplankton abundance	-0.7	1.7	2.9	0.9	0.5	-17.6	0.5	0.5	11.0
Benthic invertebrate biomass	-2.6	1.1	3.2	-1.2	-0.6	4.6	-0.6	-0.6	10.2
Dry season insect emergence	-3.6	0.3	2.5	-1.7	-1.2	2.6	-1.2	-1.2	8.6
Discipline : Fish									
Rhithron resident	41.2	-0.8	8.4	0.0	-1.9	73.2	-1.9	-1.9	10.3
Main channel resident (long distance white)	95.4	-11.2	-53.3	3.3	-68.0	-9.6	-13.9	-68.0	2.1
Main channel spawner (short distance white)	26.2	-8.6	-28.8	-10.9	-44.5	-61.0	-2.8	-44.5	-18.2
Eurytopic (generalist)	-32.2	0.4	-16.6	-11.3	-1.1	-25.1	-1.1	-1.1	-13.1
Discipline : Herpetofauna									
Ranid and microhylid amphibians	-49.6	-2.7	-25.1	4.7	-1.6	-76.4	-1.6	-1.6	11.4
Aquatic serpents	-39.7	-7.2	-44.1	-1.4	-22.2	-57.9	-1.4	-22.2	8.1
Species richness of riparian/FP amphibians	-46.9	-3.5	-20.6	8.1	-0.4	-38.4	-0.4	-0.4	11.7
Species richness of riparian/FP reptiles	-55.4	-9.4	-46.5	-1.6	-16.2	-46.6	-0.6	-16.2	6.3
Discipline : Birds									
Medium/large ground-nesting channel spp	-1.3	-2.9	4.1	-5.6	-2.9	5.1	-2.9	-2.9	-9.0
Bank / hole nesting species	-0.6	-3.9	-1.1	-2.3	-2.2	-1.8	-2.2	-2.2	-1.6
Small non-flocking landbird;seasonally flooded veg	-44.7	1.0	-2.5	1.3	-0.1	-0.1	-0.1	-0.1	10.0

5.1.3 Time-series

The time-series for the calibration data sets for the biophysical indicators show the annual changes in abundance behind the mean values given in Table 5.3. The period simulated is 1985-2008. These show the year-on-year changes in each indicator in response to the condition specified in each CS. They are presented here because they are useful for the discipline specialists when assessing the results.

5.1.3.1 Geomorphology

The changes in the geomorphological indicators at FA1 can be summarised as follows (refer to Table 5.3 and Figure 5.2):

CS1: No major changes. Note: This scenario resulted in large changes (decline in erosion) at the more downstream FAs, which probably reflects different channel slopes in the various BioRA zones/FAs. FA1 is steeper than any of the other FAs, and the effect of a shortened wet season is felt more in the lower, less steep, reaches.

CS2: Slightly lower erosion rates and slightly clearer water.

CS3: Slightly lower erosion rates and slightly clearer water. This apparent anomaly is because the bulk of the erosion (and sediment suspension and transport) occurs in the wet season, which is shorter than Preliminary Reference in CS3. There is also an increase in exposed habitat linked to the lower water levels associated with CS3.

CS4: A slight increase in erosion and a slight increase in water clarity; both linked the reduced sediment supply in CS4. The increased erosion would have a knock-on effect on the availability of sandy and rocky habitat, with the former decreasing and the latter increasing.

CS5: No major changes.

CS7: Similar to CS3. Slightly lower erosion rates and slightly clearer water. This apparent anomaly is because the bulk of the erosion (and sediment suspension and transport) occurs in the wet season, which is shorter than Preliminary Reference in CS7.

CS8: No major changes.

CS9: No major changes.

CS10: A *c*. 36% increase in erosion, relative to Preliminary Reference (remembering that Preliminary Reference already has higher erosion for the latter part of the record as it is using measured data), with concomitant changes in the availability of sandy and rocky habitat, and in water clarity (*c.* 240% increase in water clarity).

5.1.3.2 Vegetation

The changes in the vegetation indicators at FA1 can be summarised as follows (refer to Table 5.3 and Figure 5.3):

CS1: Major loss of lower bank vegetation. This vegetation is expected to be lost as a direct result of elevated dry season flows, which will drown out the existing flower bank vegetation. The lower bank vegetation is presumed to account for about 50% of the total riparian biomass; consequently there is also a reduction in riparian biomass.

CS2: No major changes.

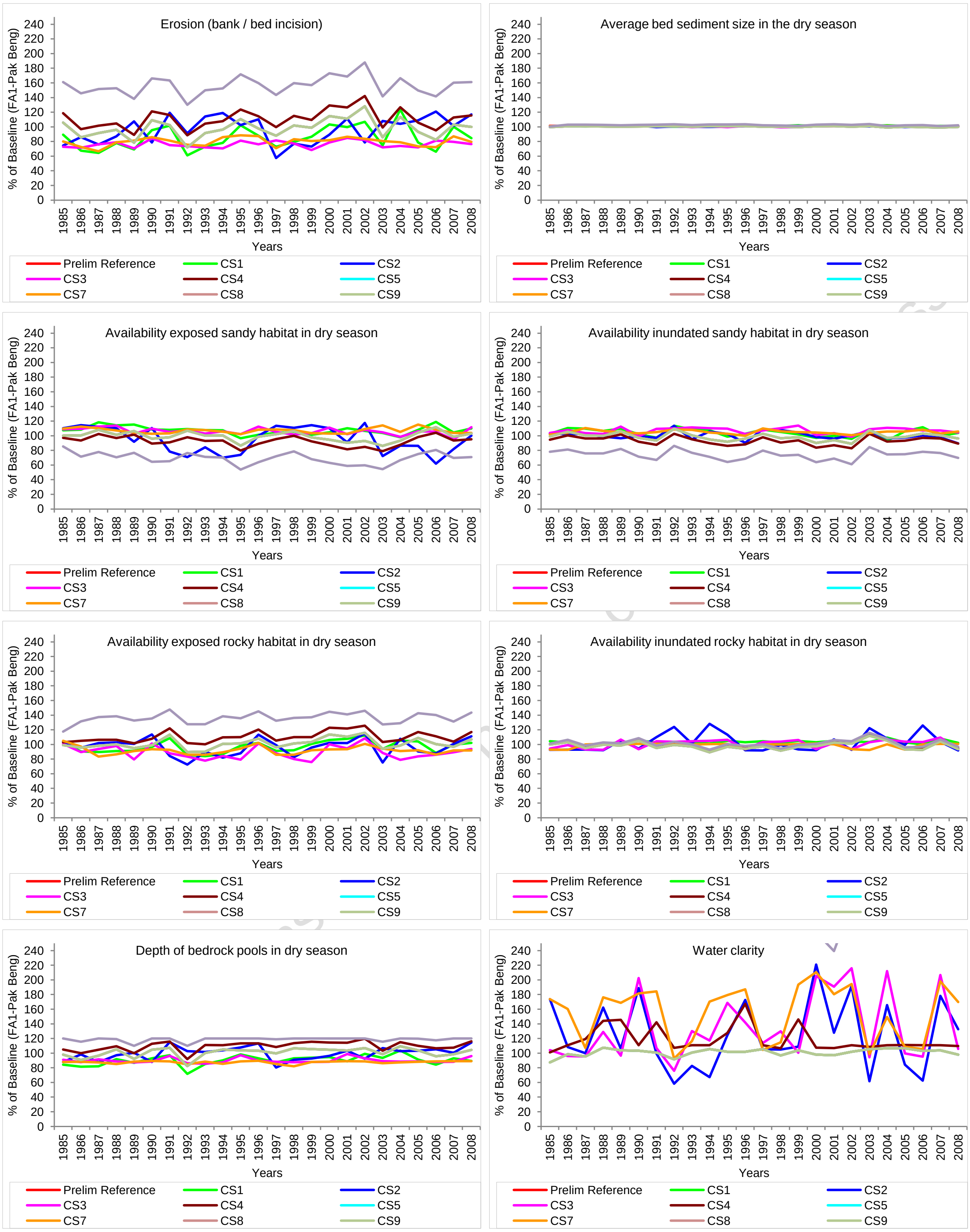


Figure 5.2 **Time-series of predicted changes in geomorphological indicators at FA1. Scenario lines not visible are hidden by those showing.**

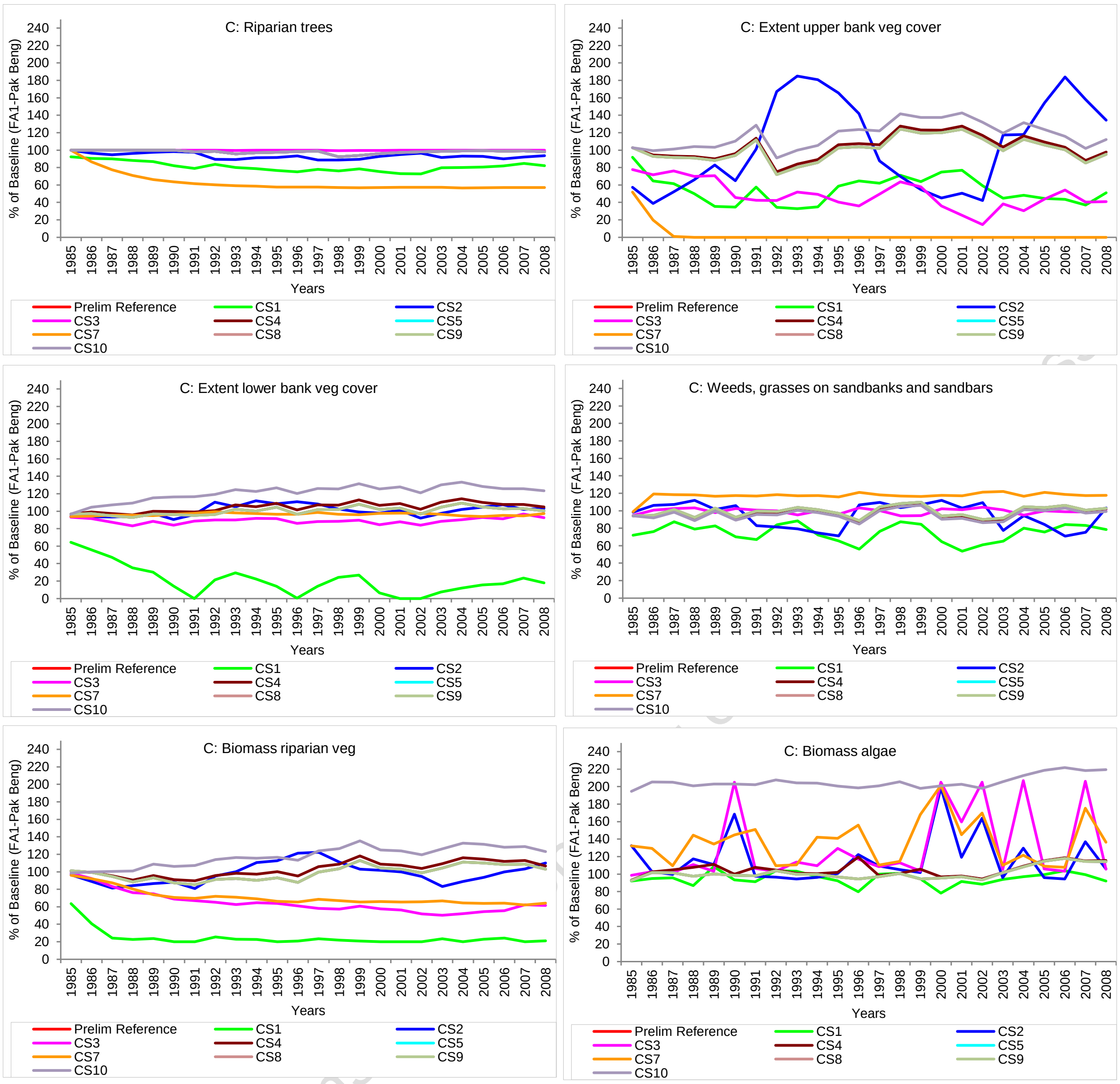


Figure 5.3 **Time-series of predicted changes in vegetation indicators at FA1. Scenario lines not visible are hidden by those showing.**

CS3: A c. 40% reduction in upper bank cover. This is driven by a major reduction in duration of wet season, which is expected to reduce the number of tree-damaging floods each year, and thus allow for encroachment of terrestrial forest to the detriment of riparian upper bank vegetation.

CS4: No major changes.

CS5: No major changes.

CS7: Similar to CS3. CS7 results in a predicted major reduction in upper bank cover driven by a perceived reduction in the number of tree-damaging floods each year. This is expected to increase encroachment of terrestrial forest into the upper bank vegetation.

CS8: No major changes.

CS9: No major changes.

5.1.3.3 Macroinvertebrates

The changes in the macroinvertebrate indicators at FA1 can be summarised as follows (refer to Table 5.3 and Figure 5.4):

CS1: No major changes.

CS2: No major changes.

CS3: No major changes.

CS4: No major changes.

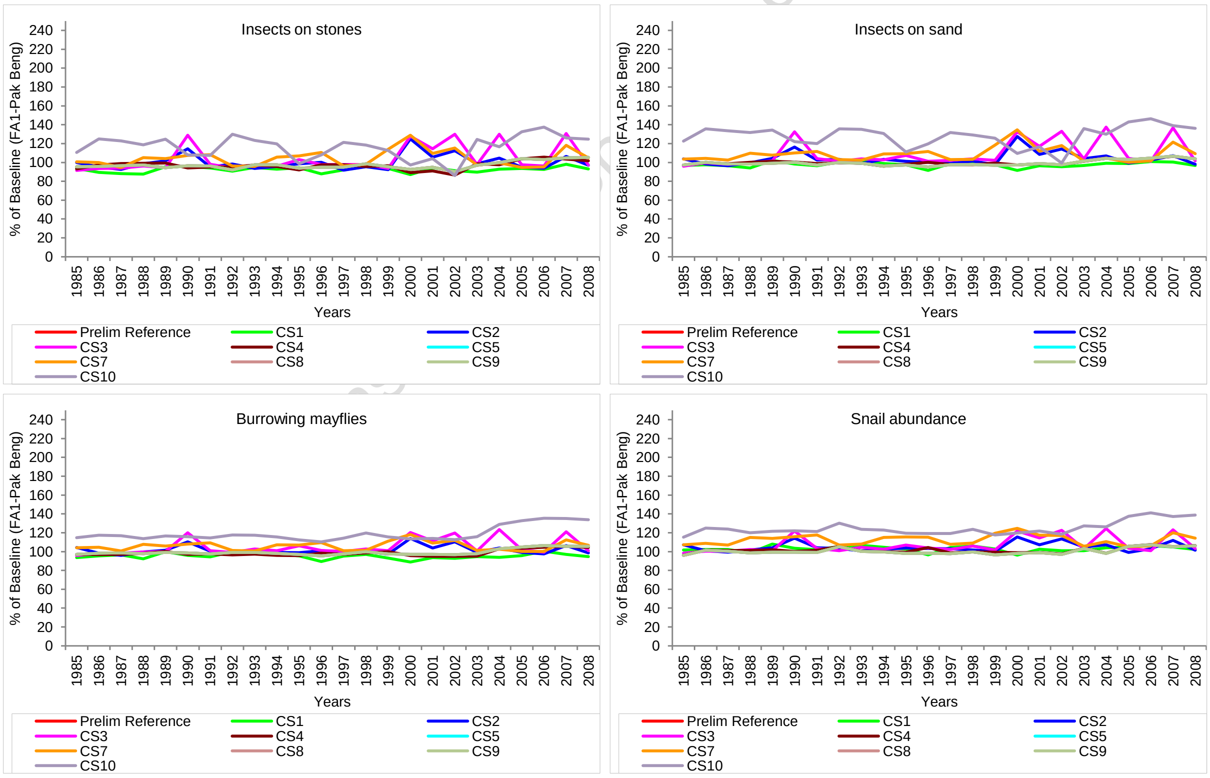
CS5: No major changes.

CS7: A small increase in most indicators in response to a slight increase in algae resulting from less sediment, clear water and hence better light penetration. The only decrease is a small decline in zooplankton, linked to the lower volumes of water associated with this scenario. This is offset somewhat by the increase in algae, which are a favoured food source to zooplankton.

CS8: No major changes.

CS9: No major changes.

CS10: Response similar to but slightly larger than CS7. Increases in most indicators in response to a slight increase in algae due lower sediment loads, clearer water, and hence better light penetration.



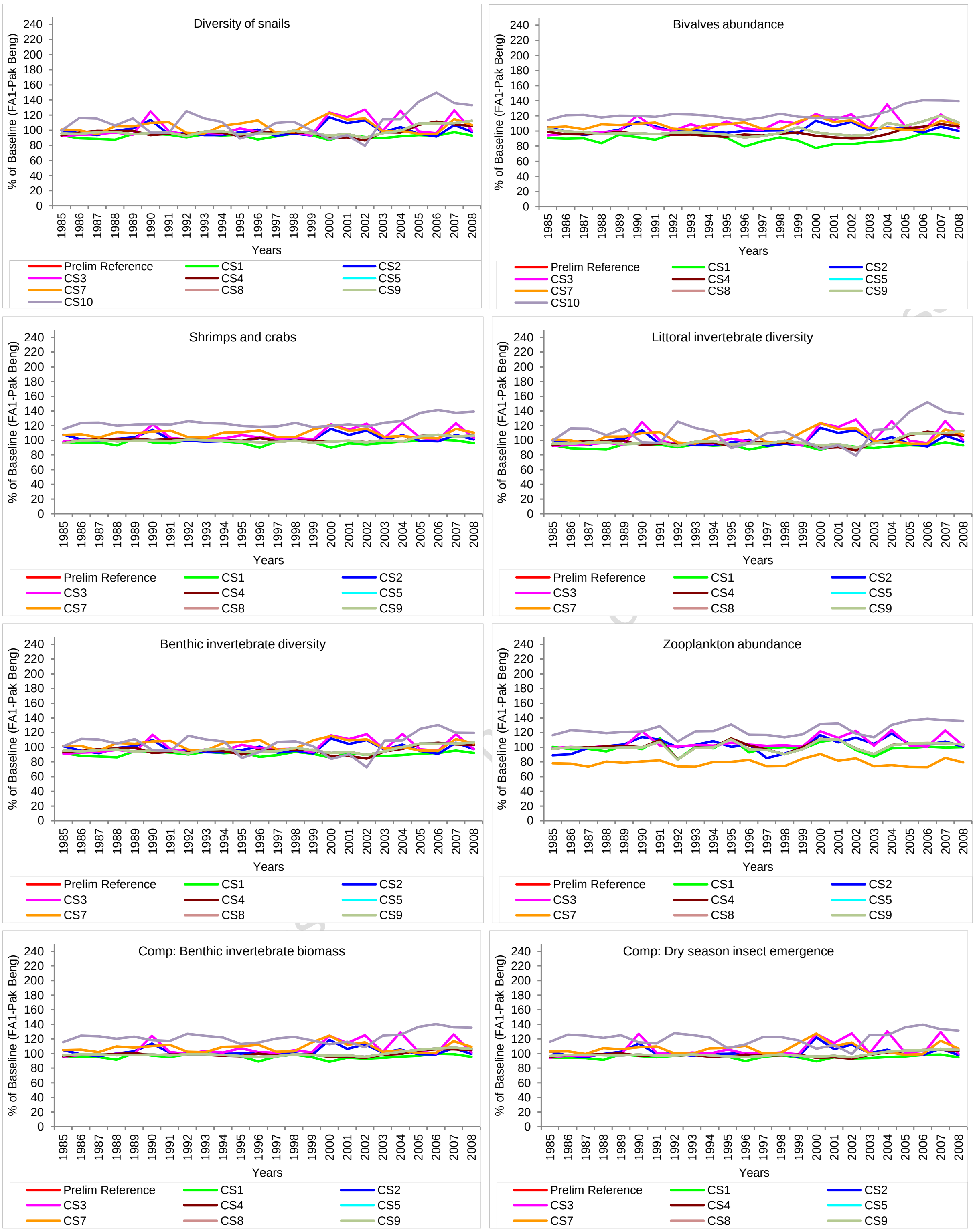


Figure 5.4 Time-series of predicted changes in macroinvertebrate indicators at FA1. Scenario lines not visible are hidden by those showing.

5.1.3.4 *Fish*

The changes in the fish indicators at FA1 can be summarised as follows (refer to Table 5.3 and Figure 5.5):

CS1: The Main channel resident (long distance white) guild (increase by *c.* 100%) is most affected by the flow changes in CS1, although Rithron residents and Main channel spawners are also predicted to increase. Predicted increases in the abundance of these fish will also have knock-on effect on fish biomass, which is also predicted to be higher under CS1 (increase by c. 20%). These changes are driven by several factors. Of these, possibly the most relevant is increase in dry season flows, which can assist recruitment by flushing spawning beds and maintaining dry season pool depths, which the fish use as refuge areas. It may be, however, that these improvements are a little exaggerated in the current DSS. Eurytopic fish are expected to do less well, mostly as a result of competition from the other fish.

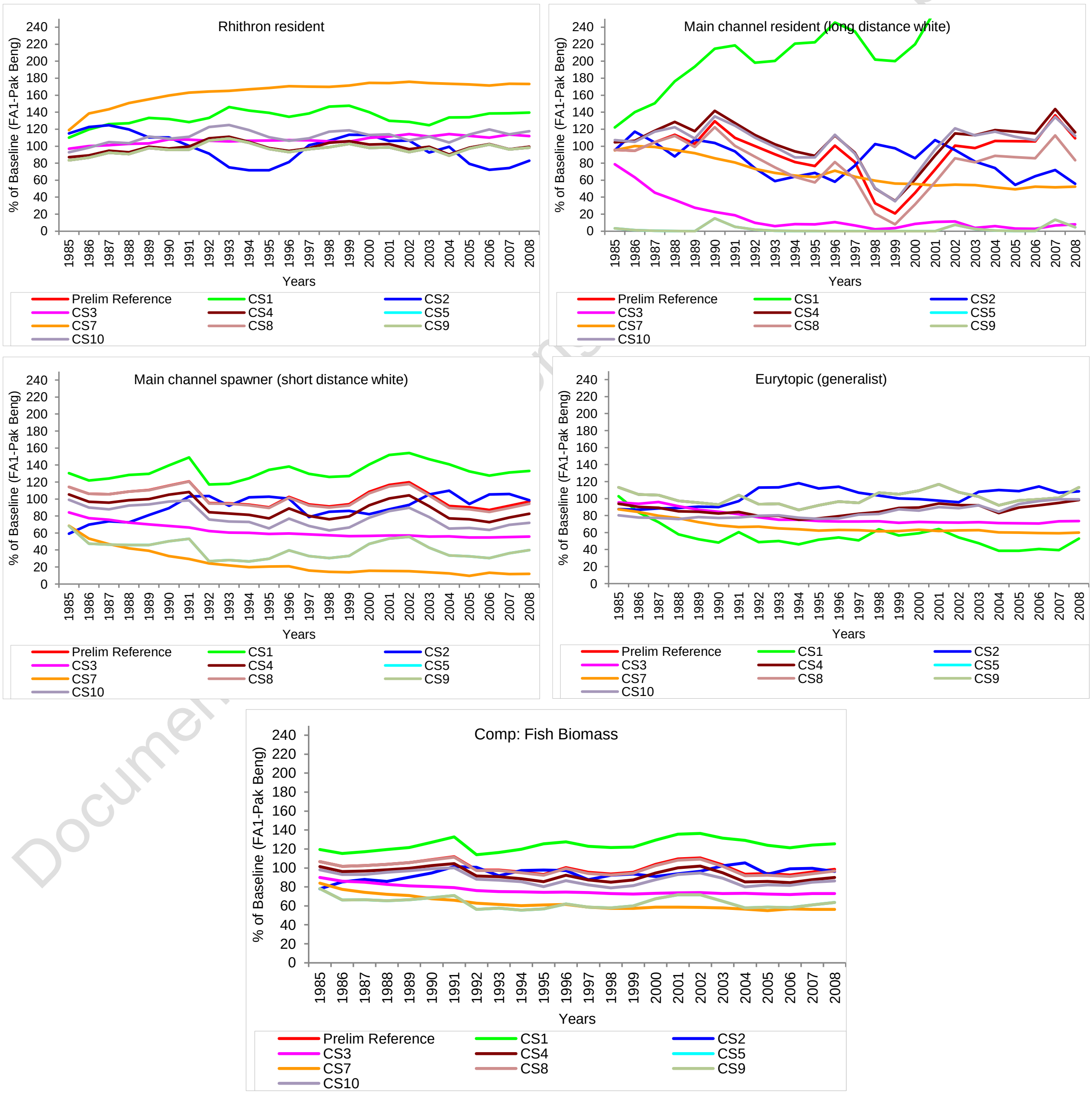


Figure 5.5 **Time-series of predicted changes in fish indicators at FA1. Scenario lines not visible are hidden by those showing.**

CS2: No major changes.

CS3: The Main channel resident (long distance white) guild is most affected by the flow changes in CS3, and is predicted to decline by c. 50%. Main channel spawners (short-distance white) and eurytopes are also predicted to decrease. These reductions are mainly due to the reduced duration of the wet season in this scenario. Flood duration is important to white fish as they migrate upstream for breeding and growth out. The longer the duration of the flood season the more opportunities to spawn and grow, and the greater the time the inundated vegetation has to decay and release nutrients to stimulate primary and secondary production.

CS4: No major changes predicted. Some minor changes related to increase erosion, clearer water and increased algal growth.

CS5: Major changes in .main channel residents and Main channel spawners as a result of an in-channel obstruction between FA1 and FA2. An important part component of the life cycle of any migratory species is connectivity between habitats or areas of rivers that enable such species to complete their life cycles. All migratory species typically migrate up or downstream from feeding and refuge areas to breeding and nursery areas and free movement between these areas is imperative. Consequently, there is a need to link zones both downstream and upstream and net importer or net exporters of different life stages to complete their life cycles and maintain productivity. In the case of main channel long distance migrators, it is critical that free movement is possible between key grow-on habitats, such as the Viet Namese Delta, the Cambodian floodplain and Tonle Sap system, and potential breeding areas upstream in the main channel and tributaries.

CS7: CS7 favours Rithron species (increase of c. 70%) because the dry season duration is important to Rhithron fishes as conditions over shallower waters and rapids become more suitable for breeding and growth. The longer the duration of the dry season the opportunities to spawn and grow before the onset of torrential flows, provided reasonable flows and depths are maintained, which is the case in CS7. Conversely, the Main channel spawners (decline of c. 60%) prefer longer wet seasons, as they migrate upstream and / or to the floodplain for breeding and growth out, and so they are expected to decline under CS7.

CS8: CS8 is similar to CS5 in that it is a migratory scenario, but CS8 has a barrier between FA4 and FA5, which has a correspondingly small impact on the fishes at FA1 than does a barrier between FA1 and FA2.

CS9: Similar to CS5, but with the addition of the impact at FA4 and FA5.

CS10: Similar pattern of predicted changes as for CS4, but more marked in line with the added reduction in sediment supply.

5.1.3.5 Herpetofauna

The changes in the herpetofauna indicators at FA1 can be summarised as follows (refer to Table 5.3 and Figure 5.6):

CS1: Ranids are negatively affected (decrease by c. 50%) under CS1 because riparian vegetation provides shelter, ambush place (for foraging) and foods for wildlife, including amphibians (Catterall 1993, Catterall et al. 2007) and this is predicted to be seriously compromised under CS1. Obvious inhabitants of the riparian zone are frogs whose life cycles are inextricably linked with riparian habitat. When it is lost, many amphibians can no longer survive due to loss of habitat or exposure to their predators, including human.

CS2: No major changes.

CS3: Ranids are negatively affected (decrease by c. 25%) under CS2 because all amphibians depend to some extent on the availability of fresh water for successful reproduction, regardless of whether they engage in direct development in the terrestrial environment or deposit their eggs in aquatic habitats. Short wet season duration will not provide enough water for small pools, ponds in the floodplain around the lake for frog breeding, resulted in frog population decline. The water snakes are also negatively affected (decrease by c. 45%), mainly through their food. Most water snakes in the LMB are among the top predators, feeding predominantly on fishes and amphibians, but also on other reptiles and crustacean. Thus the reduction and fish biomass and amphibian biomass that is triggered by CS3 is expected to result in a decline in water snakes.

CS4: No major changes.

CS5: The water snakes are negatively affected by CS5 (decrease by c. 20%), mainly because of a loss of fish, which form an important part of their prey.

CS7: Similar to CS3. CS7 results in a predicted reduction in amphibians (c. 75%) and water snakes (c. 60%).

CS8: Similar to CS5.

CS9: No major changes predicted. Some minor changes related to increase erosion, clearer water and increased algal growth.

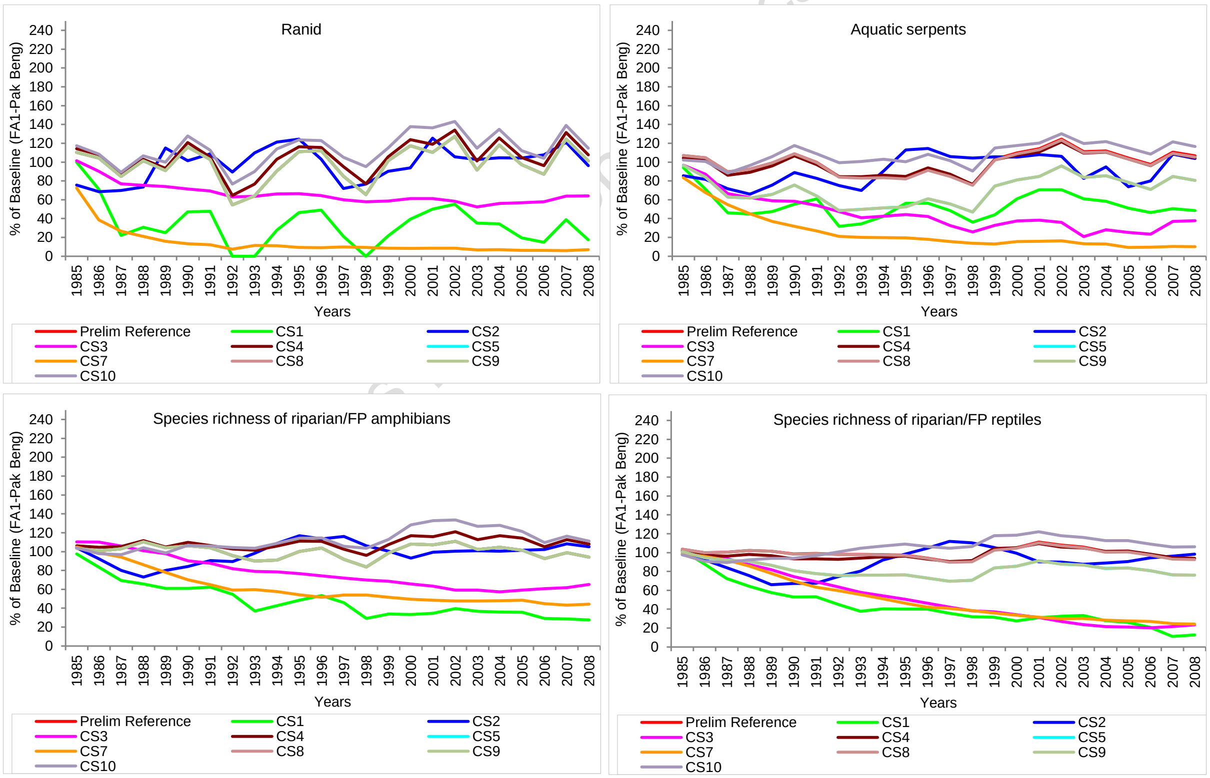


Figure 5.6 **Time-series of predicted changes in herpetofauna indicators at FA1. Scenario lines not visible are hidden by those showing.**

5.1.3.6 Birds

The changes in the bird indicators at FA1 can be summarised as follows (refer to Table 5.3 and Figure 5.7):

CS1: Jerdon's bushchat (Small non-flocking land bird of seasonally-flooded vegetation) is negatively affected (decrease by c. 45%) because it breeds in 'channel bushland' in the channel, i.e., lower bank vegetation, which is predicted to be seriously compromised by CS1.

CS2: Medium/large ground nesting species and Bank/hole nesters are predicted to be slightly positively affected by CS2, mainly because of slightly reduced erosion, which promotes sandy banks required for nesting.

CS3-9: No major changes.

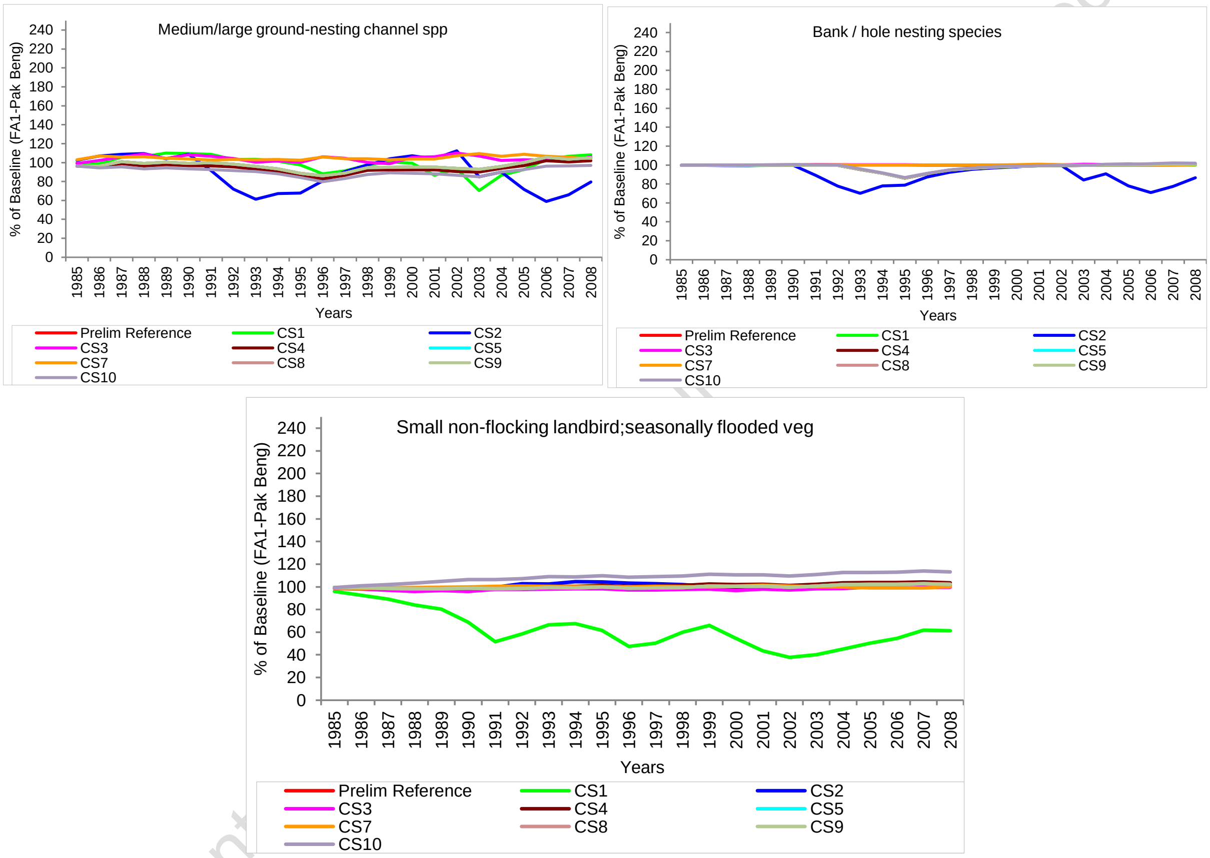


Figure 5.7 Time-series of predicted changes in bird indicators at FA1. Scenario lines not visible are hidden by those showing.

5.1.4 Overall integrity

The Overall Ecological Integrity for each calibration scenario relative to the Preliminary Reference Scenario at FA 1 is illustrated in Figure 5.8.

In terms of the predictions generated by the preliminary calibrated BioRA DSS, the ecosystem at FA1 is most affected by CS3 and CS7, both of which have short wet seasons. The prediction is a drop in integrity from a C to a D for CS3 and a D/E for CS7.

The migration scenarios, CS5 and CS9, both of which have a barrier between FA1 and FA2 are also predicted to affected overall integrity but mainly because of their impact on migratory fish, in particular the Main channel residents (long distance white fish). The barrier between FA4 and FA5 did not have a major effect on integrity. The weights for the fish contribution to integrity are based on guild contribution to composition of catch (Interim Technical Report 1: Volume 1 – Specialists' Report) and it may be that this would be better based on contribution to diversity.

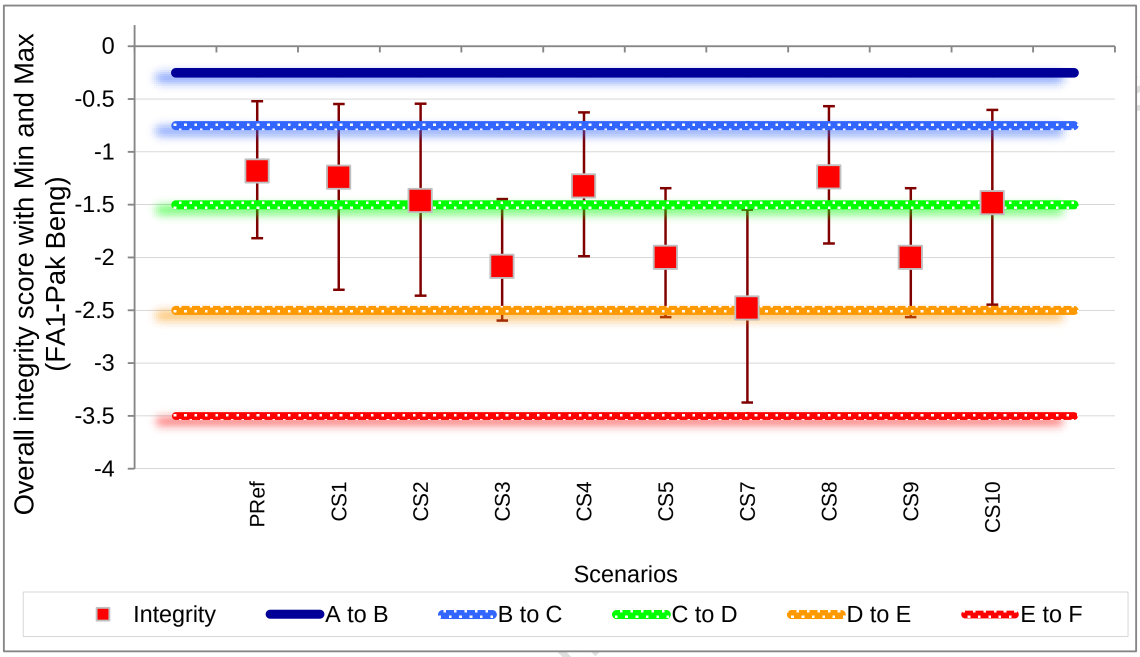


Figure 5.8 **Overall Ecological Integrity scores for the Preliminary Reference Scenario (PRef) and each of the calibration scenarios at FA1 (CS1-10)**

5.2 Focus Area 2: Vientiane

FA2: Vientiane represents BioRA Zone 2, which extends from Pak Beng to just upstream of Vientiane.

5.2.1 Characteristics of the flow regime of each CS at FA2

The main characteristics of the flow regimes at FA2 associated with each of the CSs are summarised in Table 5.4.

Table 5.4 **Characteristics of the flow regime (median values) of each CS at FA2 (Vientiane)**

FA2-Vientiane	Units	PRef	CS1	CS2	CS3	CS4	CS5	CS7	CS8	CS9	CS10
Mean annual runoff	m^3/s	4678.58	4674.19	4528.52	4022.93	4678.58	4678.58	3092.02	4678.58	4678.58	4678.58
Dry onset	week	50.00	52.00	50.00	48.00	50.00	50.00	47.00	50.00	50.00	50.00
Dry duration	days	167.50	137.00	163.50	211.00	167.50	167.50	226.00	167.50	167.50	167.50
Dry Min 5day Q	m^3/s	960.99	1817.93	940.29	757.90	960.99	960.99	1085.84	960.99	960.99	960.99
Wet onset	week	25.00	25.00	25.00	28.00	25.00	25.00	28.00	25.00	25.00	25.00
Wet duration	days	148.00	148.00	148.00	108.00	148.00	148.00	93.00	148.00	148.00	148.00

FA2-Vientiane	Units	PRef	CS1	CS2	CS3	CS4	CS5	CS7	CS8	CS9	CS10
Wet Max 5day Q	m^3/s	15508.2	13056	15953.1	13272.1	15508.2	15508.2	8248.79	15508.2	15508.2	15508.2
Flood volume	MCM	109007	96656.9	107937	87592.6	109007	109007	48389.3	109007	109007	109007
Dry ave daily vol	MCM	129.05	187.26	124.44	121.99	129.05	129.05	143.80	129.05	129.05	129.05
T1 ave daily vol	MCM	317.14	311.14	302.41	311.21	317.14	317.14	405.48	317.14	317.14	317.14
Wet ave daily vol	MCM	754.96	668.99	797.57	811.04	754.96	754.96	520.31	754.96	754.96	754.96
T2 ave daily vol	MCM	287.90	298.27	302.38	291.54	287.90	287.90	357.49	287.90	287.90	287.90
T1 onset	week	21.00	20.00	21.50	26.00	21.00	21.00	21.00	21.00	21.00	21.00
T2 onset	week	46.00	46.00	46.00	44.00	46.00	46.00	46.00	46.00	46.00	46.00
D: ave w/in day range	m^3/s	30.32	24.55	40.15	26.49	30.32	30.32	31.63	30.32	30.32	30.32
T1: ave w/in day range	m^3/s	183.71	150.12	142.38	72.12	183.71	183.71	45.07	183.71	183.71	183.71
T2: ave w/in day range	m^3/s	74.15	60.10	77.55	51.29	74.15	74.15	76.72	74.15	74.15	74.15
D: ave Ch Velocity	m/s	0.41	0.49	0.42	0.39	0.41	0.41	0.44	0.41	0.41	0.41
W: ave Ch Velocity	m/s	0.79	0.77	0.77	0.75	0.79	0.79	0.68	0.79	0.79	0.79
D: ave Ch Depth	m	5.04	5.18	4.11	3.57	5.04	5.04	5.24	5.04	5.04	5.04
Wet: ave Ch Depth	m	11.14	11.02	11.15	10.79	11.15	11.14	8.93	11.14	11.14	11.15
D: min Ch Depth	m	4.45	4.51	3.00	2.63	4.45	4.45	4.73	4.45	4.45	4.45
D: max Ch Depth	m	6.87	6.75	7.47	4.99	6.59	6.87	6.48	6.87	6.87	6.59
W: ave Wetted perimeter	m	1246.45	1240.79	1241.92	1238.65	1246.53	1246.45	1219.87	1246.45	1246.45	1246.53
D: ave Sediment conc	mg/l	98.4	98.4	97.8	91.7	73.8	98.4	116.4	98.4	98.4	24.6
T1: ave Sediment conc	mg/l	201.0	201.0	203.0	141.9	150.7	201.0	123.5	201.0	201.0	50.2
W: ave Sediment conc	mg/l	513.8	513.8	513.8	390.2	385.4	513.8	287.6	513.8	513.8	128.5
T2: ave Sediment conc	mg/l	188.1	188.1	184.5	103.0	141.1	188.1	164.2	188.1	188.1	47.0
D: ave Sediment load	t/ day	13536	19706	15132	10260	10152	13536	15466	13536	13536	3384
W: ave Sediment load	t/ day	429192	374446	416981	287559	321894	429192	135389	429192	429192	107298
T1: ave Sediment load	t/ day	67417	69696	59639	23215	50563	67417	19385	67417	67417	16854
T2: ave Sediment load	t/ day	56015	60327	52026	23142	42011	56015	37182	56015	56015	14004
W: ave Sediment grain-size	mm	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
W: ave Sediment Onset	week	31.0	30.0	30.0	31.0	31.0	31.0	29.0	31.0	31.0	31.0
W: ave Sediment Duration	days	59.5	64.5	59.5	60.0	59.5	59.5	93.0	59.5	59.5	59.5
D: ave Dissolved Oxygen	mg/l	7.76	7.76	7.88	7.54	7.76	7.76	8.82	7.76	7.76	7.76
D: ave Conductivity	mS/m	26.62	26.62	26.31	22.91	26.62	26.62	26.14	26.62	26.62	26.62
D: ave Total Nitrogen	mg/l	0.28	0.28	0.26	0.31	0.28	0.28	0.35	0.28	0.28	0.28
D: ave Total Phosphorous	mg/l	0.04	0.04	0.05	0.07	0.04	0.04	0.06	0.04	0.04	0.04
D: max Temperature	^oC	29.70	29.70	28.95	32.60	29.70	29.70	28.80	29.70	29.70	29.70

5.2.2 Mean percentage changes

The mean percentage changes (relative to Preliminary Reference Scenario) for the indicators in response to each CS at FA2 (Vientiane) are given in Table 5.5.

Table 5.5 **The mean percentage changes in abundance at FA2 (relative to Preliminary Reference Scenario) for the indicators for the data sets.** Blue and green are changes that represent increases: green = 40-70%; blue = >70%. Orange and red are changes that represent decreases: orange = 40-70%; red = >70%. Preliminary reference, by definition, equals 100%.

Indicators	Calibration scenarios								
	CS1	CS2	CS3	CS4	CS5	CS7	CS8	CS9	CS10
Discipline : Geomorphology									
Erosion (bank / bed incision)	-12.0	-6.0	3.0	9.1	-1.6	-5.9	-1.6	-1.6	37.2
Average bed sediment size in the dry season	-0.5	0.3	1.3	0.7	-0.2	0.2	-0.2	-0.2	2.1

Indicators	Calibration scenarios								
	CS1	CS2	CS3	CS4	CS5	CS7	CS8	CS9	CS10
Availability exposed sandy habitat in dry season	9.6	4.4	16.1	-2.8	1.6	3.9	1.6	1.6	-19.5
Availability inundated sandy habitat in dry season	8.1	-0.7	-6.2	-3.8	1.2	0.3	1.2	1.2	-14.4
Availability exposed rocky habitat in dry season	-2.9	-2.3	21.9	8.3	-0.8	-1.9	-0.8	-0.8	26.9
Availability inundated rocky habitat in dry season	-5.7	-4.8	-5.3	2.8	-1.1	-2.9	-1.1	-1.1	14.8
Depth of bedrock pools in dry season	-8.7	-4.5	-4.5	4.1	-0.8	-10.6	-0.8	-0.8	10.4
Water clarity	-0.3	-2.7	3.8	6.4	-0.3	0.1	-0.3	-0.3	129.8
Discipline : Vegetation									
C: Riparian trees	-0.2	-8.8	-10.4	0.2	0.2	11.5	0.2	0.2	0.2
C: Extent upper bank veg cover	-7.2	13.2	-8.6	1.6	-1.1	-79.9	-1.1	-1.1	15.4
C: Extent lower bank veg cover	-28.3	10.6	16.2	2.5	-0.7	13.3	-0.7	-0.7	19.0
C: Extent herbaceous marsh vegetation cover	-12.4	10.1	4.0	-0.1	-1.9	-5.4	-1.9	-1.9	8.4
C: Weeds, grasses on sandbanks and sandbars	-1.2	8.3	20.2	0.1	0.6	3.4	0.6	0.6	-2.7
C: Biomass riparian veg	-45.3	38.8	38.1	1.9	-2.0	-4.9	-2.0	-2.0	28.1
C: Biomass algae	-0.7	6.7	15.8	2.3	1.9	11.0	1.9	1.9	29.0
Discipline : Macro-invertebrates									
Insects on stones	-4.1	-1.6	0.8	-2.2	-1.2	-0.1	-1.2	-1.2	-5.1
Insects on sand	1.7	0.1	0.5	-0.3	0.7	2.5	0.7	0.7	0.6
Burrowing mayflies	-0.7	0.9	2.0	-0.6	0.3	2.6	0.3	0.3	2.5
Snail abundance	5.6	1.8	4.2	0.3	0.3	7.3	0.3	0.3	5.8
Diversity of snails	-3.5	-0.7	4.1	-1.9	-0.8	0.4	-0.8	-0.8	-4.7
Bivalves abundance	-1.4	1.5	3.3	-2.2	-0.7	3.3	-0.7	-0.7	4.5
Shrimps and crabs	-0.3	0.7	1.4	-0.7	-0.8	2.9	-0.8	-0.8	4.8
Littoral invertebrate diversity	-3.7	-0.8	4.4	-2.0	-0.9	0.3	-0.9	-0.9	-4.9
Benthic invertebrate diversity	-5.2	-2.0	1.2	-3.5	-1.6	-0.4	-1.6	-1.6	-8.8
Zooplankton abundance	0.2	0.6	1.4	0.0	0.0	-24.3	0.0	0.0	4.9
Comp: Benthic invertebrate biomass	0.1	0.6	2.0	-1.0	-0.2	3.1	-0.2	-0.2	2.2
Comp: Dry season insect emergence	-1.0	-0.2	1.1	-1.1	0.0	1.7	0.0	0.0	-0.7
Discipline : Fish									
Rhithron resident	38.9	1.8	30.8	-2.7	-1.5	62.9	-1.5	-1.5	0.7
Main channel resident (long distance white)	91.5	-14.6	-76.8	-4.9	-8.2	-42.2	-23.2	-23.2	-5.6
Main channel spawner (short distance white)	37.5	-12.8	-68.1	-13.2	-22.4	-50.9	-6.9	-26.3	-22.8
Eurytopic (generalist)	-13.9	21.6	14.0	-6.2	2.4	-10.3	2.4	2.4	-7.1
Comp: Fish Biomass	45.7	-7.8	-43.9	-7.9	-12.0	-23.6	-9.2	-17.6	-11.7
Discipline : Herpetofauna									
Ranid	-10.8	14.6	-17.5	3.4	-2.0	-47.2	-2.0	-2.0	10.8
Aquatic serpents	28.1	0.2	-14.5	-2.4	-4.7	-18.7	-3.4	-6.4	-0.8
Aquatic Turtles	36.8	-4.6	-71.9	-12.0	-6.3	-46.7	-4.4	-12.0	-44.9
Species richness of riparian/FP amphibians	-26.1	18.0	15.1	6.9	1.1	-10.2	1.1	1.1	13.3
Species richness of riparian/FP reptiles	1.6	28.1	13.1	-2.9	-7.9	-16.1	-5.3	-12.0	12.3
Discipline : Birds									
Medium/large ground-nesting channel spp	-0.2	-8.5	20.9	-3.8	-0.8	6.6	-0.8	-0.8	-11.8
Bank / hole nesting species	-0.3	-0.5	-4.0	-0.4	-2.2	-1.8	-0.3	-1.8	-1.8
Natural rocky crevice nester in channels	-2.1	-2.1	-4.4	5.1	0.4	-1.7	-1.7	-1.7	-1.7
Small non-flocking landbird;seasonally flooded veg	-10.9	5.7	9.0	1.1	-0.2	7.7	-0.2	-0.2	10.2
Discipline : Mammals									
Otters	5.5	43.1	24.8	1.2	-8.0	-7.5	-4.9	-10.5	37.0

5.2.3 Time-series

5.2.3.1 Geomorphology

The changes in the geomorphological indicators at FA2 are similar to those at FA1 and can be summarised as follows (refer to Table 5.4 and Figure 5.9):

CS1: Slightly lower erosion rates. This is because the bulk of the erosion (and sediment suspension and transport) occurs in the wet season, and wet season flows (and thus shear stresses) are reduced relative to the Preliminary Reference in CS1.

CS2: No major changes.

CS3: Slightly increased erosion rates and slightly clearer water. This apparent anomaly is because the bulk of the erosion (and sediment suspension and transport) occurs in the wet season, which is shorter than Preliminary Reference in CS3. There is also an increase in exposed habitat linked to the lower water levels associated with CS3.

CS4: A slight increase in erosion and a slight increase in water clarity; both linked the reduced sediment supply in CS4.

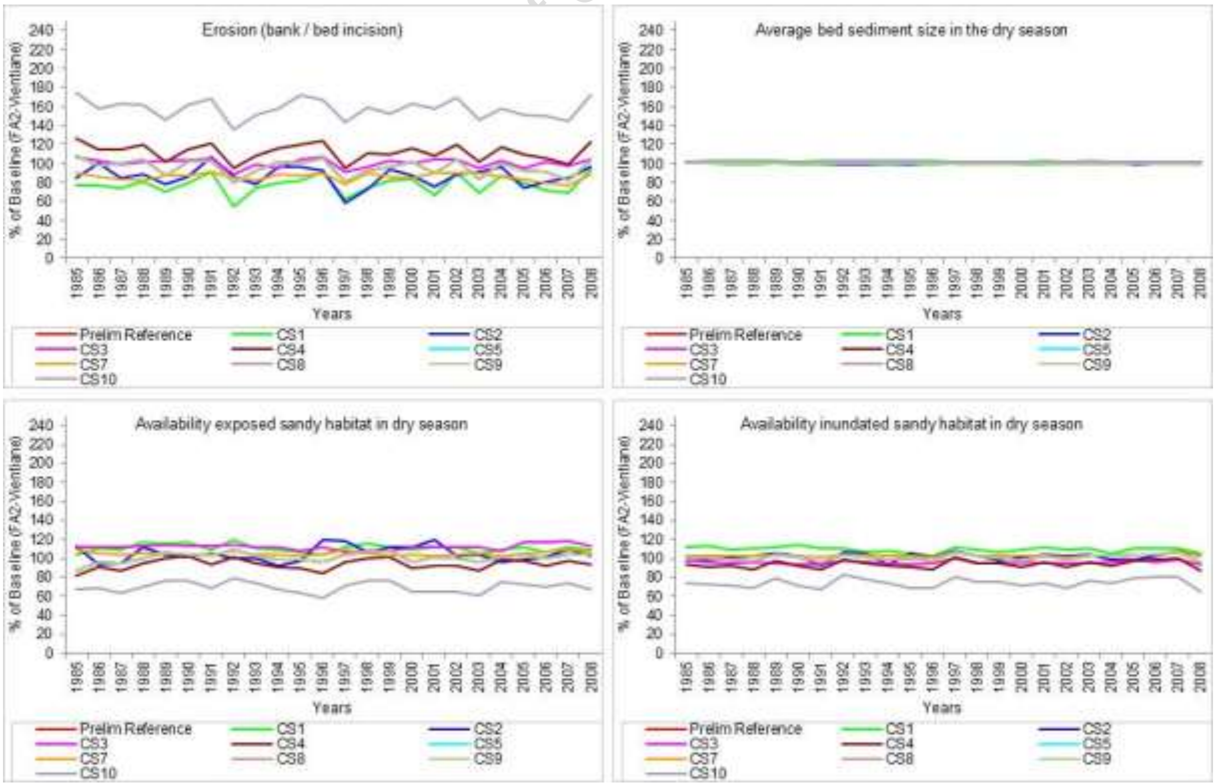
CS5: No major changes.

CS7: No major changes.

CS8: No major changes.

CS9: No major changes.

CS10: A *c.* 37% increase in erosion, relative to the Preliminary Reference Scenario (remembering that Preliminary Reference already has higher erosion as it is using measured data), with concomitant changes in the availability of sandy and rocky habitat, and in water clarity (c130% increase in water clarity).



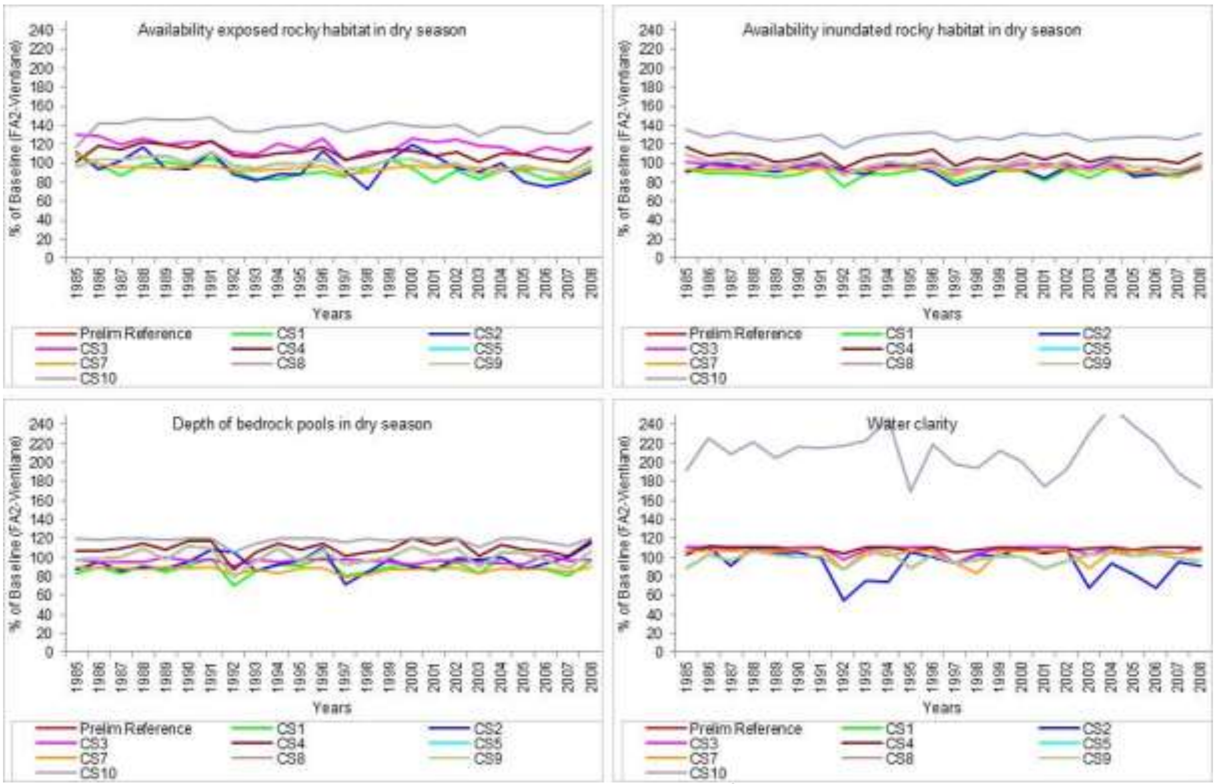


Figure 5.9 **Time-series of predicted changes in geomorphological indicators at FA2. Scenario lines not visible are hidden by those showing.**

5.2.3.2 Vegetation

The changes in the vegetation indicators at FA2 are similar to those at FA1 and can be summarised as follows (refer to Table 5.4 and Figure 5.10):

CS1: CS1 is predicted to result in a *c.* 25% loss of lower bank vegetation and a c. 12% loss in herbaceous marsh. This is as a result of elevated dry season flows, which will drown it. Herbaceous marshes are not well represented in FA2, but might account for up to 2% total biomass. However, the lower bank vegetation is presumed to account for about 50% of the total riparian biomass, consequently there is also a reduction in riparian biomass.

CS2: No major changes.

CS3: A c. 40% reduction in upper bank cover. This is driven by a major reduction in duration of wet season, which is expected to reduce the number of tree-damaging floods each year, and thus allow for encroachment of terrestrial forest to the detriment of riparian upper bank vegetation.

CS4: No major changes.

CS5: No major changes.

CS7: Similar to CS3. CS7 was predicted to reduce upper bank cover driven because of a reduction in the number of tree-damaging floods each year. This is expected to increase encroachment of terrestrial forest into the upper bank vegetation.

CS8: No major changes.

CS9: No major changes.

CS10: Under CS10, the increased water clarity associated with reduced sediment supply was predicted to increase algal biomass in the channel (c. 30%). There were also slight changes in other indicators, related to increased erosion, particularly of sandy banks and insets.

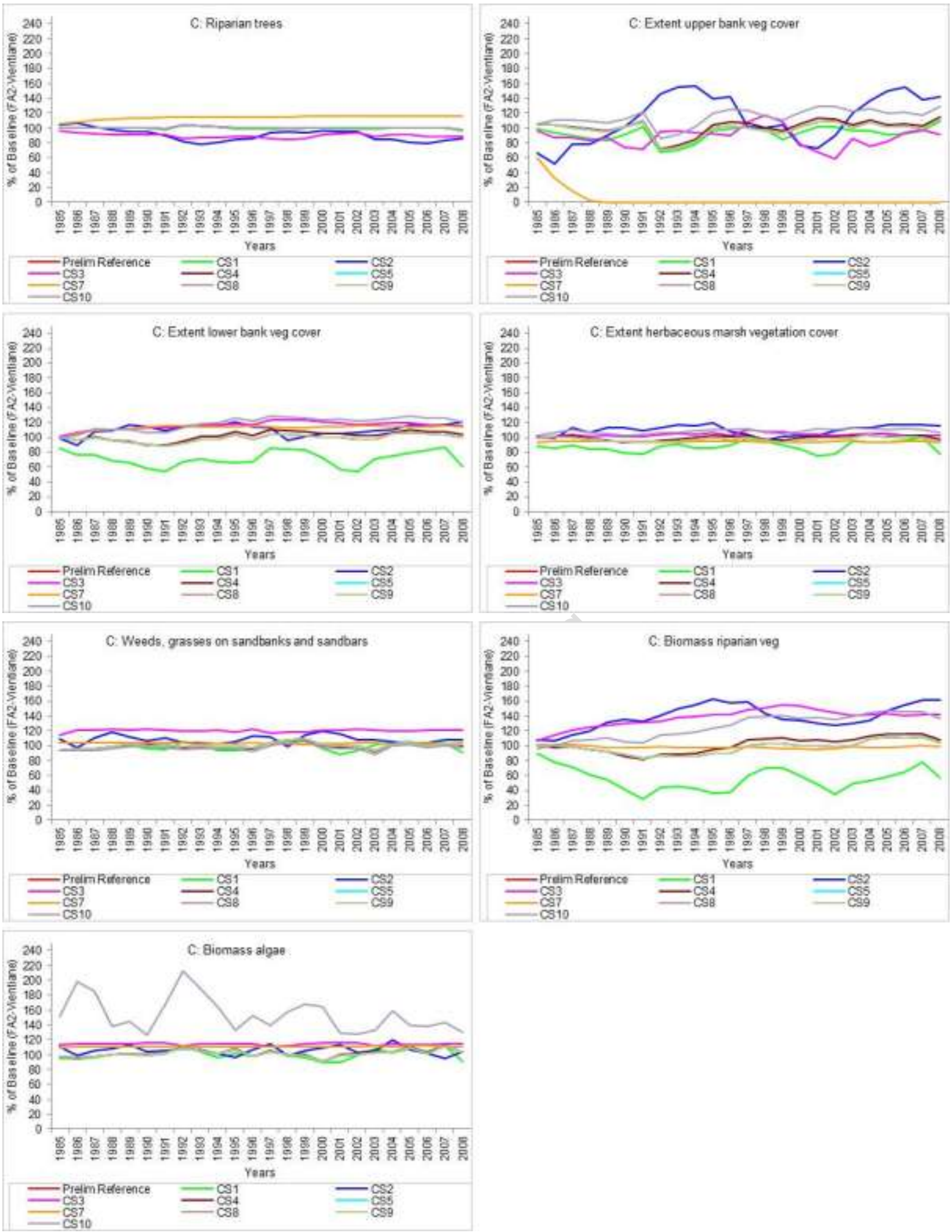


Figure 5.10 **Time-series of predicted changes in vegetation indicators at FA2. Scenario lines not visible are hidden by those showing.**

5.2.3.3 Macroinvertebrates

The changes in macroinvertebrate indicators at FA2 can be summarised as follows (refer to Table 5.4 and Figure 5.11):

CS1: No major changes.

CS2: No major changes.

CS3: No major changes.

CS4: No major changes.

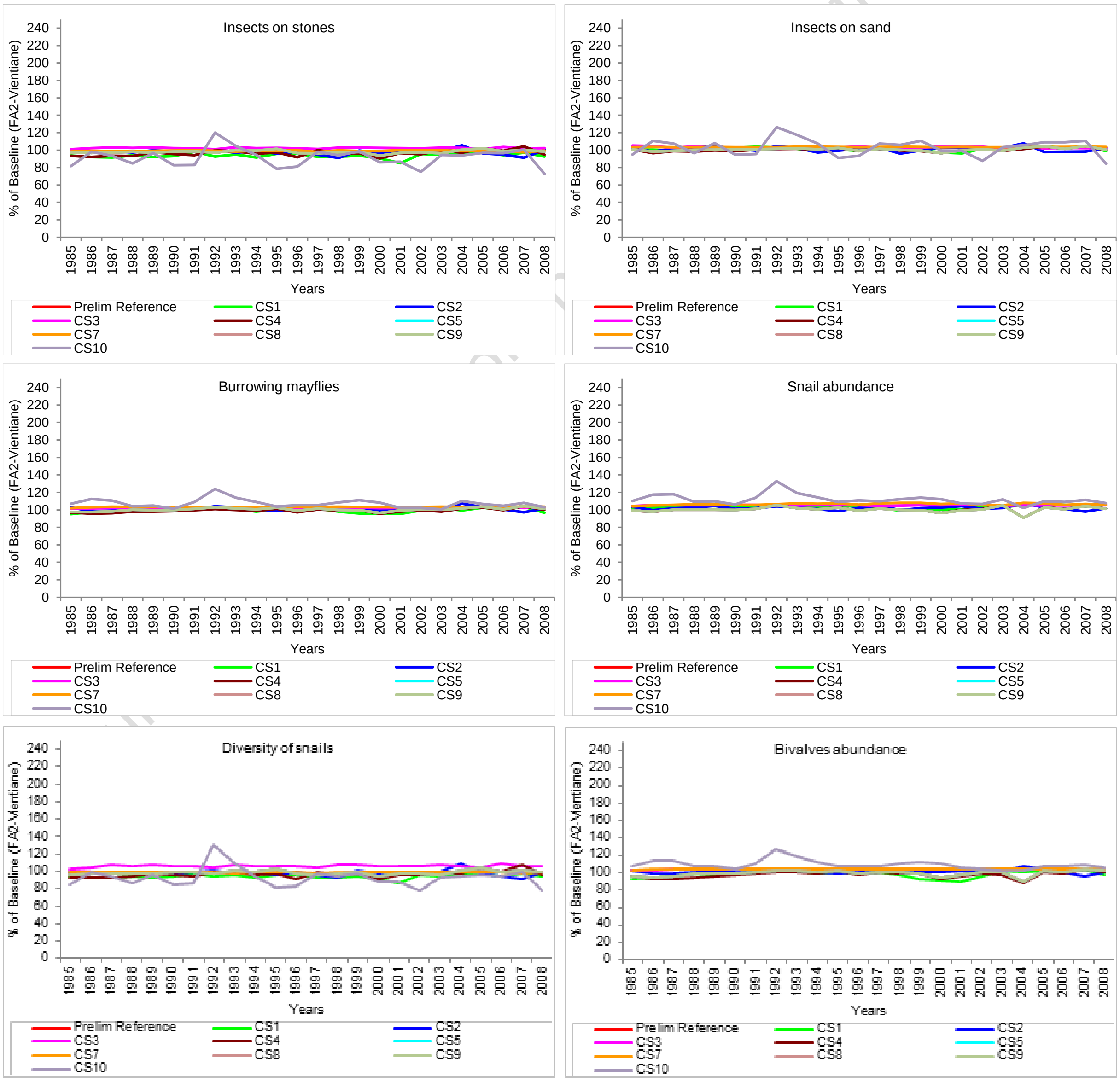
CS5: No major changes.

CS7: A small decline in zooplankton (c. 25%), linked to the lower water volumes of this scenario. This is offset somewhat by an increase in algae, which are a favoured food source of zooplankton.

CS8: No major changes.

CS9: No major changes.

CS10: No major changes.



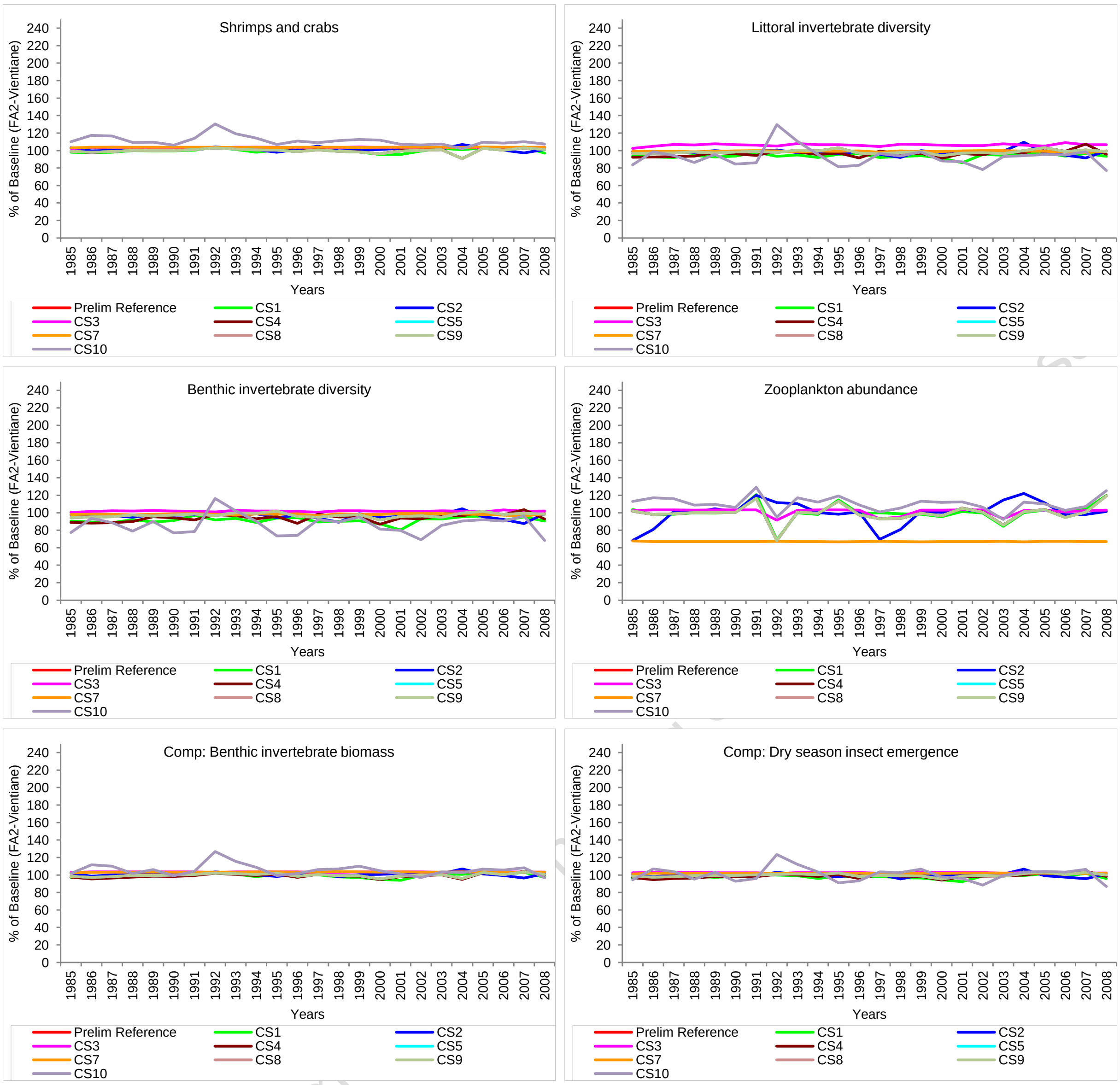


Figure 5.11 **Time-series of predicted changes in macroinvertebrate indicators at FA2. Scenario lines not visible are hidden by those showing.**

5.2.3.4 *Fish*

The changes in the fish indicators at FA2 can be summarised as follows (refer to Table 5.4 and Figure 5.12):

CS1: As was the case at FA1, the Main channel resident (long distance white) guild (increase by *c.* 130%) is most affected by the flow changes in CS1, although Rithron residents and Main channel spawners are also predicted to increase. Predicted increases in the abundance of these fish will also have knock-on effect on fish biomass, which is also predicted to be higher under CS1 (increase by c. 20%). These changes are driven several factors. Of these, possibly the most relevant is increase dry season flows, which can assist recruitment by flushing spawning beds and maintain dry season pool depths, which the fish use as refuge areas. Eurytopic fish are expected to do less well, mostly as a result of competition from the other fish.

CS2: No major changes.

CS3: The Main channel resident (long distance white) guild is most affected by the flow changes in CS3, and is predicted to decline by c. 75%. Main channel spawners (short-distance white) are also predicted to decrease. These reductions are mainly due to the reduced duration of the wet season in this scenario. Flood duration is important to white fish as they migrate upstream for breeding and growth out. The longer the duration of the flood season the more opportunities to spawn and grow, and the greater the time the inundated vegetation has to decay and release nutrients to stimulate primary and secondary production.

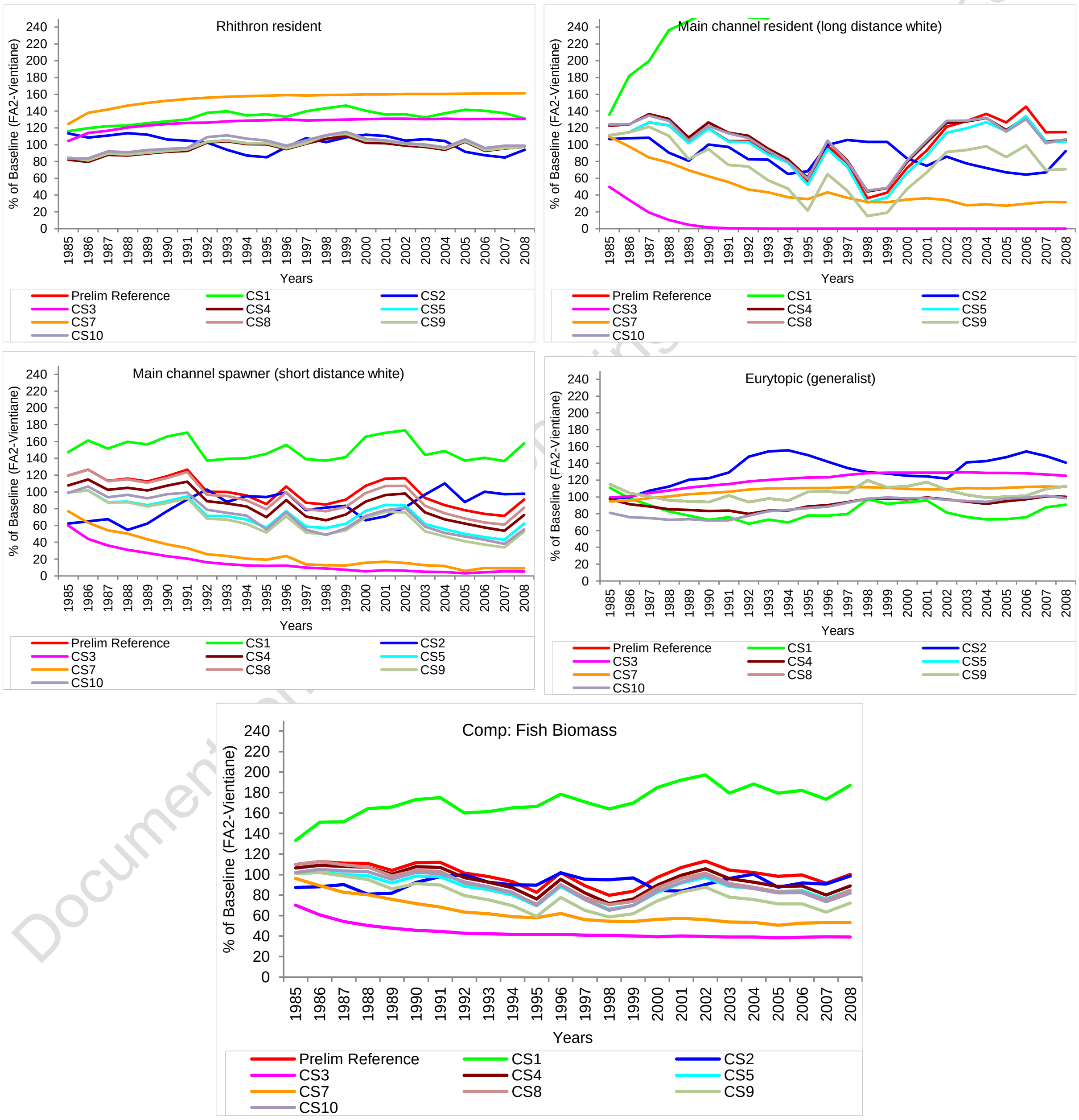


Figure 5.12 Time-series of predicted changes in fish indicators at FA2. Scenario lines not visible are hidden by those showing.

CS4: No major changes predicted. Some minor changes related to increase erosion, clearer water and increased algal growth.

CS5: Major changes in .main channel residents and Main channel spawners as a result of an in-channel obstruction between FA1 and FA2. These changes are less marked than those at FA1 because the barrier is upstream of the FA2.

CS7: CS7 favours Rithron species (increase of c. 60%) because the dry season duration is important to rhithron fishes as conditions over shallower waters and rapids become more suitable for breeding and growth. The longer the duration of the dry season the opportunities to spawn and grow before the onset of torrential flows, provided reasonable flows and depths are maintained, which is the case in CS7. Conversely, the Main channel spawners (decline of c. 50%) prefer longer wet seasons, as they migrate upstream and / or to the floodplain for breeding and growth out, and so they are expected to decline under CS7.

CS8: CS8 is similar to CS5 in that it is a migratory scenario, but CS8 has a barrier between FA4 and FA5.

CS9: Similar to CS5, but with the addition of the impact at FA4 and FA5.

CS10: Similar pattern of predicted changes as for CS4, but more marked in line with the added reduction in sediment supply.

5.2.3.5 Herpetofauna

The changes in the herpetofauna indicators at FA2 can be summarised as follows (refer to Table 5.4 and Figure 5.13):

CS1: The aquatic snakes and turtles increase (*c.* 30 and *c.* 35%, respectively) under CS1 mainly because of an increase in fish, which forms a major part of their diet. They are also assisted by the reduced erosion and a slight increase in exposed sandy habitats.

CS2: No major changes.

CS3: Ranids are negatively affected (decrease by c. 25%) under CS2 because all amphibians depend to some extent on the availability of fresh water for successful reproduction, regardless of whether they engage in direct development in the terrestrial environment or deposit their eggs in aquatic habitats. Short wet season duration will not provide enough water for small pools, ponds in the floodplain around the lake for frog breeding, resulted in frog population decline. The water snakes and aquatic turtles are also negatively affected (decrease by c. 15 and 70%, respectively), mainly through their food. Water snakes and aquatic turtles in the LMB are among the top predators, feeding predominantly on fishes and amphibians, but also on other reptiles and crustacean. Thus the reduction in fish biomass and amphibian biomass that is triggered by CS3 is expected to result in a decline in water snakes and aquatic turtles.

CS4: No major changes.

CS5: The water snakes are slightly negatively affected by CS5 (decrease by c. 6%), mainly because of a loss of fish, which form an important part of their prey.

CS7: Similar to CS3. CS7 results in a predicted reduction in amphibians (c. 50%), water snakes (20%) and aquatic turtles (c. 45%).

CS8: Similar to CS5.

CS9: No major changes predicted. Some minor changes related to increase erosion, clearer water and increased algal growth.

CS10: Aquatic turtles (decrease by c. 45%) mainly because of the increased erosion expected under CS10. The turtles lay their eggs in the soft sediments on the side of the river, which will be removed with increased erosion.

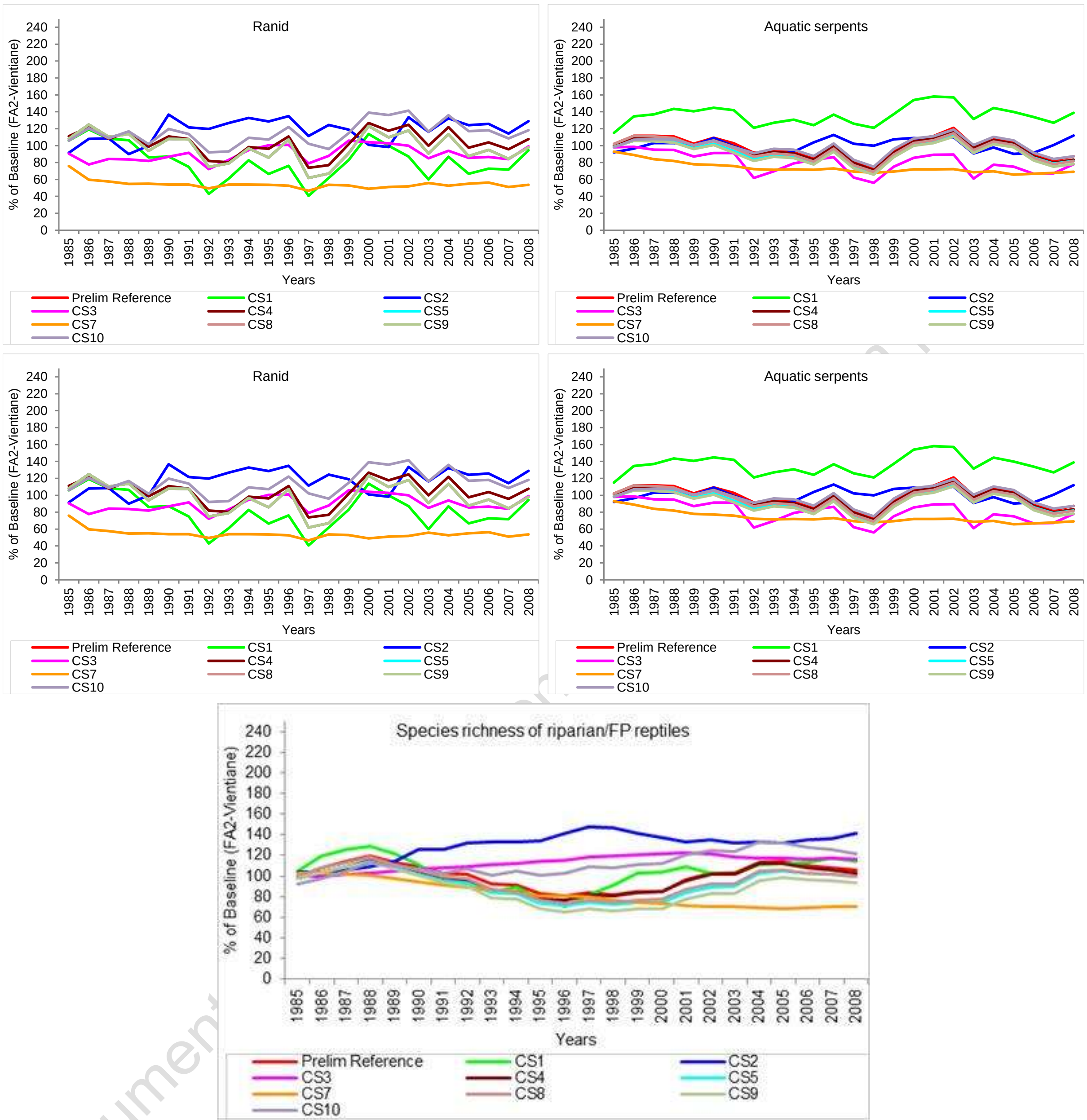


Figure 5.13 Time-series of predicted changes in herpetofauna indicators at FA2. Scenario lines not visible are hidden by those showing.

5.2.3.6 Birds

The changes in the bird indicators at FA2 can be summarised as follows (refer to Table 5.4 and Figure 5.14):

CS1: As was the case at FA1, Jerdon's bushchat (Small non-flocking land bird of seasonally-flooded vegetation) is negatively affected (decrease by c. 10%) because it breeds in 'channel bushland' vegetation in the channel, i.e., lower bank vegetation, which is predicted to be seriously compromised by CS1.

CS2: No major changes.

CS3: CS3 is predicted to favour the Medium/large ground nesting birds, mainly because of greater availability of sandy banks for nesting as a result of slightly reduced erosion. River lapwing prefers wide, slow-moving rivers with sand, rocky or gravel bars and islands (Duckworth *et al.* 1998). As a ground-nesting species, it is susceptible to predation and to variations in water level. River lapwing is likely to require exposure of breeding habitat from about January (when they establish territories and begin initiating nests) through the nesting season (ending around late March), and an additional 3-4 weeks for chicks to fledge. In this scenario, its main food, invertebrates, is not expected to be majorly affected.

CS4: No major changes.

CS5: No major changes.

CS7: No major changes.

CS8: No major changes.

CS9: No major changes.

CS10: CS10 is predicted to result in a decline in species that require sandy banks for breeding (e.g., Medium/large ground nesting birds; c. 12% decrease). This is related mainly to the increased erosion and resultant decline in this habitat. Small non-flocking landbirds on the other hand are expected to increase by c. 10% because of the increase in vegetation associated with this scenario.

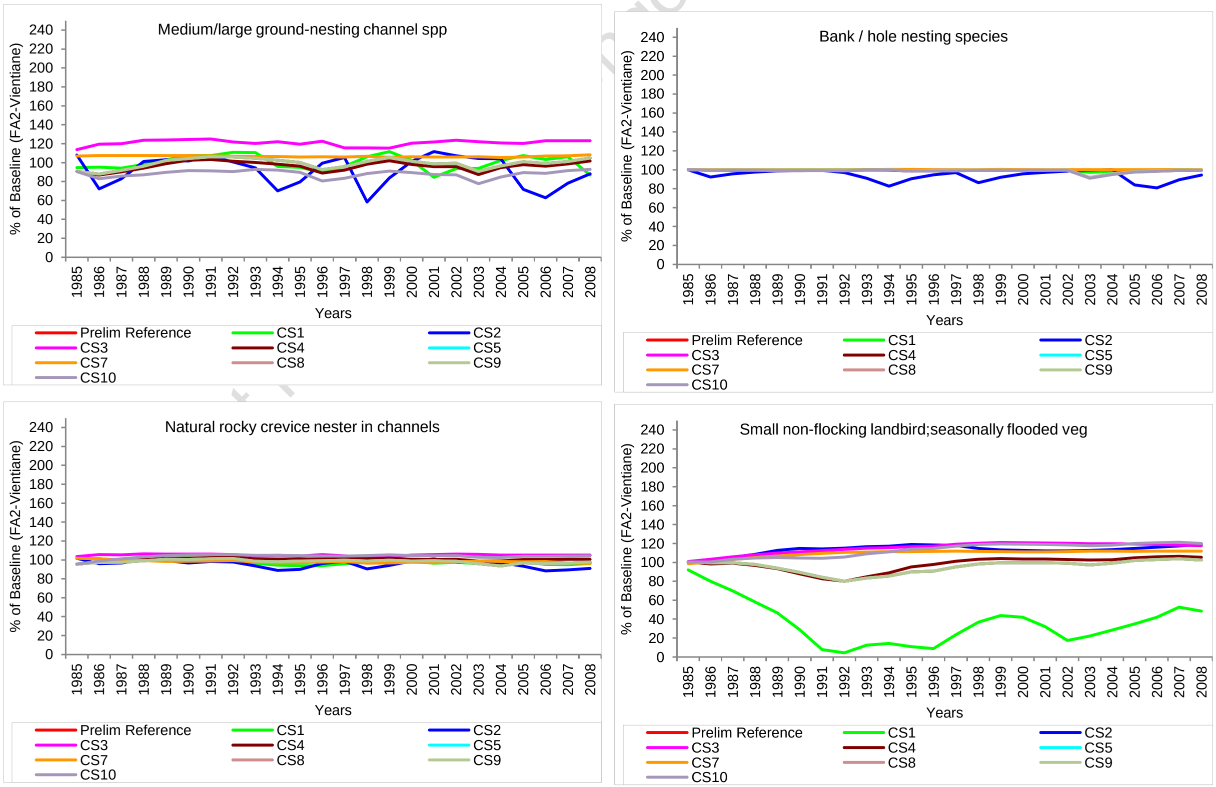


Figure 5.14 Time-series of predicted changes in bird indicators at FA2. Scenario lines not visible are hidden by those showing.

5.2.3.7 Mammals

The only mammal indicator at FA2 is otters. The changes in the otters at FA2 can be summarised as follows (refer to Table 5.4 and Figure 5.14):

CS1: There is a predicted increase in otters (c. 40%), related to the increase in fish, which are a major food item

CS2: Otters are expected to increase (c. 40%) in response the increased vegetation cover associated with CS1. The vegetation provides habitat and protection from predators.

CS4: No major changes.

CS3, CS7 and CS10 Otters are expected to increase (c. 40%) in response the increased vegetation cover associated with these scenarios. CS5, CS8 and CS9 there is a predicted small decline in otters related to the reduction in fish, which are a major food item.

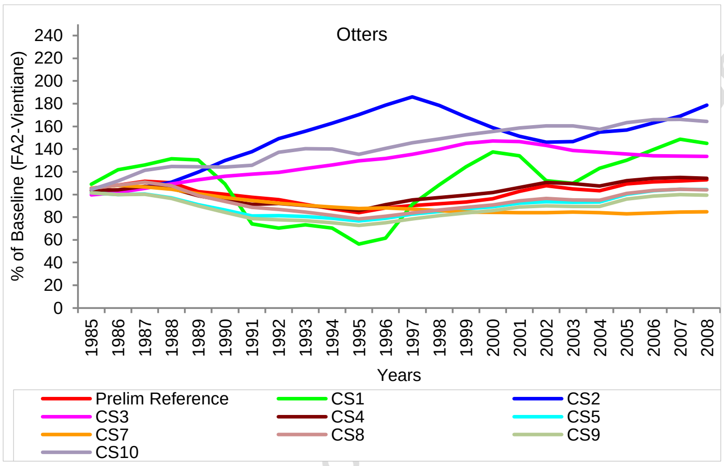


Figure 5.15 Time-series of predicted changes in mammal indicators at FA2. Scenario lines not visible are hidden by those showing.

5.2.4 Overall integrity

The Overall Ecological Integrity for each calibration scenario relative to the Preliminary Reference Scenario at FA2 is illustrated in Figure 5.16.

CS3 and CS7, both of which have short wet seasons have the greatest impact on FA2. The prediction is a drop in integrity from a C to a D.

The migration scenarios, CS5 and CS9, both of which have a barrier between FA1 and FA2 are also predicted to affected overall integrity but mainly because of their impact on migratory fish, in particular the Main channel residents (long distance white fish). The barrier between FA4 and FA5 also has a negative effect on integrity (C to C/D).

For the two sediment-reduction scenarios, CS4 (less 25% sediment supply) and CS10 (less 75% sediment supply), the DSS predicts a decline in overall integrity (by 13% and 36%, respectively). This is to be expected as the increased erosion and water clarity associated with the scenarios will have knock-on effects on habitat condition and food supply.

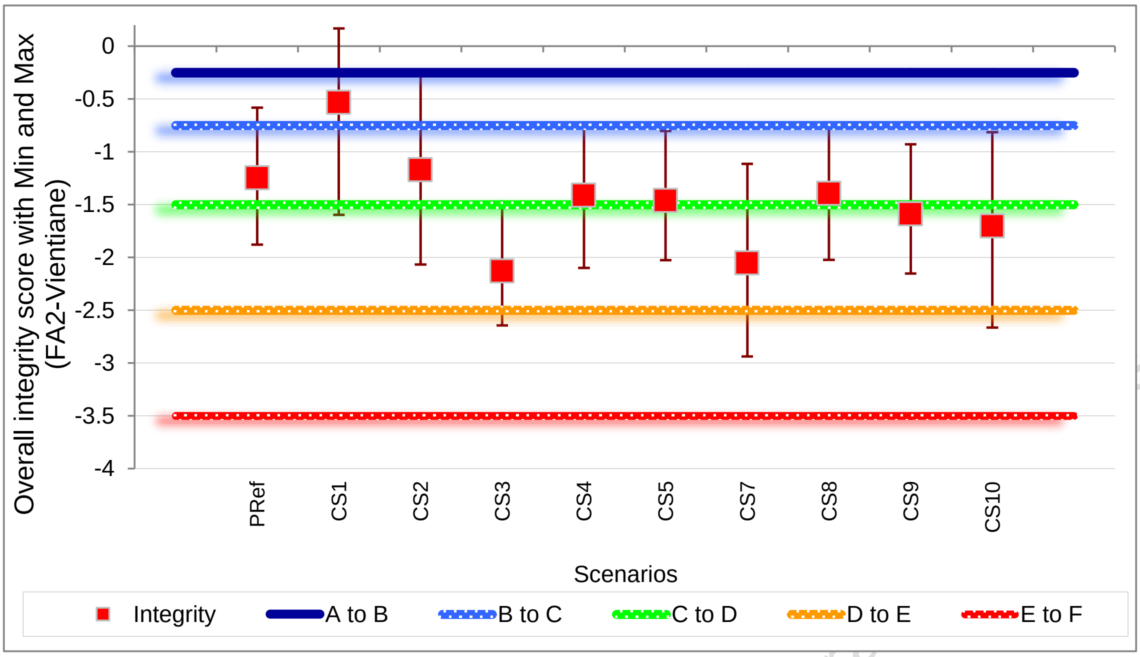


Figure 5.16 Overall Ecological Integrity scores for the Preliminary Reference Scenario (PRef) and each of the calibration scenarios at FA2 (CS1-10)

CS1 is predicted to result in an increase in overall integrity. This is partly because the reduced wet season flows decrease erosion, and offset other negative impacts. Note also that the Preliminary Reference Scenario includes reduce sediment supply at FA1 as recorded at Chaing Saen. It is likely that the Reference Scenario 2007 will not include these trends.

5.3 Focus Area 3: Se Bang Fai

5.3.1 Characteristics of the flow regime of each CS at FA3

The main characteristics of the flow regimes at FA3 associated with each of the data sets are summarised in Table 5.6.

Table 5.6 Characteristics of the flow regime (median values) of each CS at FA3 (Se Bang Fai)[12]

FA3 - Se Bang Fai	Units	PRef	CS1	CS2	CS3	CS4	CS5	CS7	CS8	CS9	CS10
Mean annual runoff	m^3/s	7893.2	7878.7	7673.1	6449.8	7893.2	7893.2	5183.4	7893.2	7893.2	7893.2
Dry onset	week	49.00	52.00	49.00	47.00	49.00	49.00	47.00	49.00	49.00	49.00
Dry duration	days	172.00	143.00	169.00	195.00	172.00	172.00	208.00	172.00	172.00	172.00
Dry Min 5day Q	m^3/s	1272.5	2906.6	1349.8	1057.5	1272.5	1272.5	1368.9	1272.5	1272.5	1272.5
Wet onset	week	24.00	24.00	25.00	27.00	24.00	24.00	28.00	24.00	24.00	24.00
Wet duration	days	142.50	142.50	137.00	101.00	142.50	142.50	89.00	142.50	142.50	142.50
Wet Max 5day Q	m^3/s	254716	20923	26423	25492	25471	25471	14559	25471	25471	25471
Flood volume	MCM	194941	170722	183503	136001	194941	194941	90475	194941	194941	194941

[12] PRef = Preliminary Reference Scenario

FA3 - Se Bang Fai	Units	PRef	CS1	CS2	CS3	CS4	CS5	CS7	CS8	CS9	CS10
Dry ave daily vol	MCM	183.02	285.67	180.78	165.39	183.02	183.02	186.95	183.02	183.02	183.02
T1 ave daily vol	MCM	558.67	527.85	556.08	547.76	558.67	558.67	508.38	558.67	558.67	558.67
Wet ave daily vol	MCM	1348.0	1176.5	1395.2	1346.6	1348.0	1348.0	1016.6	1348.0	1348.0	1348.0
T2 ave daily vol	MCM	490.29	488.54	493.41	492.30	490.29	490.29	502.92	490.29	490.29	490.29
T1 onset	week	21.00	20.00	22.00	23.00	21.00	21.00	28.00	21.00	21.00	21.00
T2 onset	week	44.00	44.00	44.00	41.00	44.00	44.00	34.00	44.00	44.00	44.00
D: ave w/in day range	m^3/s	42.27	33.73	51.70	28.29	42.27	42.27	29.63	42.27	42.27	42.27
T1: ave w/in day range	m^3/s	319.21	237.93	209.96	159.46	319.21	319.21	101.85	319.21	319.21	319.21
T2: ave w/in day range	m^3/s	130.34	99.16	120.10	81.02	130.34	130.34	135.64	130.34	130.34	130.34
D: ave Ch Velocity	m/s	0.70	0.83	0.71	0.66	0.70	0.70	0.71	0.70	0.70	0.70
Wet: ave Ch Velocity	m/s	1.31	1.26	1.29	1.22	1.31	1.31	1.15	1.31	1.31	1.31
D: ave Ch Depth	m	3.42	4.32	3.50	3.14	3.42	3.42	3.49	3.42	3.42	3.42
Wet: ave Ch Depth	m	9.48	8.84	9.36	8.48	9.48	9.48	7.69	9.48	9.48	9.48
D: min Ch Depth	m	2.81	3.96	2.88	2.65	2.81	2.81	3.00	2.81	2.81	2.81
D: max Ch Depth	m	4.89	5.32	5.28	4.12	4.89	4.89	4.40	4.89	4.89	4.89
Wet: ave Wetted perimeter	m	1487.0	1483.2	14879	1479.9	1487.0	1487.0	1472.7	1487.0	1487.0	1487.0
D: ave Sediment conc	mg/l	99.36	99.36	101.32	84.32	74.52	99.36	99.36	99.36	99.36	24.84
T1: ave Sediment conc	mg/l	181.71	181.71	194.71	137.38	136.28	181.71	181.71	181.71	181.71	45.43
Wet: ave Sediment conc	mg/l	509.10	509.10	489.14	550.23	381.82	509.10	509.10	509.10	509.10	127.27
T2: ave Sediment conc	mg/l	219.02	219.02	231.62	157.28	164.27	219.02	219.02	219.02	219.02	54.76
D: ave Sediment load	t/ day	19569	30862	22805	13605	14677	19569	17412	19569	19569	4892.2
Wet: ave Sediment load	t/ day	738478	647943	681153	722250	553859	738478	453542	738478	738478	184620
T1: ave Sediment load	t/ day	103657	107095	87524	49855	77743	103657	45520	103657	103657	25914
T2: ave Sediment load	t/ day	111206	119607	124998	59453	83405	111206	86775	111206	111206	27802
Wet: ave Sediment grain-size	mm	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Wet: ave Sediment Onset	week	30.00	29.50	30.00	29.00	30.00	30.00	30.00	30.00	30.00	30.00
Wet: ave Sediment Duration	days	57.50	64.00	55.00	55.00	57.50	57.50	60.50	57.50	57.50	57.50
D: ave Dissolved Oxygen	mg/l	21.50	22.00	23.00	21.00	21.50	21.50	24.00	21.50	21.50	21.50
D: ave Conductivity	mS/m	183.00	182.00	168.00	206.50	183.00	183.00	157.00	183.00	183.00	183.00
D: ave Total Nitrogen	mg/l	39.00	13.79	51.19	24.12	39.00	39.00	2.98	39.00	39.00	39.00
D: ave Total Phosphorous	mg/l	1.59	1.62	1.52	1.41	1.59	1.59	1.49	1.59	1.59	1.59
D: max Temperature	^oC	9.98	3.04	5.18	0.34	9.98	9.98	0.70	9.98	9.98	9.98

5.3.2 Mean percentage changes

The mean percentage changes (relative to Preliminary Reference Scenario) for the indicators in response to each CS at FA3 (Se Bang Fai) are given in Table 5.7.

Table 5.7 The mean percentage changes in abundance at FA3 (relative to Preliminary Reference Scenario) for the indicators for the data sets. Blue and green are changes that represent increases: green = 40-70%; blue = >70%. Orange and red are changes that represent decreases: orange = 40-70%; red = >70%. Preliminary reference, by definition, equals 100%.

Indicators	Calibration Scenarios								
	CS1	CS2	CS3	CS4	CS5	CS7	CS8	CS9	CS10
Discipline : Geomorphology									
Erosion (bank / bed incision)	-14.9	-3.0	-5.1	7.4	-2.0	-14.6	-2.0	-2.0	32.3
Average bed sediment size in the dry season	-1.2	0.4	1.7	0.9	0.0	0.6	0.0	0.0	2.2
Availability exposed sandy habitat in dry season	3.9	-3.2	21.2	-3.4	1.4	23.5	1.4	1.4	-18.1
Availability inundated sandy habitat in dry season	12.3	3.9	-1.3	-2.5	0.9	1.2	0.9	0.9	-11.7
Availability exposed rocky habitat in dry season	-7.3	-4.8	19.7	4.1	0.2	14.5	0.2	0.2	14.9
Availability inundated rocky habitat in dry season	1.2	2.0	-3.3	4.4	-0.1	-8.5	-0.1	-0.1	15.4
Depth of bedrock pools in dry season	-9.9	-1.9	-6.2	3.8	-1.5	-10.2	-1.5	-1.5	10.9
Water clarity	-0.4	-2.9	4.6	6.3	-0.4	-0.4	-0.4	-0.4	135.3
Discipline : Vegetation									
C: Riparian trees	-29.2	-11.4	4.0	-0.5	-1.7	3.7	-1.7	-1.7	2.6
C: Extent upper bank veg cover	-40	-4.4	-26.9	0.2	-1.6	-66.6	-1.6	-1.6	6.4
C: Extent lower bank veg cover	-61.8	-4.4	0.4	0.1	-1.8	3.0	-1.8	-1.8	6.6
C: Extent herbaceous marsh vegetation cover	21.8	2.3	-16.6	-1.3	-1.8	-0.9	-1.8	-1.8	0.4
C: Weeds, grasses on sandbanks and sandbars	-3.1	-2.6	3.1	-0.1	0.5	-6.1	0.5	0.5	-2.5
C: Biomass riparian veg	-39.5	-15.1	32.2	-5.4	-0.7	7.5	-0.7	-0.7	-21.7
C: Biomass algae	-7.1	2.3	6.0	2.1	1.7	6.0	1.7	1.7	32.4
FP: Extent of flooded forest	-18.1	0.3	-32.3	-1.8	-1.8	-37.5	-1.8	-1.8	-1.8
FP: Extent of herbaceous marsh vegetation	-22.3	9.8	-23.2	-1.4	-1.4	-52.5	-1.4	-1.4	-1.4
FP: Extent of grassland vegetation	-11.8	-0.8	-10.2	-0.5	-0.5	-7.4	-0.5	-0.5	-0.5
FP: Biomass indigenous riparian/ aquatic veg	-63.4	12.4	-57.0	-1.0	-1.0	-65.5	-1.0	-1.0	-1.0
FP: Biomass algae	-4.1	-2.8	-8.5	0.6	-0.4	-0.9	-0.4	-0.4	22.8
Extent invasive riparian cover	26.6	-5.8	26.9	1.9	1.9	44.8	1.9	1.9	1.9
Extent invasive floating/submerged plant cover	-1.1	-4.3	10.0	0.1	0.1	-4.6	0.1	0.1	0.1
Discipline : Macro-invertebrates									
Insects on stones	-4.9	-1.5	-2.3	-1.7	-1.2	-3.8	-1.2	-1.2	-1.7
Insects on sand	1.6	1.3	-0.6	0.0	0.4	0.1	0.4	0.4	3.7
Burrowing mayflies	-2.2	-0.7	-1.4	-1.0	0.2	0.5	0.2	0.2	2.9
Snail abundance	5.5	0.2	-6.5	-0.6	-0.7	1.6	-0.7	-0.7	5.6
Diversity of snails	-6.3	-1.9	-2.0	-1.8	-1.0	-2.9	-1.0	-1.0	-1.2
Neotricula aperta abundance	-8.7	-2.0	-3.0	0.3	-1.7	-6.9	-1.7	-1.7	7.6
Bivalves abundance	-4.6	-2.8	-11.8	-3.6	-1.6	0.9	-1.6	-1.6	4.8
Shrimps and crabs	0.1	-1.3	-9.5	-1.8	-1.8	2.8	-1.8	-1.8	13.8
Littoral invertebrate diversity	-6.3	-2.1	-2.0	-2.0	-1.3	-2.9	-1.3	-1.3	-2.2
Benthic invertebrate diversity	-8.9	-3.5	-4.2	-3.6	-2.0	-4.5	-2.0	-2.0	-5.3
Zooplankton abundance	-2.6	-2.8	-8.1	-1.3	-1.3	-25.6	-1.3	-1.3	4.3
Comp: Benthic invertebrate biomass	-1.9	-1.0	-5.0	-1.2	-0.9	-0.7	-0.9	-0.9	5.3
Comp: Dry season insect emergence	-1.9	-0.3	-1.4	-0.9	-0.2	-1.1	-0.2	-0.2	1.7

Indicators	Calibration Scenarios								
	CS1	CS2	CS3	CS4	CS5	CS7	CS8	CS9	CS10
Discipline : Fish									
Rhithron resident	34.9	6.3	29.4	-1.0	-2.5	52.3	-2.5	-2.5	5.2
Main channel resident (long distance white)	78.2	-13.8	-67.9	-11.3	-6.1	-64.2	-36.1	-36.1	-8.3
Main channel spawner (short distance white)	50.7	-11.5	-49.2	-10.3	-3.9	-50.2	-23.5	-23.5	-15.6
Floodplain spawner (grey)	-12.8	16.3	-44.6	-6.1	2.0	-67.6	2.0	2.0	-8.6
Eurytopic (generalist)	-43.0	13.5	-21.2	-11.1	-1.3	-69.9	-1.3	-1.3	-21.5
Floodplain resident (black fish)	-24.9	6.5	-12.2	-6.2	1.2	-76.3	1.2	1.2	-30.5
Anadromous	78.5	-1.7	-87.2	7.7	2.4	-70.7	-15.7	-15.7	15.7
Comp: Fish Biomass	55.2	-9.1	-47.0	-9.2	-4.3	-45.5	-24.8	-24.8	-9.7
Discipline : Herpetofauna									
Ranid	-13.1	-9.2	-3.3	3.2	0.8	-34.5	0.8	0.8	-10.0
Aquatic serpents	33.9	-7.1	-41.7	-6.8	-3.0	-52.8	-18.5	-18.5	-8.9
Aquatic Turtles	33.3	-32.4	-80.7	-21.4	-8.1	-77.9	-28.7	-28.7	-47.7
Semi-aquatic Turtles	-83.8	-18.6	-32.2	-2.4	2.2	-37.7	2.2	2.2	-12.6
Amphibians-human use	0.5	-1.0	-7.3	0.5	0.5	-8.5	0.5	0.5	0.5
Aquatic/semi-aqu reptiles-human use	-13.8	17.2	-25.6	2.6	2.7	-38.1	2.7	2.7	2.6
Species richness of riparian/FP amphibians	-14.0	-11.2	11.2	2.8	2.7	0.8	2.7	2.7	-18.1
Species richness of riparian/FP reptiles	-2.1	-35.9	-11.3	-23.2	-8.1	-16.6	-23.1	-23.1	-49.8
Discipline : Birds									
Medium/large ground-nesting channel spp	8.5	-2.1	34.0	-2.7	0.2	35.6	0.2	0.2	-8.9
Bank / hole nesting species	0.0	-0.9	-2.4	-1.2	-0.3	-1.0	-0.3	-0.3	-2.5
Natural rocky crevice nester in channels	-4.3	-8.9	0.7	-1.2	-1.9	3.3	-1.9	-1.9	1.7

5.3.3 Time-series

5.3.3.1 Geomorphology

The changes in the geomorphological indicators at FA3 are similar to those at FA1 and FA2 and can be summarised as follows (refer to Table 5.7 and Figure 5.17):

CS1: Erosion rates were lower, the bulk of erosion (and sediment suspension and transport) occurring in the wet season, and flows (and thus shear stresses) reduced relative to the Preliminary Reference. The effect of this at FA3 was greater than at FA1 or FA2 because of the relatively flatter gradient at this site, which affects current speed and shear stress.

CS2: No major changes.

CS3: Slightly increased erosion rates and slightly clearer water. This is because the bulk of the erosion (and sediment suspension and transport) occurs in the wet season, which was shorter than Preliminary Reference in CS3. There was also an increase in exposed habitat linked to the lower water levels associated with CS3.

CS4: A slight increase in erosion and a slight increase in water clarity, both linked to the reduced sediment supply in CS4. Pool depth also increased, but not by much as these are bedrock-controlled pools.

CS5: No major changes.

CS8: No major changes.

CS8: No major changes.

CS9: No major changes.

CS10: A *c.* 32% increase in erosion, relative to Preliminary Reference (remembering that Preliminary Reference already has high erosion as it used measured data), with concomitant changes in the availability of rocky habitat. Water clarity also increased (c. 135%) with the reduced sediment input. Pool depth increased, but not by much as these are bedrock-controlled pools.

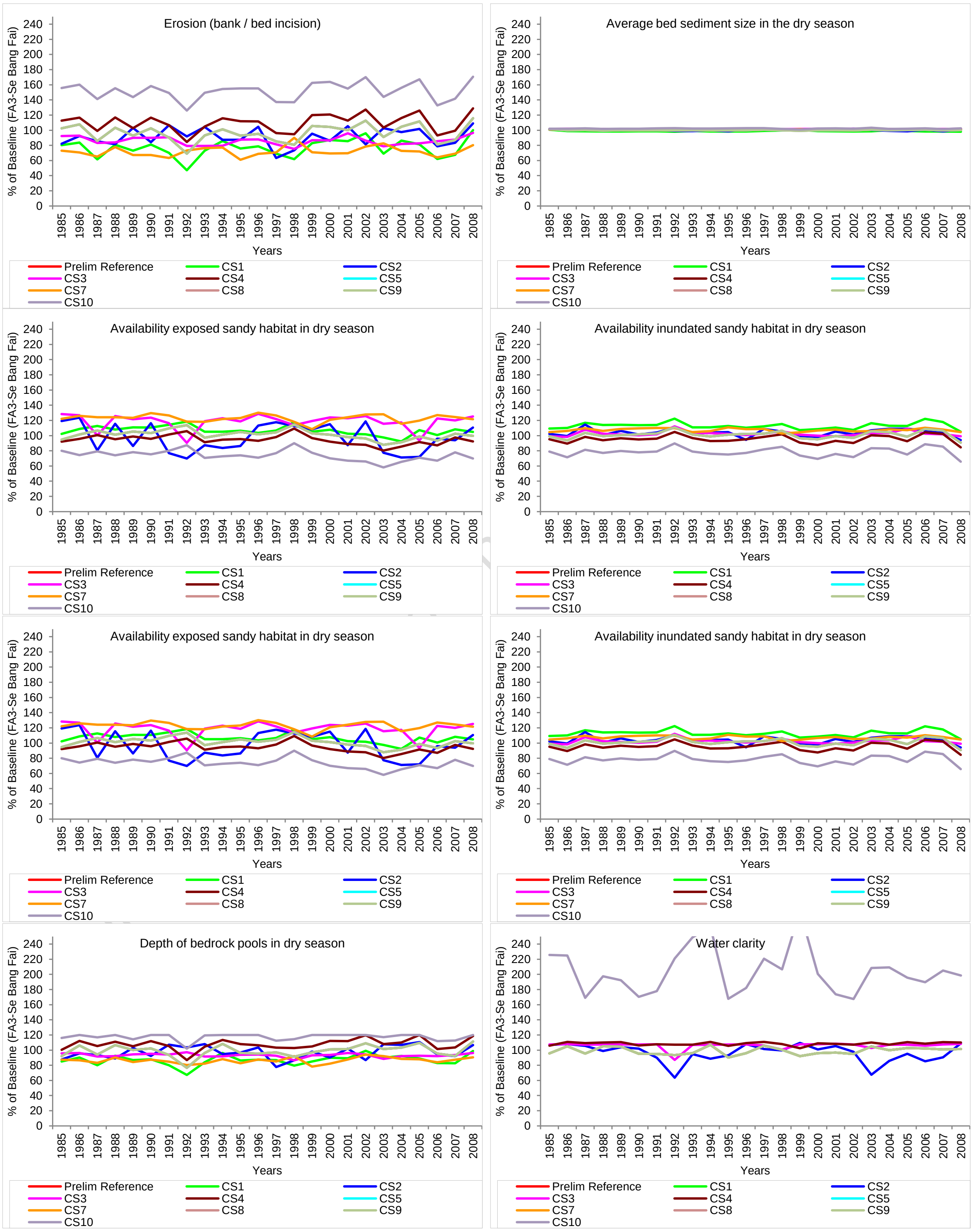


Figure 5.17 **Time-series of predicted changes in geomorphological indicators at FA3. Scenario lines not visible are hidden by those showing.**

5.3.3.2 *Vegetation*

The changes in the vegetation indicators at FA3 are similar to those at FA1 and can be summarised as follows (refer to Table 5.4 and Figure 5.18):

CS1: Predicted to result in *c.* 60% loss of lower bank vegetation, and c. 22% loss in floodplain herbaceous marsh. These reductions were a result of the combined effects of elevated dry season flows, which will drown out marginal channel vegetation, and reduced flooding of the floodplain, which will reduce floodplain marshes and floodplain trees and/or grasslands. The resultant stress on the indigenous vegetation is predicted to provide opportunities for the invasive non-native vegetation to expand its range/cover.

CS2: No major changes.

CS3: A c. 27% reduction in channel upper bank cover, c. 23% reduction in floodplain herbaceous marsh, and a concomitant reduction in floodplain biomass (c. 60%). This is driven by the reduction in duration of wet season, which is expected to reduce the number of tree-damaging floods each year, and thus allow for encroachment of terrestrial forest to the detriment of riparian upper bank vegetation. The biomass prediction of the channel requires investigation, as it appears to be reacting in the opposite direct from expected, but this may be because the upper bank represents a very small proportion of riparian biomass. Floodplain biomass is predicted to be reduced by c. 66%.

CS4: No major changes.

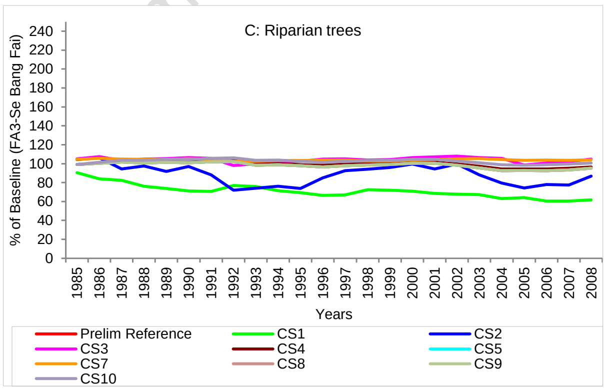
CS5: No major changes.

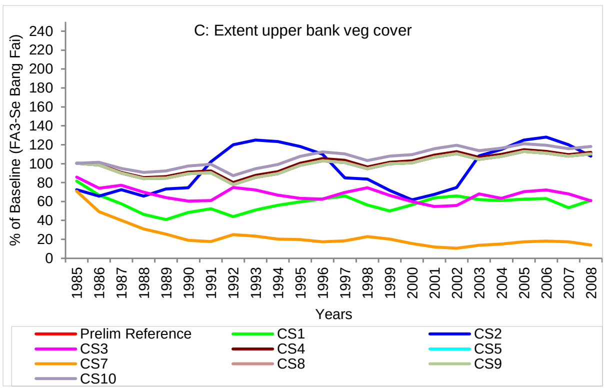
CS7: Similar to CS3. A reduction in upper bank cover was predicted, driven by a reduction in the number of tree-damaging floods each year. This is expected to increase encroachment of terrestrial and/or non-native plant species forest into the riparian vegetation.

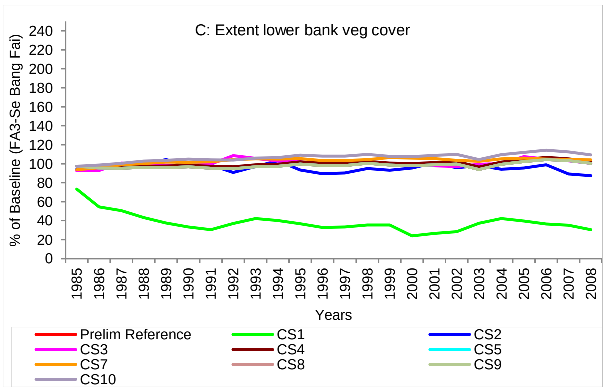
CS8: No major changes.

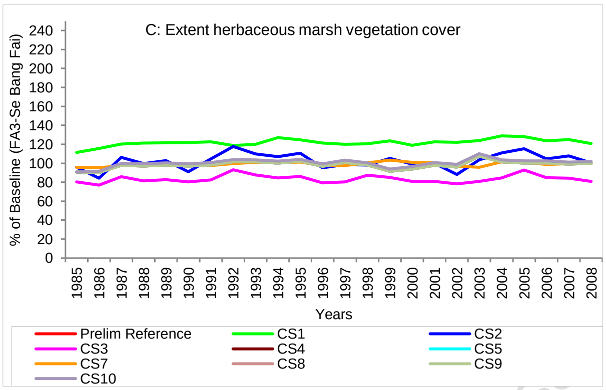
CS9: No major changes.

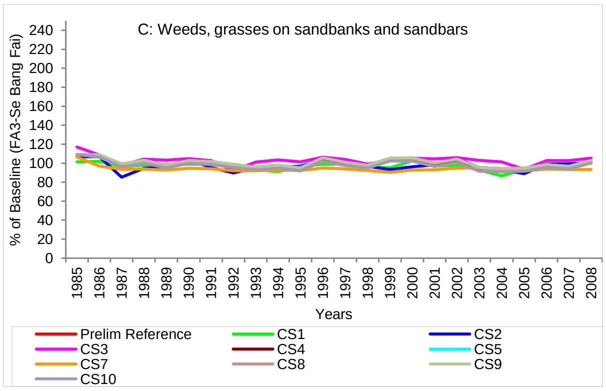
CS10: Under CS10, the cover of the riparian plants is not predicted to change in a major way, but the biomass is expected to be reduced (c. 20%). This is probably mainly as a result of increased erosion associated with this scenario. Algal growth is also predicted to increase markedly (c. 20-30%) as a result of improved water clarity and this improved light penetration. Again biomass of riparian vegetation at FA3 requires investigation, and probably further calibration.

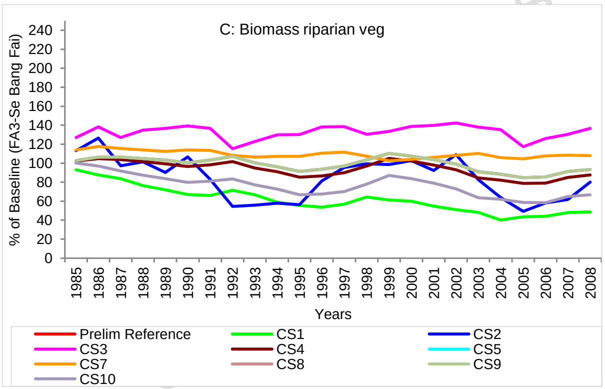


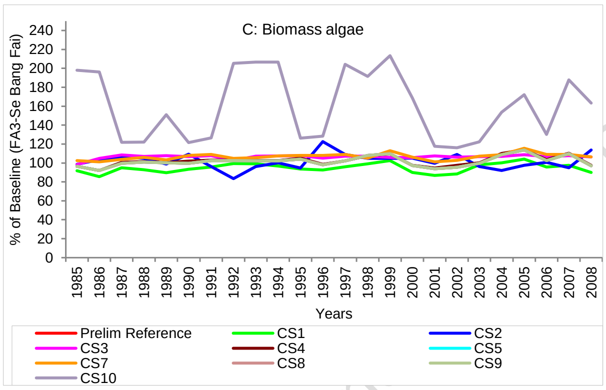


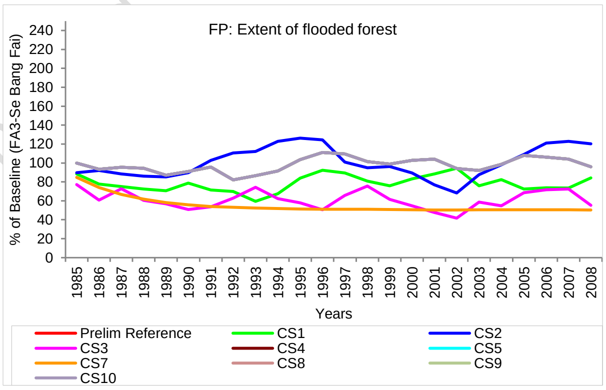

C: Extent lower bank veg cover
% of Baseline (FA3-Se Bang Fai)
Years
Prelim Reference
CS1
CS2
CS3
CS4
CS5
CS7
CS8
CS9
CS10

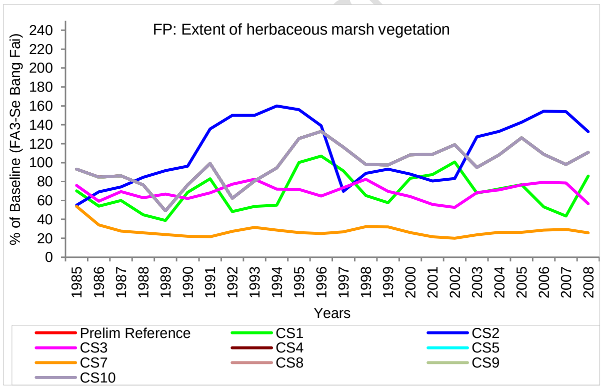

C: Extent herbaceous marsh vegetation cover
% of Baseline (FA3-Se Bang Fai)
Years
Prelim Reference
CS1
CS2
CS3
CS4
CS5
CS7
CS8
CS9
CS10

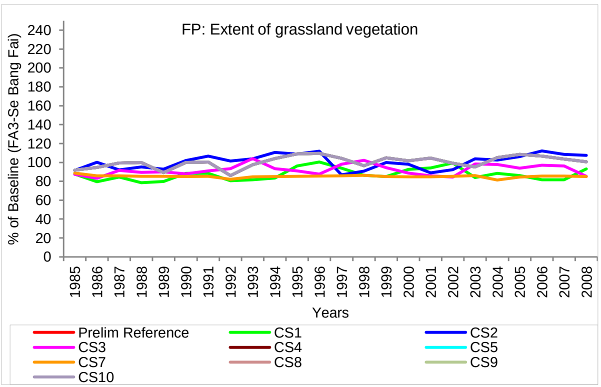

C: Weeds, grasses on sandbanks and sandbars
% of Baseline (FA3-Se Bang Fai)
Years
Prelim Reference
CS1
CS2
CS3
CS4
CS5
CS7
CS8
CS9
CS10


C: Biomass riparian veg
% of Baseline (FA3-Se Bang Fai)
Years
Prelim Reference
CS1
CS2
CS3
CS4
CS5
CS7
CS8
CS9
CS10


C: Biomass algae
% of Baseline (FA3-Se Bang Fai)
Years
Prelim Reference
CS1
CS2
CS3
CS4
CS5
CS7
CS8
CS9
CS10


FP: Extent of flooded forest
% of Baseline (FA3-Se Bang Fai)
Years
Prelim Reference
CS1
CS2
CS3
CS4
CS5
CS7
CS8
CS9
CS10


FP: Extent of herbaceous marsh vegetation
% of Baseline (FA3-Se Bang Fai)
Years
Prelim Reference
CS1
CS2
CS3
CS4
CS5
CS7
CS8
CS9
CS10


FP: Extent of grassland vegetation
% of Baseline (FA3-Se Bang Fai)
Years
Prelim Reference
CS1
CS2
CS3
CS4
CS5
CS7
CS8
CS9
CS10

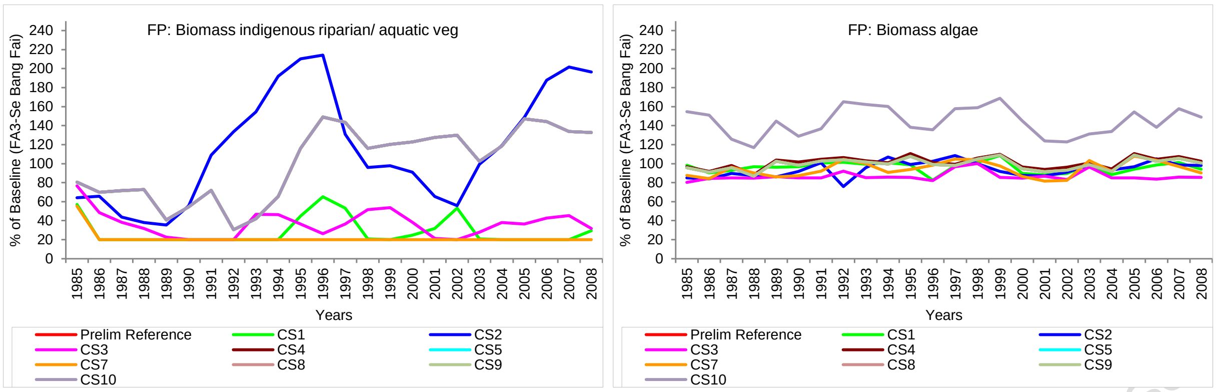


Figure 5.18 Time-series of predicted changes in vegetation indicators at FA3. Scenario lines not visible are hidden by those showing.

5.3.3.3 Macroinvertebrates

There are no major changes predicted for the macroinvertebrate communities under any of the calibration scenarios (Table 5.7).

5.3.3.4 Fish

The changes in the fish indicators at FA3 can be summarised as follows (refer to Table 5.7 and Figure 5.19).

CS1: As was the case at the upstream FAs, the Main channel resident (long distance white) guild (increase by *c.* 80%) is most affected by the flow changes in CS1, although Rithron residents and Main channel spawners are also predicted to increase. Predicted increases in the abundance of these fish will have knock-on effect on fish biomass, which is also predicted to be higher under CS1 (increase by c. 50%). These changes are driven by an increase in dry season flows, which can assist recruitment by flushing spawning beds and maintain dry season pool depths, which the fish use as refuge areas. Eurytopic fish are expected to do less well, possibly as a result of competition from the other fish.

CS2: The six-year cycle of wet and dry is clearly visible in some of the indicators, and shows a period of boom and bust that is fairly common in natural ecosystems. This trend is strongest in the fish that use the floodplain because the dry cycle is accompanied by less inundation of the floodplain, and the wet cycle by more than average. This is why it does not show up as strongly in FA1 and FA2, which lack the large floodplains of the more downstream sites. It may, however, be necessary to revisit the response curves to ensure that they upper and lower levels are in line with expectations for CS2, and to check for the reasons that the cycle was not strongly captured in some of the indicators.

CS3: The Main channel resident (long distance white) guild is most affected by the flow changes in CS3, and is predicted to decline by c. 65%. Main channel spawners (short-distance white) are also predicted to decrease. These reductions are mainly due to the reduced duration of the wet season in this scenario. Flood duration is important to white fish as they migrate upstream for breeding and growth out. The longer the duration of the flood season the more opportunities to spawn and grow, and the greater the time the inundated vegetation has to decay and release nutrients to stimulate primary and secondary production.

CS4: No major changes predicted.

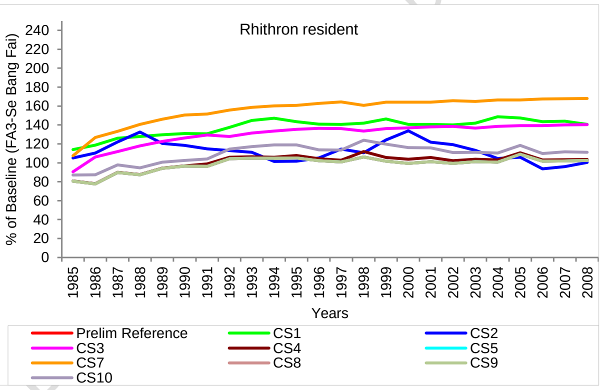
CS5: No major changes predicted. The barrier between F1 and FA2 is not predicted to have a major impact at FA3 as not all the main channel resident and/or spawner populations migrate as far as FA1.

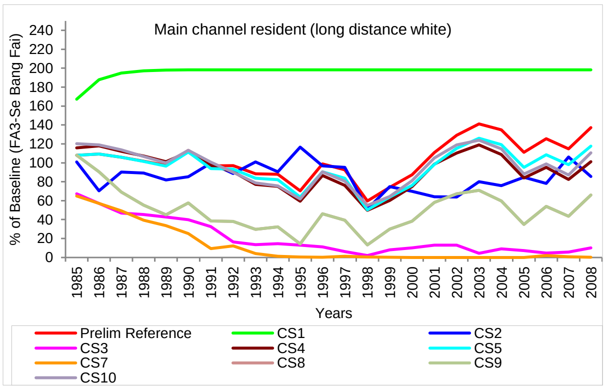
CS7: CS7 favours Rithron species (increase of c. 50%) because the dry season duration is important to Rhithron fishes as conditions over shallower waters and rapids become more suitable for breeding and growth. The longer the duration of the dry season the opportunities to spawn and grow before the onset of torrential flows, provided reasonable flows and depths are maintained, which is the case in CS7. Conversely, the Main channel residents and spawners (decline of c. 65% and c. 50% respectively), and floodplain spawners and residents (decline of c. 65% and c. 75% respectively) prefer longer wet seasons, as they migrate upstream and / or to the floodplain for breeding and growth out, and so they are expected to decline under CS7.

CS8: Under CS8 the migratory fish are expected to be prejudiced by the barrier between FA4 and 5.

CS9: Similar to CS8.

CS10: Similar pattern of predicted changes as for CS4, but more marked in line with the added reduction in sediment supply. Floodplain residents are most affected by this scenario. Wet average sediment concentration, which is reduced by 75% in this CS, is used as a surrogate of nutrients [N and P], which underpin the food chain, as well as to habitat quality. As sediment concentrations decline nutrient delivery is expected to decline proportionally, especially the availability of P which is considered limiting to primary production. Less sediment loading also means the habitat is more suitable for larval fish hatching and nursing after fertilisation. It should be noted that not all nutrients in sediment is bio-available and much (especially P) is locked into the sediment.





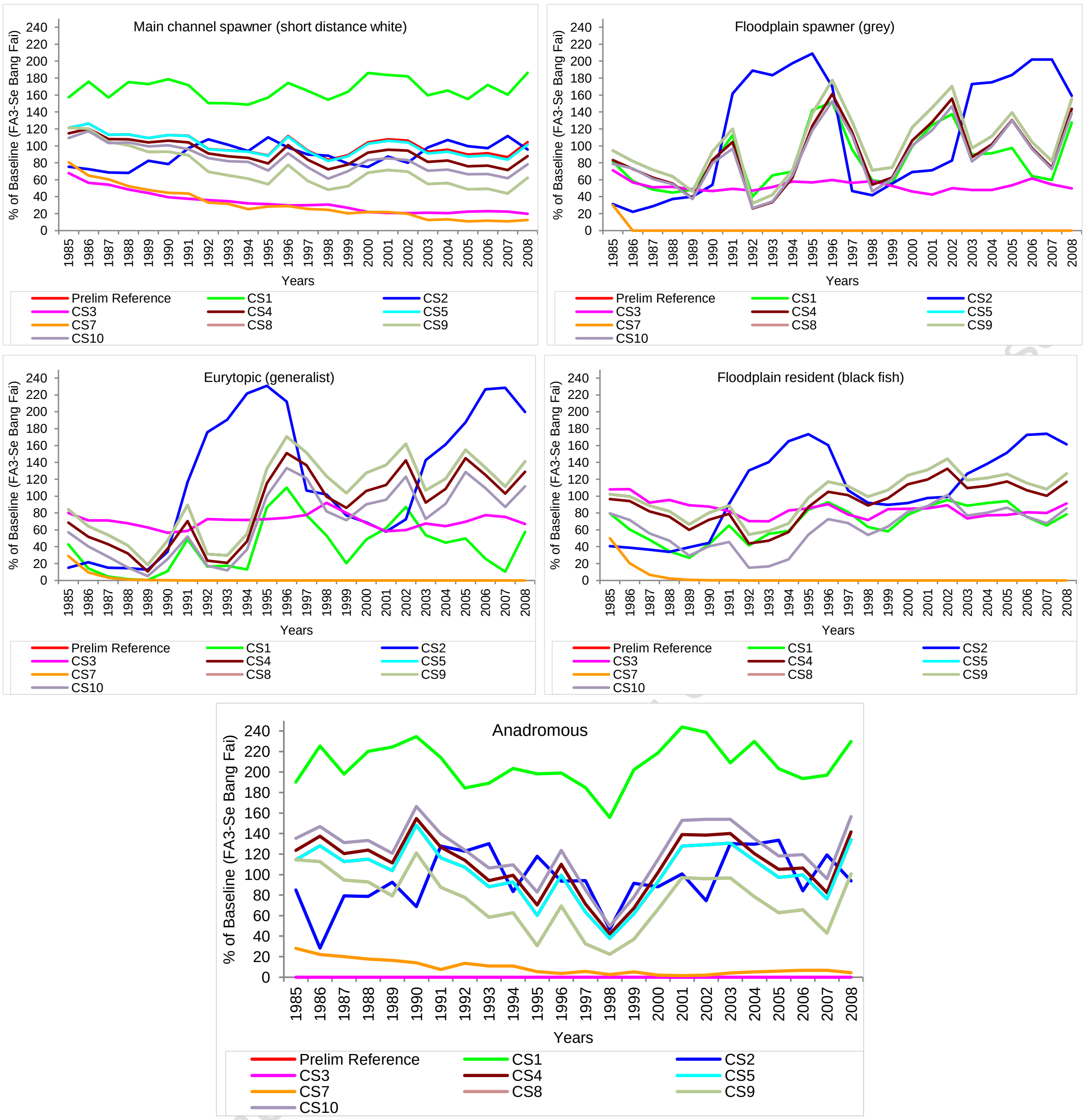


Figure 5.19 Time-series of predicted changes in fish indicators at FA3. Scenario lines not visible are hidden by those showing.

5.3.3.5 Herpetofauna

The changes in the herpetofauna indicators at FA3 can be summarised as follows (refer to Table 5.7 and Figure 5.20.

CS1: The aquatic snakes and turtles increase (*c.* 30 and *c.* 35%, respectively) under CS1 mainly because of an increase in fish, which forms a major part of their diet. They are also assisted by the reduced erosion and a slight increase in exposed sandy habitats. Semi-aquatic turtles on the other hand are predicted to decline by c. 80%. This is because, unlike the aquatic snakes and turtles, the semi-aquatic turtles have a link to the Extent of lower bank vegetation cover, which is drastically reduced under CS1.

CS2: The six-year cycle of wet and dry is clearly visible in some of the indicators, and shows a period of boom and bust that is fairly common in natural ecosystems. It may, however, be necessary to revisit the response curves to ensure that the upper and lower levels are in line with expectations for CS2, and to check for the reasons that the cycle was not strongly captured in some of the indicators.

CS3: The water snakes and aquatic turtles are negatively affected (decrease by c. 40 and 80%, respectively) by CS3, mainly through their food. Water snakes and aquatic turtles in the LMB are among the top predators, feeding predominantly on fish and amphibians, but also on other reptiles and crustacean. Thus the reduction in fish and amphibian biomass that is triggered by CS3 is expected to result in a decline in water snakes and aquatic turtles. Semi-aquatic turtles are also negatively affected by CS3 (decrease by c. 30%), which is due to the direct impacts of a shortened wet season duration.

CS4: Aquatic turtles are reduced by c. 20%, and aquatic serpents to a lesser extent (c. 6% reduction) %), mainly because of a loss of fish, which form an important part of their prey.

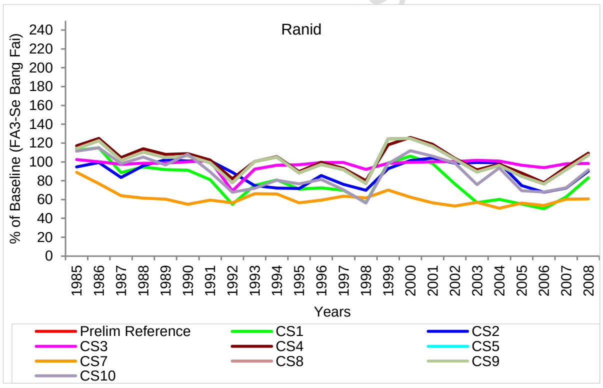
CS5: Aquatic snakes and turtles are slightly negatively affected by CS5 (decrease by c. 3% and 8% respectively), mainly because of a loss of fish, which form an important part of their prey.

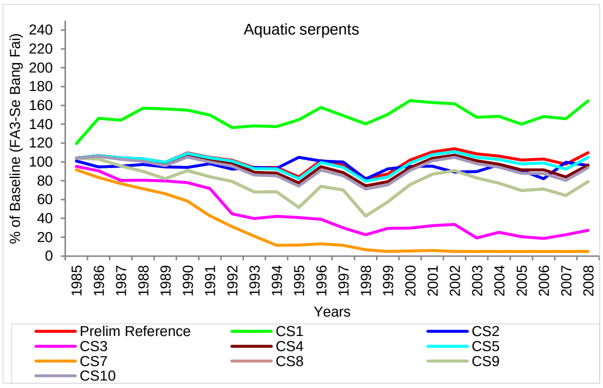
CS7: Similar to CS3, CS7 results in a predicted reduction in amphibians/Ranids (c. 35%), water snakes (50%), aquatic turtles (c. 70%) and semi-aquatic turtles (c. 38%). Amphibians are negatively affected because they depend to varying extents on the availability of fresh water for successful reproduction. Short or dry wet seasons will not provide enough water for pools or ponds in the floodplain for frog breeding, resulting in population decline. The reduction in Semi-aquatic turtles is mainly due to the reduced duration of the wet season.

CS8: Similar to CS5, although the water snakes and aquatic turtles are more affected because of the greater reduction in fish biomass associated with CS8.

CS9: Similar to CS8.

CS10: Aquatic turtles (decrease by c. 48%) mainly because of the increased erosion expected under CS10. The turtles lay their eggs in the soft sediments on the side of the river, which will be removed with increased erosion.





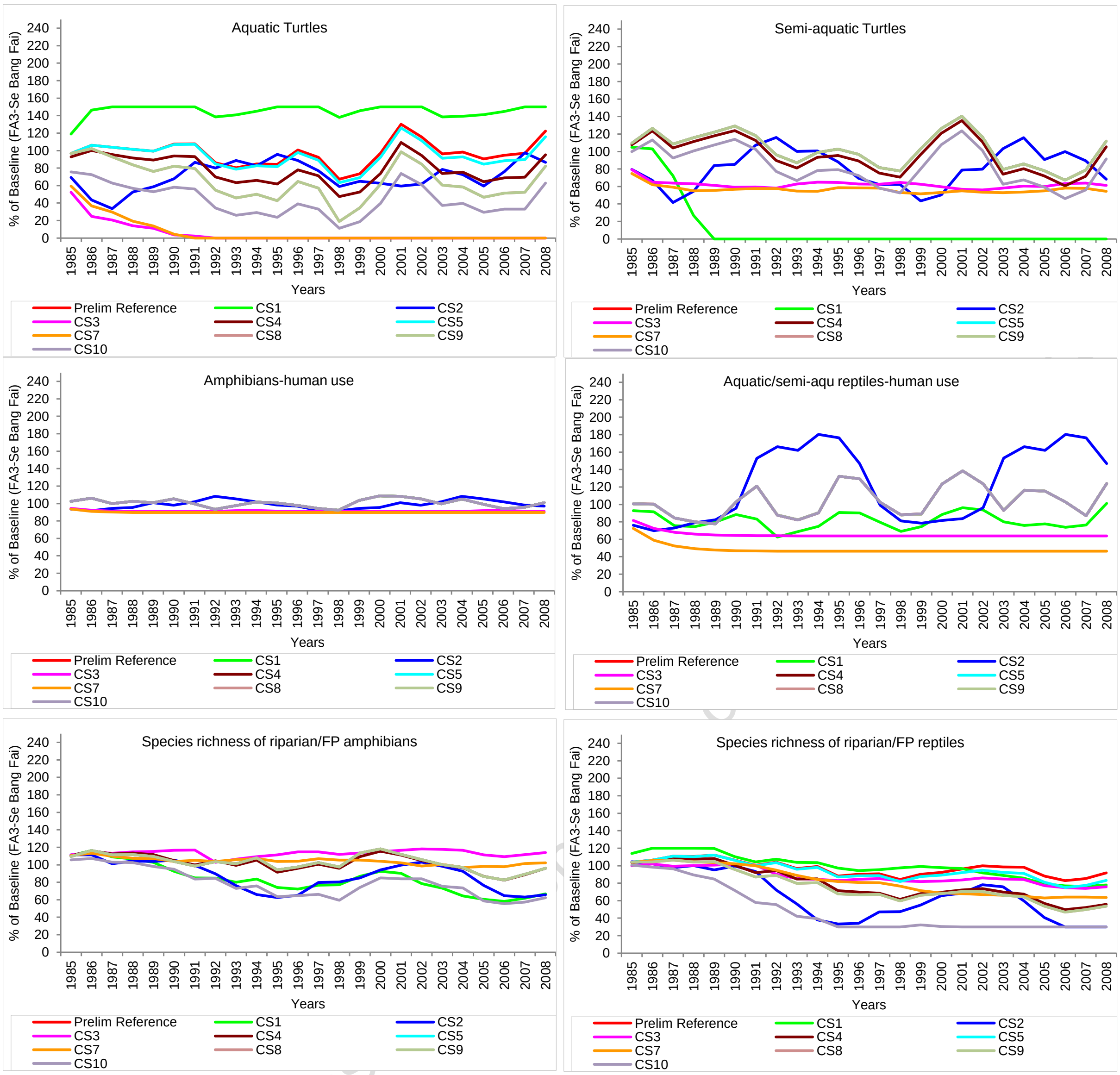


Figure 5.20 Time-series of predicted changes in herpetofauna indicators at FA3. Scenario lines not visible are hidden by those showing.

5.3.3.6 Birds

The changes in the bird indicators at FA3 can be summarised as follows (refer to Table 5.7 and Figure 5.7):

CS1: No major changes.

CS2: No major changes.

CS3: CS3 is predicted to favour the Medium/large ground nesting birds, mainly because of greater availability of sandy banks for nesting. River lapwing prefers wide, slow-moving rivers with sand, rocky or gravel bars and islands (Duckworth *et al.* 1998). As a ground-nesting species, it is susceptible to predation, and to variations in water level. River lapwing is likely to require exposure of breeding habitat from about January (when they establish territories and begin initiating nests) through the nesting season (ending around late March), and probably about an additional 3-4 weeks for chicks to fledge. In this scenario it is helped by the fact that its main food, invertebrates, is not expected to be majorly affected.

CS4: No major changes.

CS5: No major changes.

CS7: CS7 is predicted to favour the Medium/large ground nesting birds, mainly because of greater availability of sandy banks for nesting. See CS3.

CS8: No major changes.

CS9: No major changes.

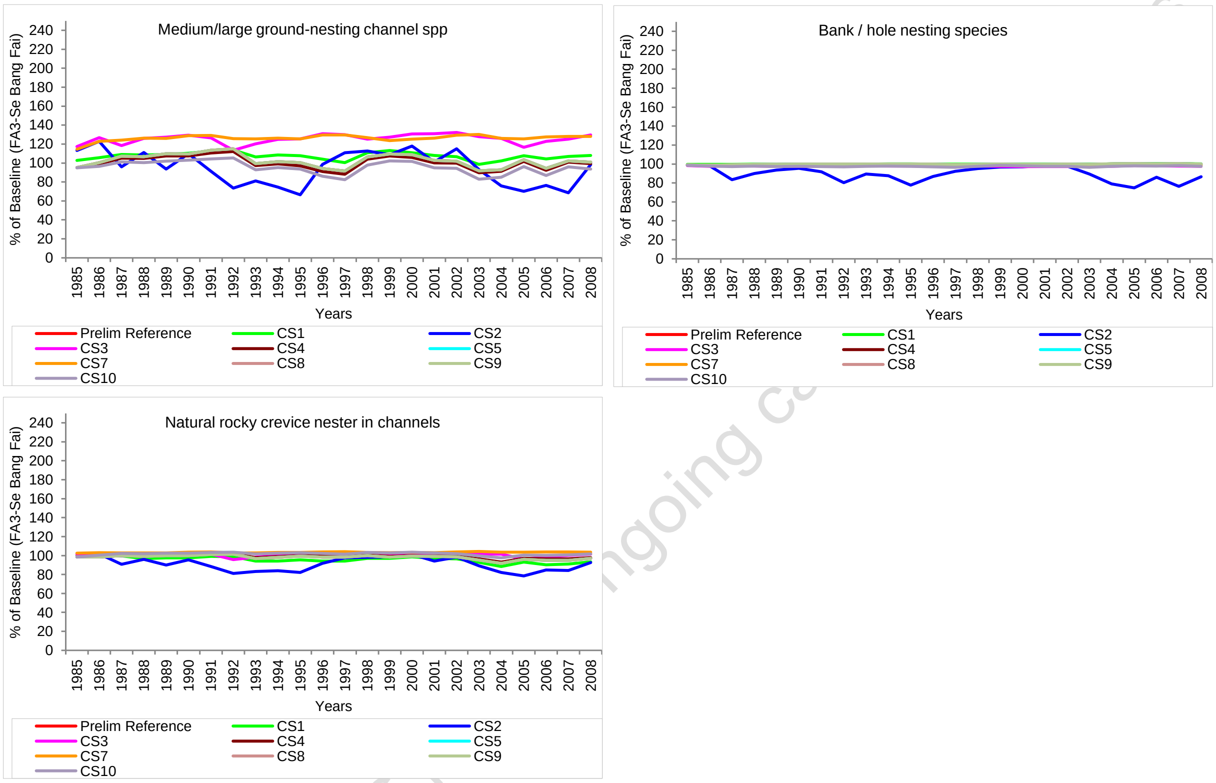


Figure 5.21 Time-series of predicted changes in bird indicators at FA3. Scenario lines not visible are hidden by those showing.

5.3.4 Overall integrity

The Overall Ecological Integrity for each calibration scenario relative to the Preliminary Reference Scenario at FA3 is illustrated in Figure 5.22.

CS3 and CS7, both of which have short wet seasons have the greatest impact on FA3. The prediction is a drop in integrity from a C to a D/E.

The migration scenarios, CS8 and CS9, both of which have a barrier between FA4 and FA5 were predicted to affect overall integrity (from C to a relatively high D), mainly because of their impact on migratory fish (both the Main channel residents (long distance white fish), and the Main channel spawners (grey)). The barrier between FA1 and FA2 was predicted to have virtually no effect on integrity at this site.

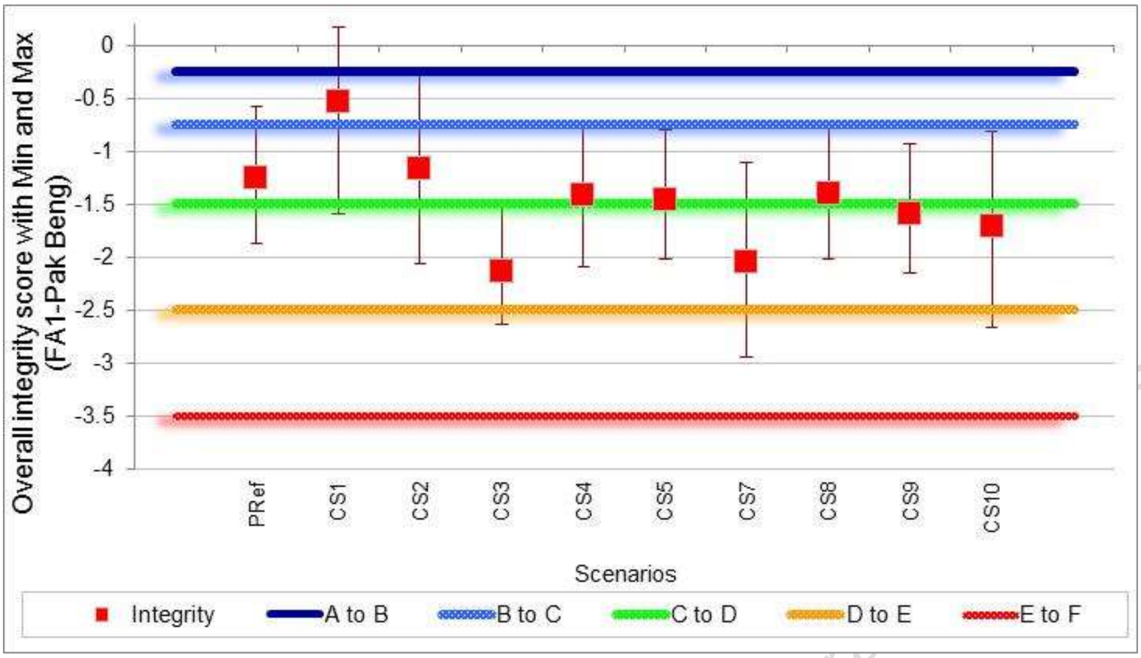


Figure 5.22 Overall Ecological Integrity scores for the Preliminary Reference Scenario (PRef) and each of the calibration scenarios (CS1-10) at FA3

For the two sediment-reduction scenarios, CS4 (less 25% sediment supply) and CS10 (less 75% sediment supply), the DSS predicts a decline in overall integrity (by 20% and 50%, respectively). This is to be expected as the increased erosion and water clarity associated with the scenarios will have knock-on effects on habitat condition and food supply.

CS1 was predicted to increase integrity for geomorphology, invertebrates, fish and birds, while it decreased integrity for vegetation and herpetofauna, leading to an overall increase in integrity at the site. The reduced flows in the wet season reduce erosion, leading to various positive effects, while increased depths in the dry season were the main cause of the reduced vegetation integrity.

5.4 Focus Area 4: Stung Treng

Not included in preliminary calibration – see Section 1.2.2.

5.5 Focus Area 5: Kampong Cham

5.5.1 Characteristics of the flow regime of each CS at FA5

The main characteristics of the flow regimes at FA5 associated with each of the calibration scenarios are summarised in Table 5.8.

Table 5.8 Characteristics of the flow regime (median values) of each CS at FA5 (Kampong Cham)[13]

FA5 - Kampong Cham	Units	PRef	CS1	CS2	CS3	CS4	CS5	CS7	CS8	CS9	CS10
Mean annual runoff	m^3/s	12383	12367.9	12016.3	9839.27	12383	12383	8922.71	12383	12383	12383
Dry onset	week	50.00	52.00	49.00	49.00	50.00	50.00	47.00	50.00	50.00	50.00
Dry duration	days	173.00	142.50	164.00	179.00	173.00	173.00	204.00	173.00	173.00	173.00
Dry Min 5day Q	m^3/s	1809.00	4421.85	1869.01	1825.12	1809.00	1809.00	1502.86	1809.00	1809.00	1809.00
Wet onset	week	25.00	25.00	24.50	28.00	25.00	25.00	29.00	25.00	25.00	25.00
Wet duration	days	137.50	137.50	139.00	111.00	137.50	137.50	93.00	137.50	137.50	137.50
Wet Max 5day Q	m^3/s	38567.7	32548.5	38167.3	34753	38567.7	38567.7	31319.3	38567.7	38567.7	38567.7
Flood volume	MCM	298285	254923	289592	204171	298285	298285	175129	298285	298285	298285
Dry ave daily vol	MCM	271.74	441.57	274.63	291.66	271.74	271.74	255.89	271.74	271.74	271.74
T1 ave daily vol	MCM	815.90	761.30	825.81	696.99	815.90	815.90	844.03	815.90	815.90	815.90
Wet ave daily vol	MCM	2276.13	1965.10	2042.71	1839.38	2276.13	2276.13	1883.11	2276.13	2276.13	2276.13
T2 ave daily vol	MCM	718.90	736.14	704.49	731.25	718.90	718.90	761.89	718.90	718.90	718.90
T1 onset	week	22.00	20.00	22.00	23.00	22.00	22.00	25.00	22.00	22.00	22.00
T2 onset	week	45.00	45.00	45.00	44.00	45.00	45.00	43.00	45.00	45.00	45.00
D: ave w/in day range	m^3/s	85.61	61.93	107.24	117.85	85.61	85.61	59.41	85.61	85.61	85.61
T1: ave w/in day range	m^3/s	488.24	373.16	450.13	256.24	488.24	488.24	269.65	488.24	488.24	488.24
T2: ave w/in day range	m^3/s	243.51	181.27	265.57	278.86	243.51	243.51	163.24	243.51	243.51	243.51
D: ave Ch Velocity	m/s	0.27	0.41	0.71	0.71	0.27	0.27	0.26	0.27	0.27	0.27
Wet: ave Ch Velocity	m/s	1.28	1.18	1.31	1.31	1.28	1.28	1.08	1.28	1.28	1.28
D: ave Ch Depth	m	23.57	25.02	23.71	23.66	23.57	23.57	23.43	23.57	23.57	23.57
Wet: ave Ch Depth	m	32.15	31.48	31.52	30.26	32.15	32.15	30.44	32.15	32.15	32.15
D: min Ch Depth	m	22.35	24.46	22.62	22.58	22.35	22.35	22.18	22.35	22.35	22.35
D: max Ch Depth	m	25.78	26.40	26.22	27.16	25.78	25.78	25.45	25.78	25.78	25.78
Wet: ave Wetted perimeter	m	1161.00	1140.89	1139.23	1112.15	1161.00	1161.00	1108.08	1161.00	1161.00	1161.00
D: ave Sediment conc	mg/l	30.63	30.63	35.56	29.45	22.97	30.63	29.89	30.63	30.63	7.66
T1: ave Sediment conc	mg/l	96.13	96.13	87.68	55.68	72.10	96.13	53.28	96.13	96.13	24.03
Wet: ave Sediment conc	mg/l	402.75	402.75	360.09	217.43	302.07	402.75	293.07	402.75	402.75	100.69
T2: ave Sediment conc	mg/l	96.26	96.26	94.51	92.73	72.19	96.26	78.18	96.26	96.26	24.06
D: ave Sediment load	t/ day	9653.15	15371.1	11961.4	10148.6	7239.86	9653.15	8325.54	9653.15	9653.15	2413.29
Wet: ave Sediment load	t/ day	1002603	854611	856543	414864	751952	1002603	602846	1002603	1002603	250651
T1: ave Sediment load	t/ day	83949.9	87802.2	73443.8	33633.5	62962.4	83949.9	29640.8	83949.9	83949.9	20987.5
T2: ave Sediment load	t/ day	69716	76423	69239.7	66085.1	52287	69716	49452.1	69716	69716	17429
Wet: ave Sediment grain-size	mm	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Wet: ave Sediment Onset	week	32.00	31.00	32.00	32.00	32.00	32.00	33.00	32.00	32.00	32.00
Wet: ave Sediment Duration	days	52.50	58.00	57.00	54.00	52.50	52.50	45.00	52.50	52.50	52.50
D: ave Dissolved Oxygen	mg/l	22.00	22.00	22.50	27.00	22.00	22.00	24.00	22.00	22.00	22.00
D: ave Conductivity	mS/m	186.50	172.00	165.50	144.00	186.50	186.50	163.00	186.50	186.50	186.50
D: ave Total Nitrogen	mg/l	305.12	4.72	282.70	132.19	305.12	305.12	197.64	305.12	305.12	305.12
D: ave Total Phosphorous	mg/l	2.29	1.89	2.21	1.50	2.29	2.29	1.69	2.29	2.29	2.29
D: max Temperature	^oC	231.17	9.92	216.18	86.21	231.17	231.17	124.98	231.17	231.17	231.17

5.5.2 Mean percentage changes

The mean percentage changes (relative to Preliminary Reference Scenario) for the indicators in response to each CS at FA5 (Kampong Cham) are given in Table 5.9.

[13] PRef = Preliminary Reference Scenario

Table 5.9 **The mean percentage changes in abundance at FA5 (relative to Preliminary Reference Scenario) for the indicators for the data sets.** Blue and green are changes that represent increases: green = 40-70%; blue = >70%. Orange and red are changes that represent decreases: orange = 40-70%; red = >70%. Preliminary reference, by definition, equals 100%.

Indicators	Calibration Scenarios								
	CS1	CS2	CS3	CS4	CS5	CS7	CS8	CS9	CS10
Discipline : Geomorphology									
Erosion (bank / bed incision)	-23.9	-14.3	-20.3	9.1	-1.3	-14.5	-1.3	-1.3	34.2
Average bed sediment size in the dry season	-1.4	-0.2	0.2	0.8	-0.1	-0.6	-0.1	-0.1	2.1
Availability exposed sandy habitat in dry season	12.1	1.1	-6.0	-4.3	1.2	19.5	1.2	1.2	-19.3
Availability inundated sandy habitat in dry season	13.1	5.7	10.2	-3.8	-0.1	2.9	-0.1	-0.1	-13.3
Depth of bedrock pools in dry season	-16.7	-7.0	-14.5	6.0	-1.9	-13.3	-1.9	-1.9	15.6
Water clarity	-1.2	-5.3	5.8	9.6	-1.2	5.5	-1.2	-1.2	78.3
Discipline : Vegetation									
C: Weeds, grasses on sandbanks and sandbars	-12.8	-2.5	-4.6	-2.4	-0.7	16.0	-0.7	-0.7	-7.3
C: Biomass algae	-7.4	3.3	-0.8	3.4	1.9	8.2	1.9	1.9	12.6
FP: Extent of flooded forest	-0.1	4.7	-1.4	1.3	1.3	0.0	1.3	1.3	1.3
FP: Extent of herbaceous marsh vegetation	-38.2	24.5	8.1	-1.9	-1.9	-33.3	-1.9	-1.9	-1.9
FP: Extent of grassland vegetation	-9.6	1.5	-12.7	-0.7	-0.7	-0.9	-0.7	-0.7	-0.7
FP: Biomass indigenous riparian/ aquatic veg	-70.0	36.8	-67.6	0.6	0.6	-62.1	0.6	0.6	0.6
FP: Biomass algae	-5.6	-1.2	-3.1	0.8	-0.6	6.6	-0.6	-0.6	10.1
Extent invasive riparian cover	39.5	-26.4	0.6	0.4	0.4	26.5	0.4	0.4	0.4
Extent invasive floating/submerged plant cover	-5.6	-11.4	-7.9	0.0	0.0	10.6	0.0	0.0	0.0
Discipline : Macro-invertebrates									
Insects on stones	-8.3	-3.1	-5.0	-1.7	-0.9	-1.2	-0.9	-0.9	-6.6
Insects on sand	0.4	1.3	1.7	-0.1	0.1	1.6	0.1	0.1	-0.9
Burrowing mayflies	-2.2	0.0	-1.0	-0.6	0.3	2.0	0.3	0.3	-1.0
Snail abundance	8.5	-3.4	-1.1	-0.4	-0.7	-4.8	-0.7	-0.7	1.7
Diversity of snails	-11.5	-4.5	-7.3	-2.4	-1.4	-2.1	-1.4	-1.4	-8.8
Neotricula aperta abundance	90.8	-12.2	-12.2	1.9	0.0	-39.8	0.0	0.0	4.2
Bivalves abundance	-3.8	-3.9	-2.2	-2.4	-1.4	-1.7	-1.4	-1.4	-1.3
Shrimps and crabs	11.0	-1.2	-0.9	-0.4	-0.8	-6.1	-0.8	-0.8	3.0
Littoral invertebrate diversity	-8.1	-3.1	-5.0	-1.7	-0.9	-1.2	-0.9	-0.9	-6.2
Benthic invertebrate diversity	-8.2	-3.3	-5.2	-2.1	-1.0	-1.2	-1.0	-1.0	-7.4
Zooplankton abundance	-2.4	-2.4	-20.4	-1.1	-1.4	-23.9	-1.4	-1.4	0.7
Comp: Benthic invertebrate biomass	13.8	-3.2	-3.0	-0.5	-0.5	-7.1	-0.5	-0.5	-0.1
Comp: Dry season insect emergence	-3.4	-0.6	-1.4	-0.8	-0.2	0.8	-0.2	-0.2	-2.8
Discipline : Fish									
Rhithron resident	41.8	-3.6	-9.6	-0.2	-2.0	32.8	-2.0	-2.0	0.7
Main channel resident (long distance white)	44.5	-65.8	-63.4	-64.1	-31.4	-67.7	-59.3	-61.3	-63.4
Main channel spawner (short distance white)	23.8	-11.1	-49.7	-15.4	-1.8	-60.9	-24.3	-24.3	-27.2
Floodplain spawner (grey)	-46.6	6.8	-70.8	-8.0	0.1	-73.9	0.1	0.1	-16.3
Eurytopic (generalist)	-58.1	-4.9	-67.1	-12.5	-2.1	-59.1	-2.1	-2.1	-27.9
Floodplain resident (black fish)	-51.3	11.6	-70.3	-6.8	1.7	-57.2	1.7	1.7	-32.9
Anadromous	42.8	3.0	-15.6	6.2	-1.5	-45.7	-12.1	-12.1	16.5
Catadromous	2.6	0.2	0.1	0.0	0.0	-2.4	-3.9	-3.9	0.0
Comp: Fish Biomass	-39.6	-5.6	-63.9	-13.5	-2.5	-61.2	-6.8	-6.9	-26.4

Discipline : Herpetofauna									
Ranid	-32.3	4.0	-50.5	4.4	-0.8	-63.9	-0.8	-0.8	-3.4
Aquatic serpents	-82.2	10.6	-80.2	-11.2	-4.7	-81.9	-7.4	-7.5	-22.0
Aquatic Turtles	-70.1	-6.4	-93.3	-17.3	-1.2	-88.8	-5.3	-5.4	-42.8
Semi-aquatic Turtles	-83.9	12.1	-95.0	-8.8	-1.9	-92.4	-1.9	-1.9	-24.4
Amphibians-human use	-0.7	0.2	-8.5	-0.8	-0.8	-9.5	-0.8	-0.8	-0.8
Aquatic/semi-aqu reptiles-human use	-1.8	19.6	0.6	-1.7	-1.7	-22.5	-1.7	-1.7	-1.7
Species richness of riparian/FP amphibians	-40.8	15.9	-45.1	7.2	-0.2	-42.4	-0.2	-0.2	7.4
Species richness of riparian/FP reptiles	-14.9	-0.7	-58.5	-15.9	-2.2	-57.0	-6.0	-6.1	-38.5
Discipline : Birds									
Medium/large ground-nesting channel spp	9.1	-5.2	-14.9	-3.1	-0.4	26.8	-0.4	-0.4	-8.8
Bank / hole nesting species	-24.7	-13.7	-74.8	-5.2	0.7	-66.3	-1.1	-1.1	-14.5
Flocking non-aerial pass of graminoid beds	-37.6	10.1	-43.9	-0.8	-0.7	-31.7	-0.7	-0.7	-1.1
Small non-flocking landbird;seasonally flooded veg	3.1	-0.6	-0.3	-0.4	-0.2	-1.3	-0.2	-0.2	-0.7

5.5.3 Time-series

5.5.3.1 Geomorphology

The changes in the geomorphological indicators at FA5 be summarised as follows (refer to Table 5.9 and Figure 5.23):

CS1: Lower erosion rates. This is because the bulk of the erosion (and sediment suspension and transport) occurs in the wet season, and wet season flows are reduced relative to the Preliminary Reference in CS1. The effect of this at FA5 is far greater than at FA1 and FA2 and also greater than at FA3 because of the flat gradient at FA5, which means lower current speeds and shear stresses. There is also a resultant increase in sandy habitat.

CS2: No major changes.

CS3: Slightly increased erosion rates and slightly clearer water. This is because the bulk of the erosion (and sediment suspension and transport) occurs in the wet season, which is shorter than Preliminary Reference in CS3.

CS4: A slight increase in erosion and a slight increase in water clarity; both linked the reduced sediment supply in CS4.

CS5: No major changes.

CS7: Similar to CS3.

CS8: No major changes.

CS9: No major changes.

CS10: A *c.* 35% increase in erosion, relative to Preliminary Reference (remembering that Preliminary Reference already has higher erosion as it is using measured data), with concomitant changes in the availability of sandy and rocky habitat, and in water clarity (79% increase in water clarity).

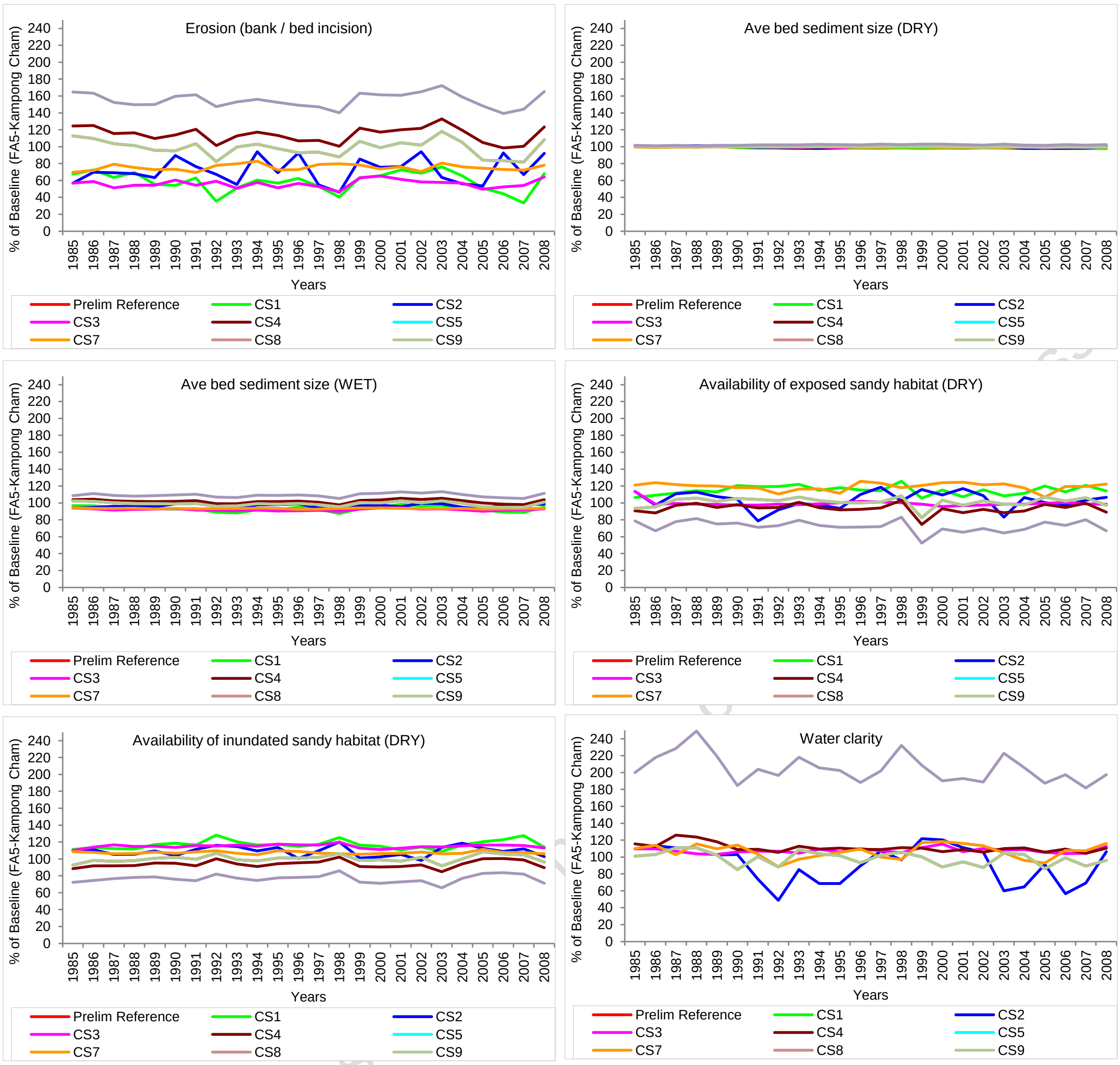


Figure 5.23 Time-series of predicted changes in geomorphological indicators at FA5. Scenario lines not visible are hidden by those showing.

5.5.3.2 Vegetation

FA5 lacks the classic riparian vegetation belt of the upper zones, and is characterised by wide floodplains. The changes in the vegetation indicators at FA5 be summarised as follows (refer to Table 5.9 and Figure 5.24):

CS1: The flow regime associated with CS1 is predicted to result in a c. 40% loss in herbaceous marsh and a c. 10% loss in floodplain grassland vegetation. This is expected as a result of reduced flooding of the floodplain, which will reduce floodplain marshes and grasslands. The resultant stress on the indigenous vegetation is predicted to provide opportunities for the invasive non-native vegetation to expand its range/cover.

CS2: The six-year cycle of wet and dry is clearly visible in some of the indicators, and shows a period of boom and bust that is fairly common in natural ecosystems. It may, however, be necessary to revisit the response curves to ensure that they upper and lower levels are in line with expectations for CS2, and to check for the reasons that the cycle was not strongly captured in some of the indicators.

CS3: A c. 35% reduction in upper bank cover, c. 10% reduction in grasslands, but an increase in herbaceous marsh (24%), and a concomitant increase in floodplain biomass (c. 35%).

CS4: No major changes.

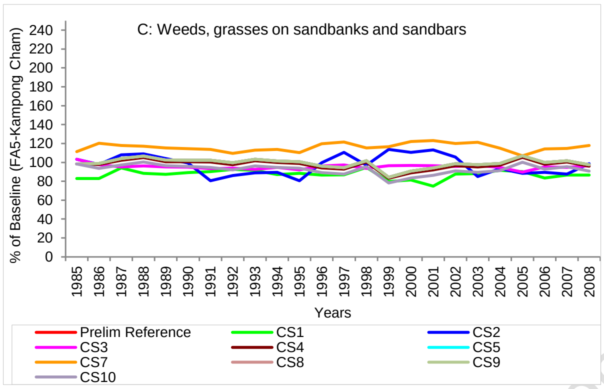
CS5: No major changes.

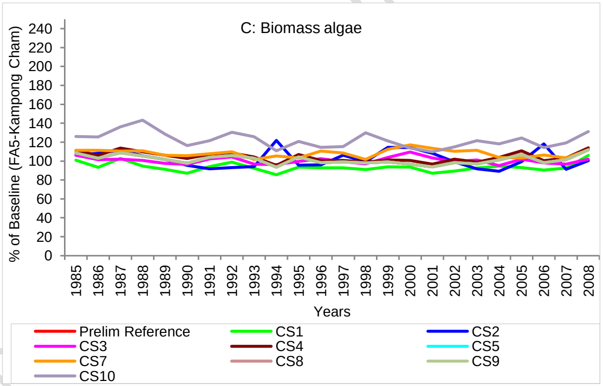
CS7: Similar to CS3, except that there is a loss (rather than a gain) in herbaceous marsh (-30%). This difference between CS3 and CS7 suggests that the herbaceous marsh response curves at FA5 require checking and possibly recalibration.

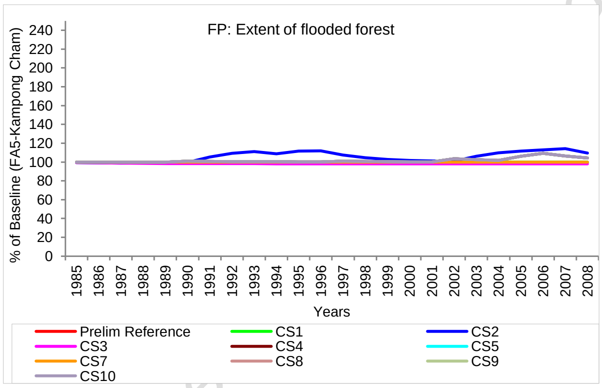
CS8: No major changes.

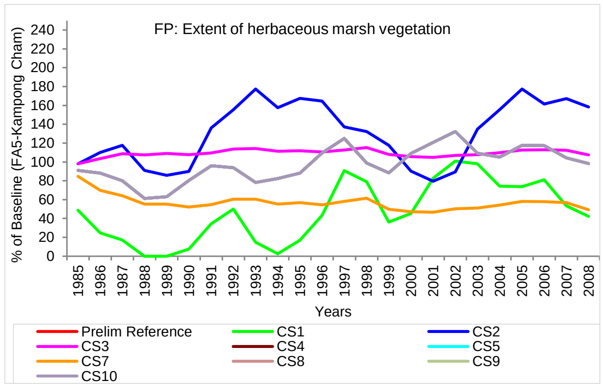
CS9: No major changes.

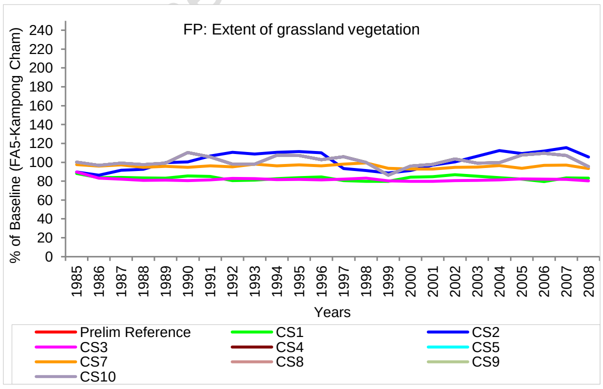
CS10: Under CS10, algal growth is predicted to increase markedly (c. 10%) as a result of improved water clarity and this improved light penetration.

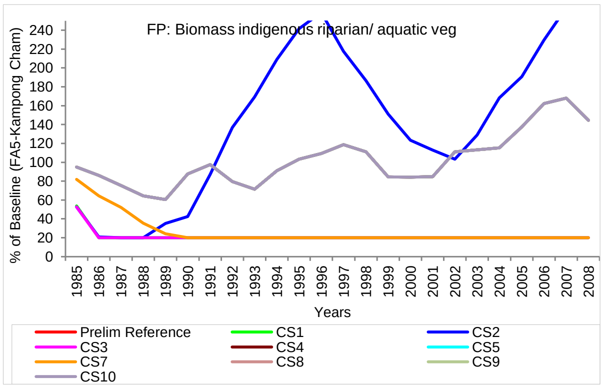












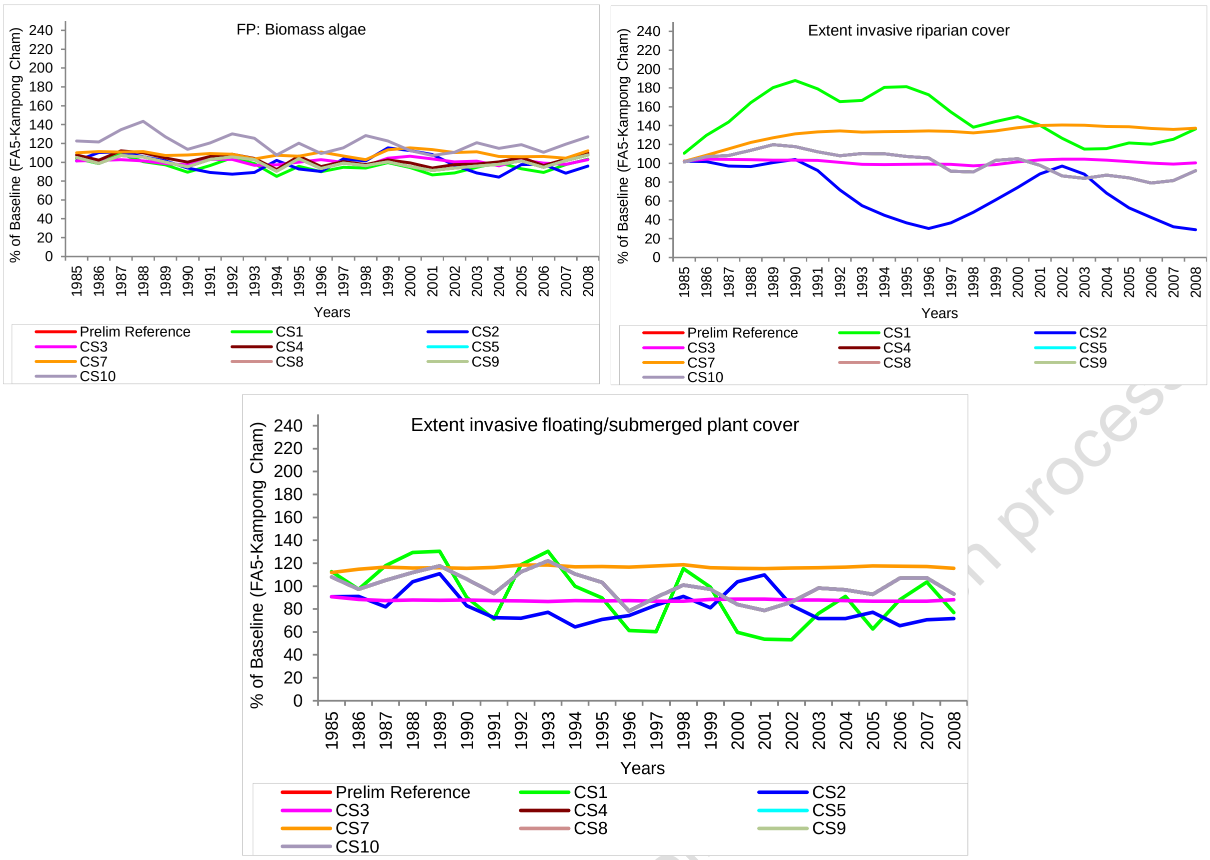


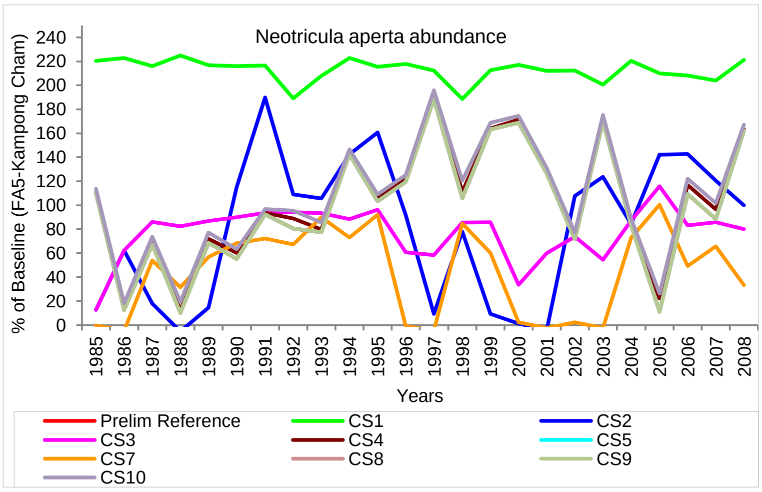
Figure 5.24 **Time-series of predicted changes in vegetation indicators at FA5. Scenario lines not visible are hidden by those showing.**

5.5.3.3 Macroinvertebrates

The calibration scenarios at FA5 are predicted to have the biggest impact on the abundance of *Neotricula aperta* and zooplankton (refer to Table 5.9 and Figure 5.25). *Neotricula aperta* is only affected by CS1, CS3 and CS7, whereas zooplankton is affected by CS2, CS3 and CS7.

Neotricula aperta is predicted to increase under CS1 (increase of c. 90%). The DSS made this prediction almost entirely in response to an increase in dry season wetted perimeter, which is expected to provide an indication of total habitat area. Habitat area is expected to correlate with snail population size. It may be, however, that this requires additional calibration. In Figure 5.25, PRef, CS2, CS4, CS5 and CS8-10 are all on top of one another, i.e., no change from Preliminary Reference Scenario.

Zooplankton abundance on the other hand decreases under CS3 and CS7 (and slightly under CS1) in response to reduced mean annual runoff relative to reference. The abundance of zooplankton increases with river size, and mean annual discharge is the best measure of river size. River size indicates how long a given mass of water has been in the channel, and thus how long the zooplankton crop has had time to develop.



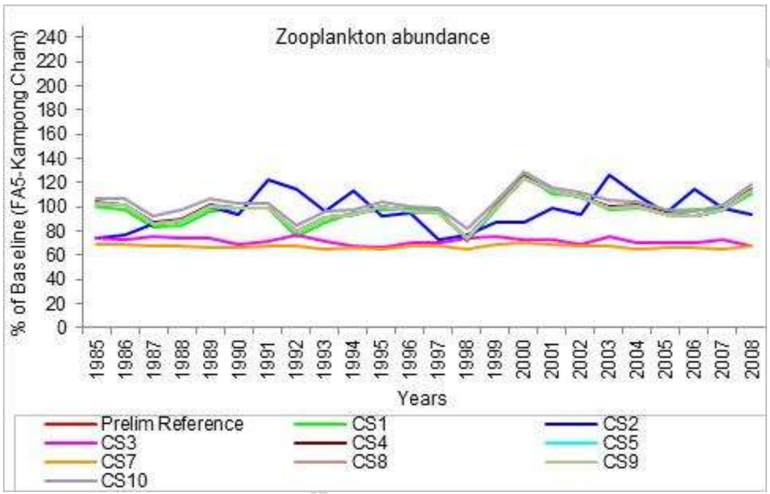


Figure 5.25 Time-series of predicted changes in *Neotricular aperta* (top) and zooplankton abundance (bottom) at FA5. Scenario lines not visible are hidden by those showing.

5.5.3.4 Fish

The changes in the fish indicators at FA5 under the CSs are similar to those at FA3, for similar reasons. That said, the migration scenarios CS8 and CS9 are predicted to have a great impact on the migratory fish because a barrier between FA4 and FA5 will cut of almost all possibilities for breeding. The flow sequence used here are only 23 years (1985-2008), however, if they were longer, then the decline would be greater.

One difference between FA3 and FA5 is that the Main channel residents and Main channel spawners make up a relatively small percentage at the biomass at FA5. Thus, despite the increase in these guilds under CS1, fish biomass declines.

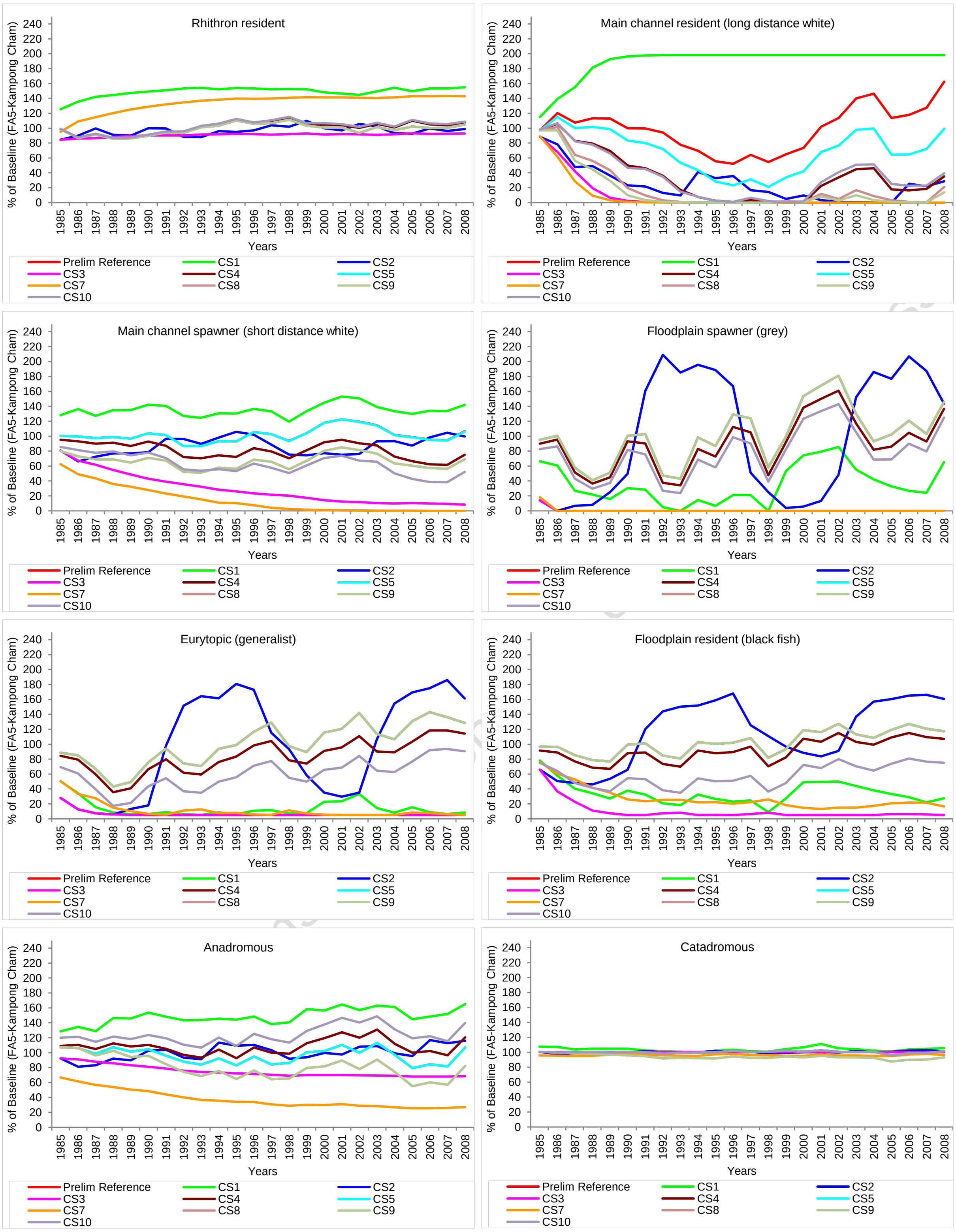


Figure 5.26 **Time-series of predicted changes in fish indicators at FA5. Scenario lines not visible are hidden by those showing.**

5.5.3.5 Herpetofauna

The changes in the fish indicators at FA5 under the CSs (refer to Table 5.9 and Figure 5.27) are similar to those at FA3, for similar reasons, although the impacts of these scenarios are greater at FA5, reflecting the larger floodplains.

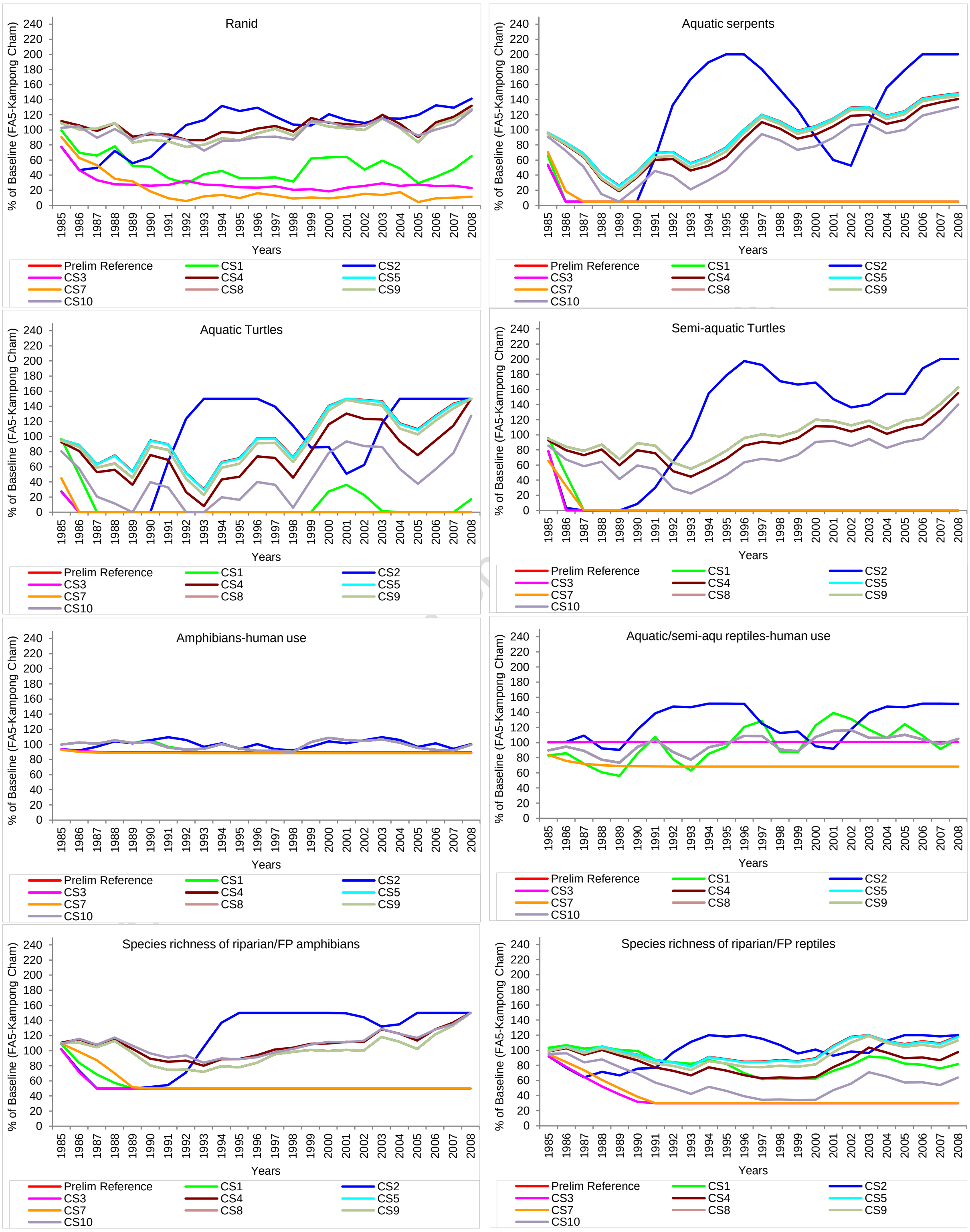


Figure 5.27 Time-series of predicted changes in herpetofauna indicators at FA5

5.5.3.6 Birds

The changes in the bird indicators at FA5 be summarised as follows (refer to Table 5.9 and Figure 5.28):

CS1: CS1 is expected to mainly affect the bank/hole nesting species and the small non-flocking land bird of seasonally-flooded vegetation (grassland and herbaceous marsh – both of which are predicted to decline under CS1). Pied kingfisher is predicted to decline (-20%) in response to a predicted decline in fish biomass as fish are its principle food source. Manchurian reed warbler winters in reedbeds, swamps and shrubby grasslands - thus a reduction in this habitat would negatively impact on the species, although this loss is not quantifiable. If there is complete loss of habitat with no replacement, then the species would cease to overwinter, which may have consequences for the maintenance of the breeding populations (the species breeds in Southeast Russia and Northeast China), although quantifying this is difficult.

CS2: No major changes.

CS3: Pied kingfisher is predicted to decline by c. 70% in response to a decline in fish biomass. Pied kingfisher, a species in this guild that breeds in FA5 is not expected to be immediately limited by fish biomass. It is considered likely to be present at c. 25-30% of the habitat's carrying capacity; thus there would be no effect on its population if there was a decline of 25-30% of fish biomass, but there would be a linear decline in population, if fish biomass declined below 70% of current levels. Manchurian reed warbler is also predicted to decline (c. 45%). It winters in reedbeds, swamps and shrubby grasslands - thus a reduction in this habitat would negatively impact on the species, although this loss is not quantifiable. If there were a complete loss of habitat, then the species would cease to overwinter, which may have consequences for the maintenance of the breeding populations (the species breeds in southeast Russia and northeast China), although quantifying this is difficult.

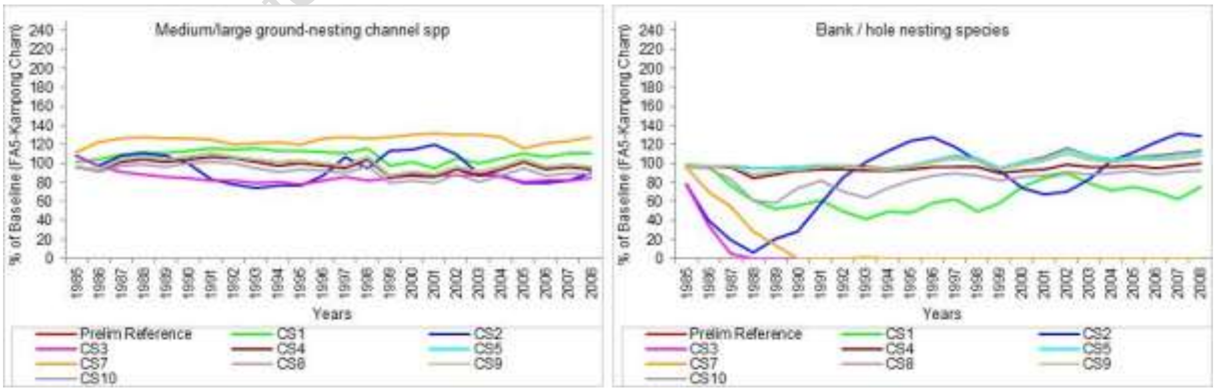
CS4: No major changes.

CS5: No major changes.

CS7: CS7 is similar to CS3.

CS8: No major changes.

CS9: No major changes.



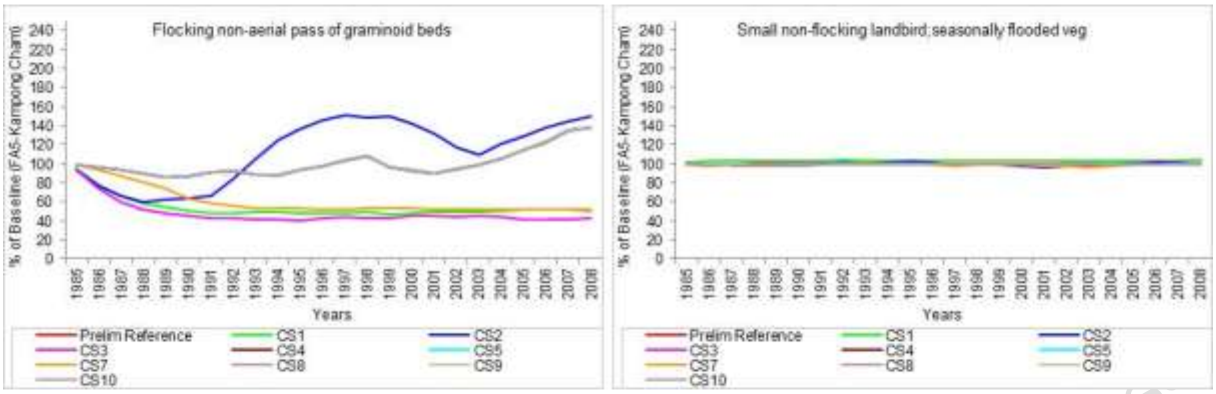


Figure 5.28 **Time-series of predicted changes in bird indicators at FA5. Scenario lines not visible are hidden by those showing.**

5.5.4 Overall integrity

The Overall Ecological Integrity for each calibration scenario relative to the Preliminary Reference Scenario at FA5 is illustrated in Figure 5.29.

In terms of the predictions generated by the preliminary calibrated BioRA DSS, the greatest impact on the ecosystem at FA2 is under CS3 and CS7, both of which have short wet seasons and limited flooding. The prediction is a drop in integrity from a C to an E. This is because FA5 is dominated by the large floodplains, which are reliant on flooding.

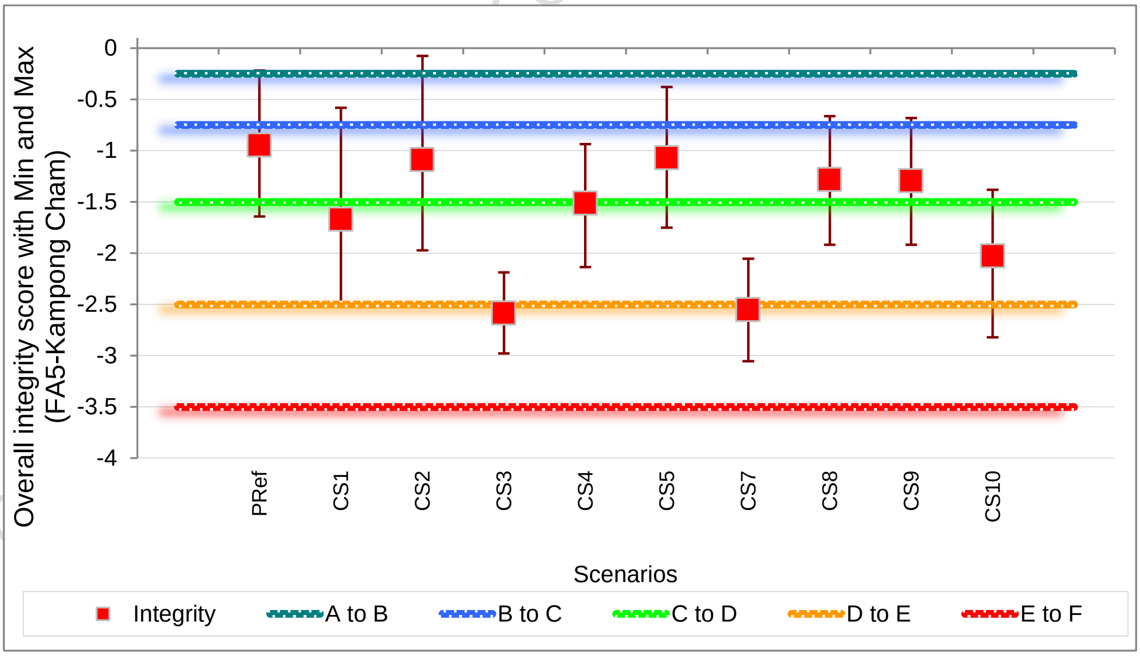


Figure 5.29 **Overall Ecological Integrity scores for the Preliminary Reference Scenario (PRef) and each of the calibration scenarios at FA4 (CS1-10)**

The migration scenarios, CS5, CS8 and CS9, do not have a major effect on Overall Integrity. Although the affect the migratory fish guild (especially CS8 and CS9), these formonly a small portion of the fish community at FA5, and so the effect on integrity is diluted by other fish guilds that are unaffected by the barriers.

For the two sediment-reduction scenarios, CS4 (less 25% sediment supply) and CS10 (less 75% sediment supply), the DSS predicts an decline in overall integrity, proportional to the decrease in sediments. This is to be expected as the increased erosion and water clarity associated with the scenarios will have knock-on effects on habitat condition and food supply.

5.6 Focus Area 6: Prek Kdam

Not included in preliminary calibration – see Section 1.2.2.

5.7 Focus Area 7: Tonle Sap Great Lake

FA7 used water level as the main driving variable.

There are only three calibrations scenarios for FA7, all of which deal with fish migration. It was not possible to generate the other scenarios without input from the DSF models, which was not available for this round of calibration.

5.7.1 Mean percentage changes

The mean percentage changes (relative to Preliminary Reference Scenario) for the indicators in response to each CS at FA7 (Tonle Sap Great Lake) are given in Table 5.9.

Table 5.10 The mean percentage changes in abundance at FA7 (relative to Preliminary Reference Scenario) for the indicators for the data sets. Blue and green are changes that represent increases: green = 40-70%; blue = >70%. Orange and red are changes that represent decreases: orange = 40-70%; red = >70%. Preliminary reference, by definition, equals 100%.

Indicators	Calibration Scenarios		
	CS5	CS8	CS9
Discipline : Vegetation			
FP: Extent of flooded forest	0.6	0.6	0.6
FP: Extent of herbaceous marsh vegetation	-1.3	-1.3	-1.3
FP: Extent of grassland vegetation	-0.6	-0.6	-0.6
FP: Biomass indigenous riparian/ aquatic veg	0.6	0.6	0.6
FP: Biomass algae	1.3	1.3	1.3
Extent invasive riparian cover	0.7	0.7	0.7
Extent invasive floating/submerged plant cover	-1.1	-1.1	-1.1

Indicators	Calibration Scenarios		
	CS5	CS8	CS9
Discipline : Macro-invertebrates			
Insects on sand	0.0	0.0	0.0
Snail abundance	-1.9	-1.9	-1.9
Diversity of snails	-0.2	-0.2	-0.2
Bivalves abundance	-0.2	-0.2	-0.2
Polychaete worms	0.0	0.0	0.0
Shrimps and crabs	-0.2	-0.2	-0.2
Littoral invertebrate diversity	0.0	0.0	0.0
Benthic invertebrate diversity	-0.2	-0.2	-0.2
Zooplankton abundance	-0.2	-0.2	-0.2
Zooplankton diversity	-0.2	-0.2	-0.2
Benthic invertebrate abundance	-0.7	-0.7	-0.7
Discipline : Fish			
Main channel resident (long distance white)	-20.3	-54.9	-58.2
Main channel spawner (short distance white)	-1.3	-4.8	-4.8
Floodplain spawner (grey)	-2.9	-2.9	-2.9
Eurytopic (generalist)	-2.8	-2.8	-2.8
Floodplain resident (black fish)	-1.4	-1.4	-1.4
Estuarine resident	0.0	0.0	0.0
Anadromous	-0.7	-35.6	-35.6
Catadromous	0.0	-22.1	-22.1
Marine visitor	0.0	0.0	0.0
Discipline : Herpetofauna			
Ranid	1.5	1.5	1.5
Aquatic serpents	-3.3	-4.5	-4.6
Aquatic Turtles	-3.5	-4.7	-4.7
Semi-aquatic Turtles	6.3	6.3	6.3
Amphibians-human use	2.6	2.6	2.6
Aquatic/semi-aqu reptiles-human use	-1.1	-1.1	-1.1
Species richness of riparian/FP amphibians	0.9	0.9	0.9
Species richness of riparian/FP reptiles	3.0	2.1	2.0
Discipline : Birds			
Tree-nesting large waterbirds.	-0.9	-4.8	-5.1
Bank / hole nesting species	-1.1	-3.6	-3.8
Flocking non-aerial pass of graminoid beds	1.1	1.1	1.1
Large ground-nesting spp: wetland FP	-1.7	-1.7	-1.7
Channel-using large spp: bankside forest	0.7	0.7	0.7
Dense woody vegetation / water interface	0.0	0.0	0.0
Small non-flocking landbird;seasonally flooded veg	-1.2	-1.2	-1.2
Discipline : Mammals			
Otters	1.2	-0.2	-0.2

5.7.2 Time-series

5.7.2.1 Geomorphology

There are geomorphology indicators for FA7 as these do not apply to the Great Lake. Sedimentation will be supplied by the MRC DSF but was not available for the preliminary calibration.

5.7.2.2 *Vegetation*

No major changes in CS5, 8 or 9.

5.7.2.3 *Macroinvertebrates*

No major changes in CS5, 8 or 9.

5.7.2.4 *Fish*

The Main channel residents are predicted to decline by c. 20% under CS1, which has an in-channel barrier between FA1 and FA2, but are predicted to be far more affected by a barrier between FA4 and FA5 (c. 55% decline).

Anadromous and catadromous fishes are also predicted to be unaffected by a barrier between FA1 and FA2, but negatively affected by a barrier between FA4 and FA5 (a decrease of c. 35% and 20%, respectively).

The main channel spawners are also predicted to be negatively affected by a barrier between FA4 and FA5 but only slightly (decrease of c. 5%).

5.7.2.5 *Herpetofauna*

No major changes in CS5, 8 or 9. Some minor changes related to slight changes in fish biomass.

5.7.2.6 *Birds*

No major changes in CS5, 8 or 9. Some minor changes related to slight changes in fish biomass.

5.7.2.7 *Mammals*

No major changes in CS5, 8 or 9. Some minor changes related to slight changes in fish biomass.

5.7.3 Overall integrity

The Overall Ecological Integrity for each calibration scenario relative to the Preliminary Reference Scenario at FA7 is illustrated in Figure 5.30. The overall effect of the migration calibration scenarios on the ecological integrity of the Tonle Sap is expected to be small, because the guilds affected by barriers in the mainstream Mekong River (G2, G8 and G9) make up only a small proportion of the fish community in the Tonle Sap Great Lake (Figure 5.31), and none of the other biophysical indicators are predicted to be affected by the barriers.

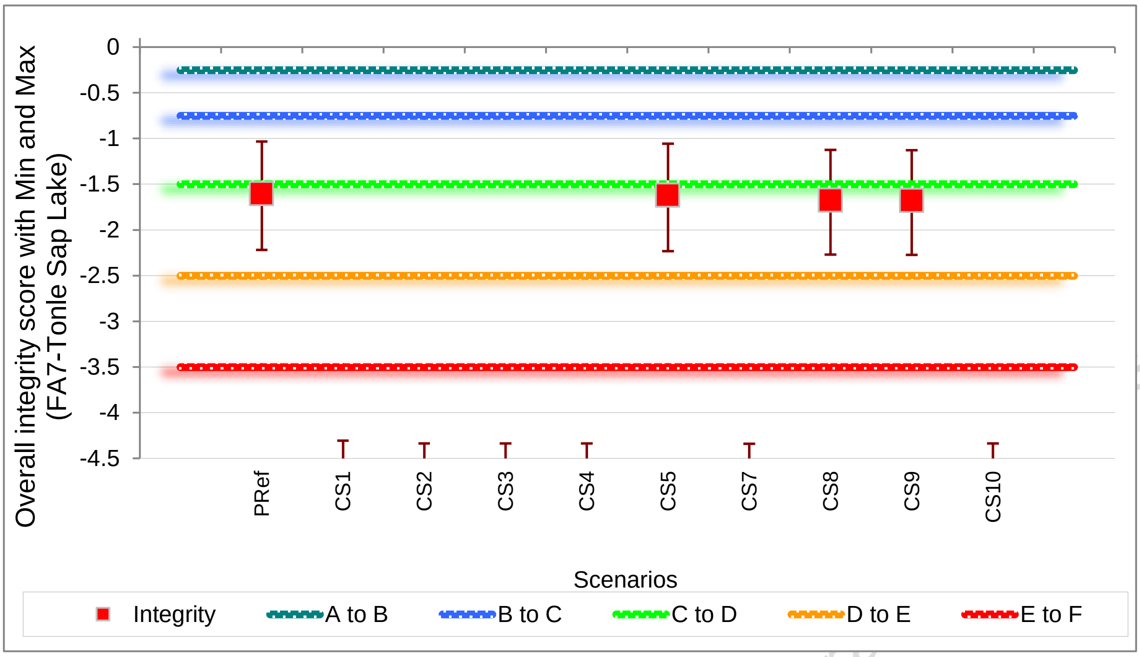


Figure 5.30 **Overall Ecological Integrity scores for the Preliminary Reference Scenario (PRef) and each of the calibration scenarios at FA7 (CS1-10)**

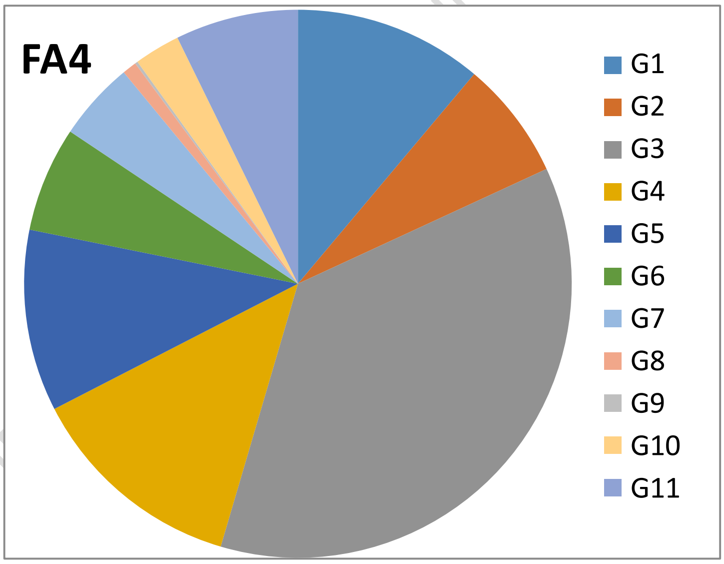


Figure 5.31 **Guild proportions at FA7**

5.8 Focus Area 8: Mekong Delta

Not included in preliminary calibration – see Section 1.2.2.

6 Calibration results per discipline

This section provides results for all disciplines for each hypothetical CS outlined in Section 4.3. This allows evaluation of DSS outputs to see if there are any anomalies longitudinally down the system.

In this section, the predicted changes for each discipline are evaluated for each CS at each FA: As for Section 5, they are presented in the form of integrity for each discipline, on a scale of A to E, where A represented a pristine ecosystem and E a critically modified one with few, if any, intact ecosystem functions (Table 6.1). The reference ecological condition is taken from the Status and Trends assessment for each discipline presented in Interim Technical Report 1: Volume 1 - Specialists' Report.

Mammals are not included here as they only occur at two FAs (FA5 and FA7), and do not react to the three CSs at FA7. The mammal results are provided in Section 5.

Table 6.1 Definitions of Overall Ecological Integrity categories (after Kleynhans 1999)

A	Unmodified, natural	As close as possible to natural conditions.
B	Largely natural	Modified from the original natural condition but not sufficiently to have produced measurable change in the nature and functioning of the ecosystem/community.
C	Moderately modified	Changed from the original condition sufficiently to have measurably altered the nature and functioning of the ecosystem/community, although the difference may not be obvious to a casual observer.
D	Largely modified	Sufficiently altered from the original natural condition for obvious impacts on the nature and functioning of the ecosystem/community to have occurred.
E	Completely modified	Important aspects of the original nature and functioning of the ecosystem community are no longer present. The area is heavily negatively impacted by human interventions.

The predicted changes in the aquatic ecosystem per FA are provided in Section 5.

Note that in order to improve readability of the graphs, the Y-axes of the graphs for each discipline are *different scales*.

6.1 Geomorphology

The geomorphological integrity for calibration scenarios at the FAs is shown in Figure 6.1. CS5, CS8 and CS9 have no effect on geomorphology as they deal with barriers to fish migration only.

The main contributor to geomorphological integrity is erosion/deposition associated with changes in sediment supply, as this also has knock on effects on the other geomorphological indicators. Flow associated with the scenarios also affects geomorphological integrity, but to a lesser extent.

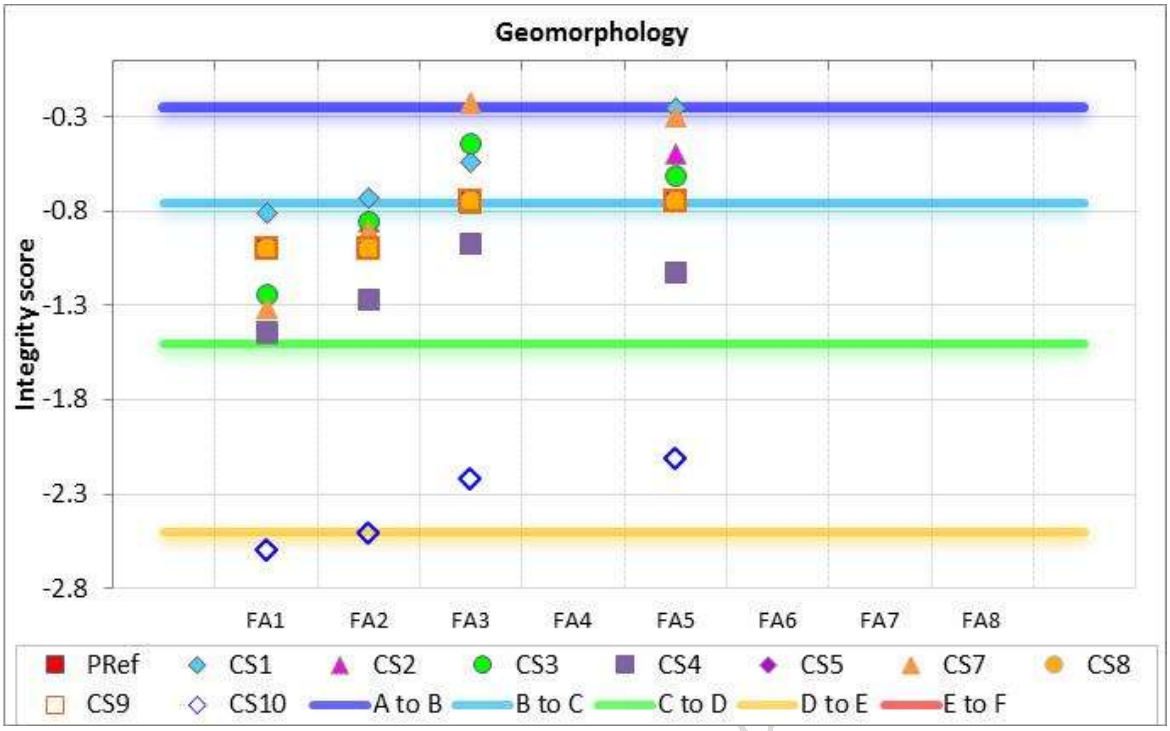


Figure 6.1 **Geomorphology integrity for all scenarios and sites**

As expected, the two calibration scenarios that affected sediment supply (CS4 and CS10) have the greatest effect on geomorphological integrity. The integrity under CS10 (sediment supply at 25% of Preliminary Reference Scenario) is significantly lower than that under CS4 (sediment supply at 75% of Preliminary Reference Scenario) at all sites, but especially at FA1. This is mainly because of the nature of the zone, which is steeper than other zones, and as a result, the level of erosion associated with reduced sediment, and the concomitant reduction in sandy habitats, is enhanced. A reduction in sediment supply to 25% of the Preliminary Reference Scenario is predicted to result in a drop in geomorphological integrity from a C to an E or from a B/C to a D, depending on the FA (Figure 6.1.)

The dry scenarios (CS3 and CS7) have, in general, higher integrity scores than the Preliminary Reference Scenario, mainly due to reduced erosion.

Of the remaining two relevant scenarios (CS1 and CS2), CS1 has slightly reduced erosion associated with decreased wet-season flows, and consequent higher integrity. CS2, on the other hand, has - for the most part - very similar integrity to the Preliminary Reference Scenario.

6.2 Vegetation

The vegetation integrity for the calibration scenarios at the FAs is shown in Figure 6.2. CS5, CS8 and CS9 have no effect on vegetation as they deal with barriers to fish migration only.

The two scenarios that have the greatest effect on vegetation integrity are CS1 (which has muted seasons) and CS7 (which is very dry). These two scenarios reduce the extent of all vegetation indicators (apart from invasives) at all FAs, which in turn affects vegetation biomass. CS3 (short wet season) also decreases integrity at FA1 and FA3, but not at FA2 and FA5. The differences in effects are partly due to the two more important driver indicators for vegetation viz., dry and wet season average depths (Table 6.2), and partly due to the different suite of vegetation indicators present at the different sites (see Table 3.2). Dry season average depth is higher at FA1, 2, 3, and 5, for CS1, but lower at FA2 and FA3 for CS3, and at FA5 for CS7. In addition, FA3 has both channel and floodplain vegetation indicators, while FA1 and FA2 have only channel indicators and FA5 has only floodplain vegetation indicators (Table 3.2). The differences between the FAs will need to be further examined for potential inconsistencies as part of further calibration.

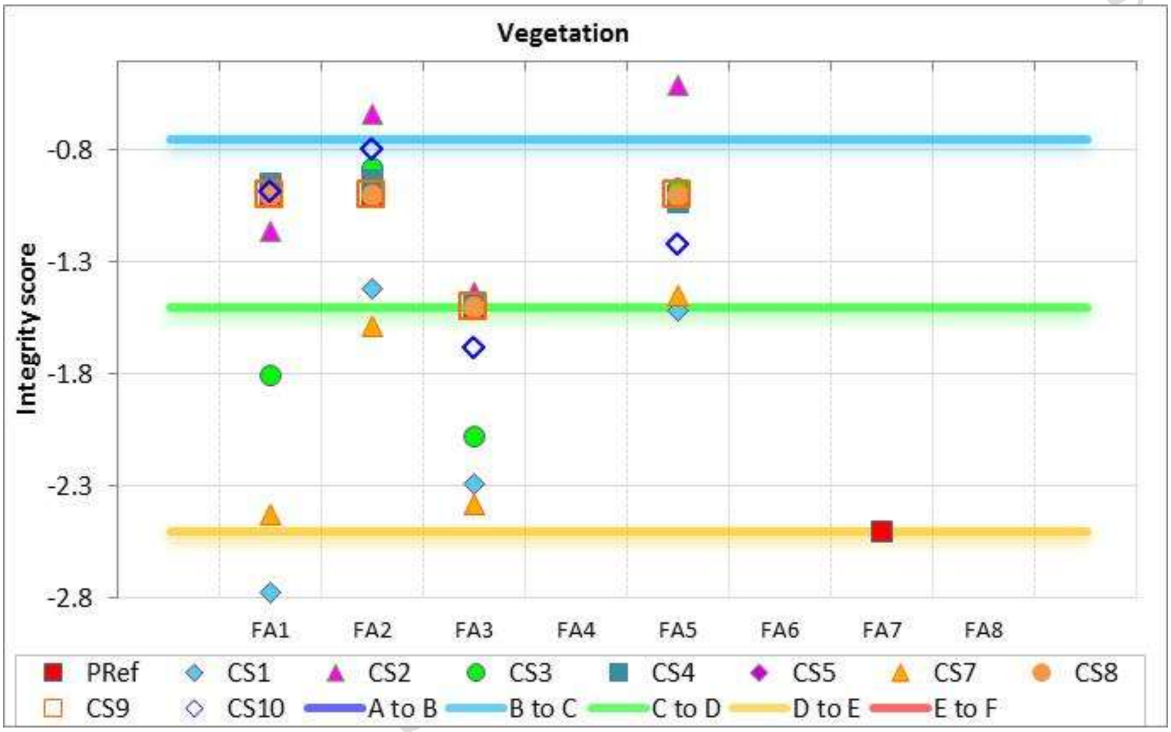


Figure 6.2 **Vegetation integrity for all scenarios and sites**

Table 6.2 **Dry and wet season average depth at FA1, 2, 3 and 5, for CS1, 3 and 7**

		PRef	CS1	CS3	CS7
FA1	Dry: ave Ch Depth	12.31	1.12	1.01	1.03
	Wet: ave Ch Depth	20	0.93	0.94	0.84
	Veg integrity	-1	-2.77	-1.80	-2.42
FA2	Dry: ave Ch Depth	5.04	1.03	0.71	1.04
	Wet: ave Ch Depth	11.14	0.99	0.97	0.80
	Veg integrity	-1.00	-1.42	-0.88	-1.59
FA3	Dry: ave Ch Depth	3.42	1.26	0.92	1.02
	Wet: ave Ch Depth	9.48	0.93	0.89	0.81
	Veg integrity	-1.50	-2.29	-2.08	-2.38
FA5	Dry: ave Ch Depth	23.57	1.06	1.00	0.99
	Wet: ave Ch Depth	32.15	0.98	0.94	0.95
	Veg integrity	-1.00	-1.52	-0.97	-1.45

6.3 Invertebrates

The invertebrate integrity for calibration scenarios at the FAs is shown in Figure 6.3. CS5, CS8 and CS9 have no effect on invertebrates as they deal with barriers to fish migration only.

The scenario with the greatest relative impacts is CS10 (sediment at 25%), which increases invertebrate integrity at FA1, 2 and 3, but has little effect at FA5. CS3 (short wet season) increases integrity at FA1 and FA2, but decreases integrity at FA3 and FA5. CS7 (very dry) increases integrity at FA1 and FA5, but decreases integrity at FA2, and FA3. CS1 decreases invertebrate integrity at FA1 and FA5, but not at FA2 and FA3. The different effects of scenarios at different sites are driven mainly by a combination of differential *degrees* of effects of the scenarios on erosion, biomass of algae and wetted perimeter. For example, CS10 increases the biomass of algae, but to a lesser extent at FA5 compared to FA1, 2 and 3. The differences at different sites will need to be further examined for potential inconsistencies.

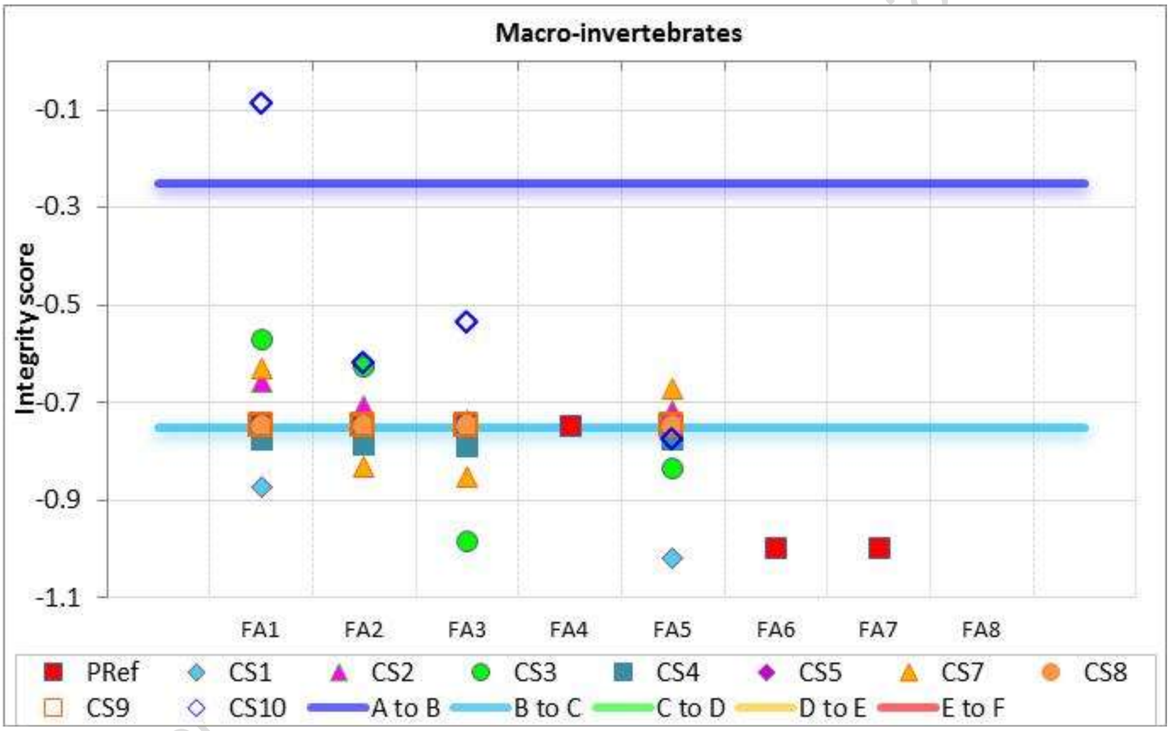


Figure 6.3 Invertebrates integrity for all scenarios and sites

6.4 Fish

CS1 increases fish abundance and consequently integrity at FA1, FA2 and FA3, due to increased dry season flows and the associated knock-on effects. However, at FA5, fish integrity decreases under CS1 (the marker is hidden behind that of CS5 in Figure 6.4). This is because the floodplain spawners, floodplain residents and eurytopic fish, which decrease under CS1, make up a bigger proportion of the fish at FA5 than do the other guilds, which increase (Figure 6.5).

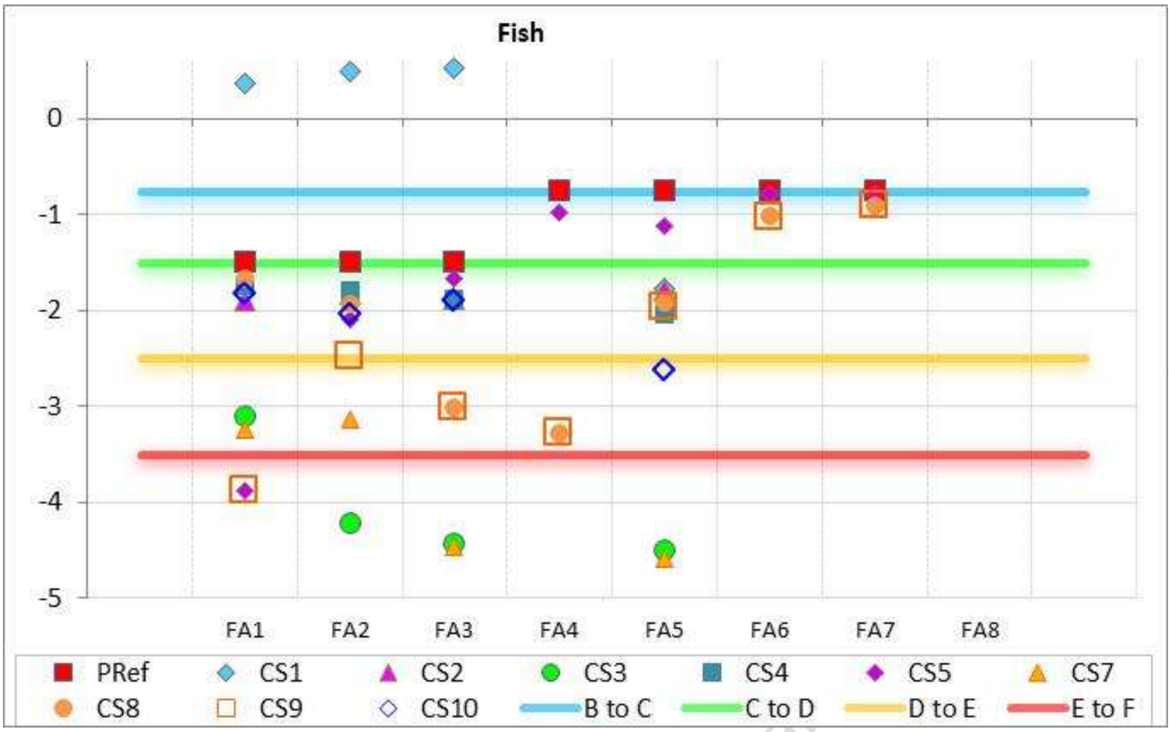


Figure 6.4 **Fish integrity for all scenarios and sites**

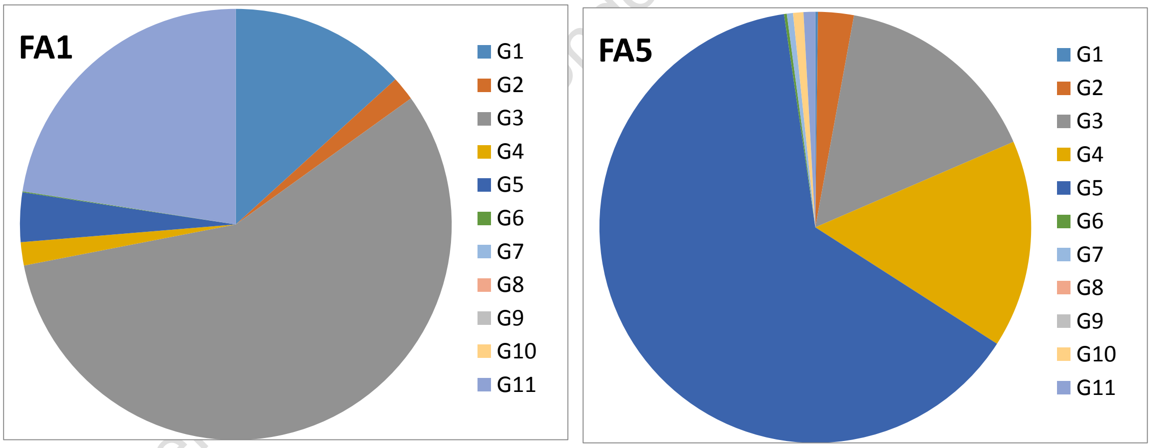


Figure 6.5 **Guild proportions at FA1 and FA5**

CS3 and CS7, which reduce wet season duration and overall flows, have a consistently negative effect on fish integrity across all FAs, as do those that reduce sediment supply (CS4 and CS10).

The predicted effects of the three migration scenarios display a somewhat more subtle pattern. CS5, which has a the barrier between FA1 and FA2, has a marked effect on fish integrity at FA1, as it is dependent on the migratory fish making their way up- and downstream of the FA. Downstream of the barrier, the predicted impacts of CS5 are progressively less marked with distance downstream. CS8 (barrier between FA4 and FA5) on the other hand, has the greatest impact at FA3, FA4 and FA5. The combined barriers (CS9) basically reflect the sum of the other two scenarios. Tonle Sap Great Lake

(FA7) is not majorly affected by the barriers because the migratory guilds (G2, G8 and G9) make up only a small proportion of the fish community there.

6.5 Herpetofauna

Herpetofauna integrity for calibration scenarios at the FAs is shown in Figure 6.6.

The largest relative effects on herpetofauna are under CS3 (short wet season) and CS7 (extreme dry), which resulted in a predicted decline in herpetofauna integrity at all FAs. The sharp increase in response at FA5 for these CS3 and CS7 (and CS1) is related to the fact that this FA is characterised as a floodplain in the DSS, i.e., no channel indicators. The fish migration scenarios (CS5, 8 and 9) also resulted in a slight decline at all FAs, in response to reduced fish biomass, which is a major part of the diet of the larger reptiles. CS1 resulted in a predicted decrease in integrity at all FAs, except for FA2, for which the DSS predicted an increase in integrity. Similarly, the DSS predictions for CS10 (sediment reduced by 75%) were inconsistent down the river, with an increase at FA1, and decreases at FA2, FA3 and FA4. The combination of factors contributing to these outcomes will be further investigated for possible inconsistencies although none were immediately apparent.

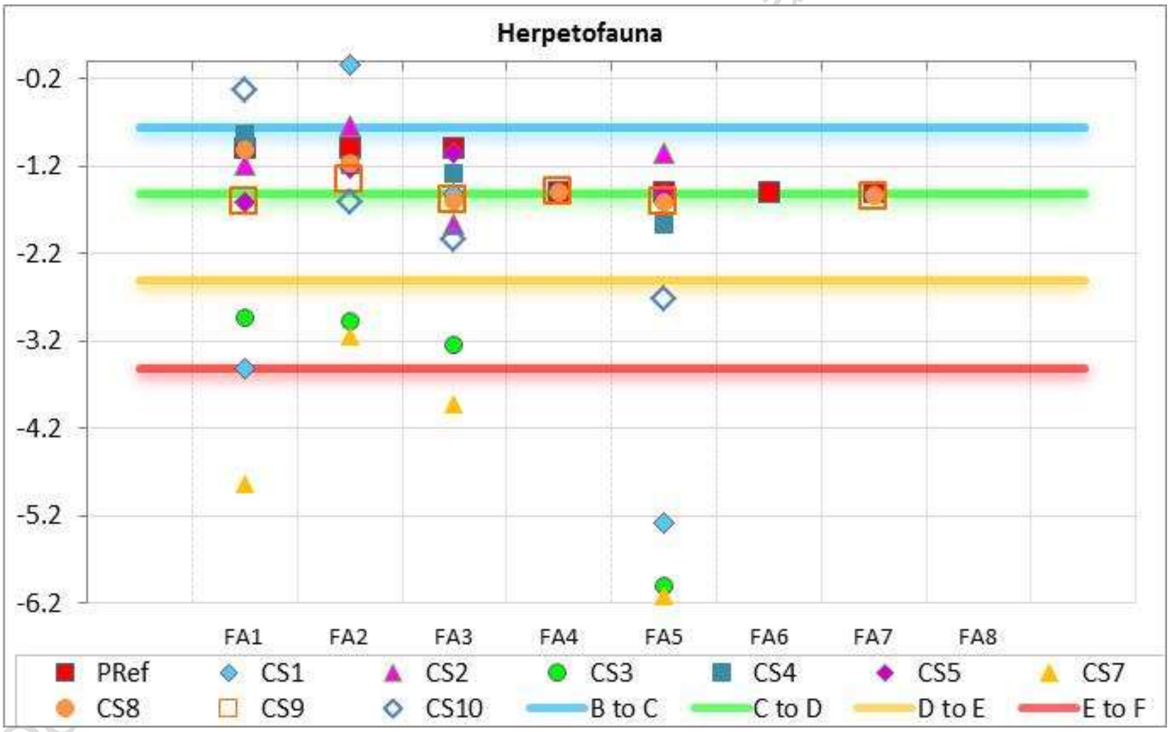


Figure 6.6 Herpetofauna integrity for all scenarios and sites

6.6 Birds

Bird integrity for calibration scenarios at the FAs is shown in Figure 6.7.

The results for the bird integrity suggest that the allocation of indicators (either per FA or in the calculation if integrity) requires review. For instance, under CS1 bird integrity was predicted to decrease at FA1, FA2, and FA5, but unchanged at FA3. These changes are driven by the results for Medium/large ground-nesting channel bird, which are predicted to increase at FA3 and FA5, but decrease at FA1 and FA2, but also (mainly) by the addition of the Flocking non-aerial passerine of tall graminoid beds at FA5. The differences in CS2 are similarly related to an additional indicator (pied king fisher) at FA5.

CS4, CS5, CS8, CS9 and CS10 were predicted to have little or no effect at all FAs.

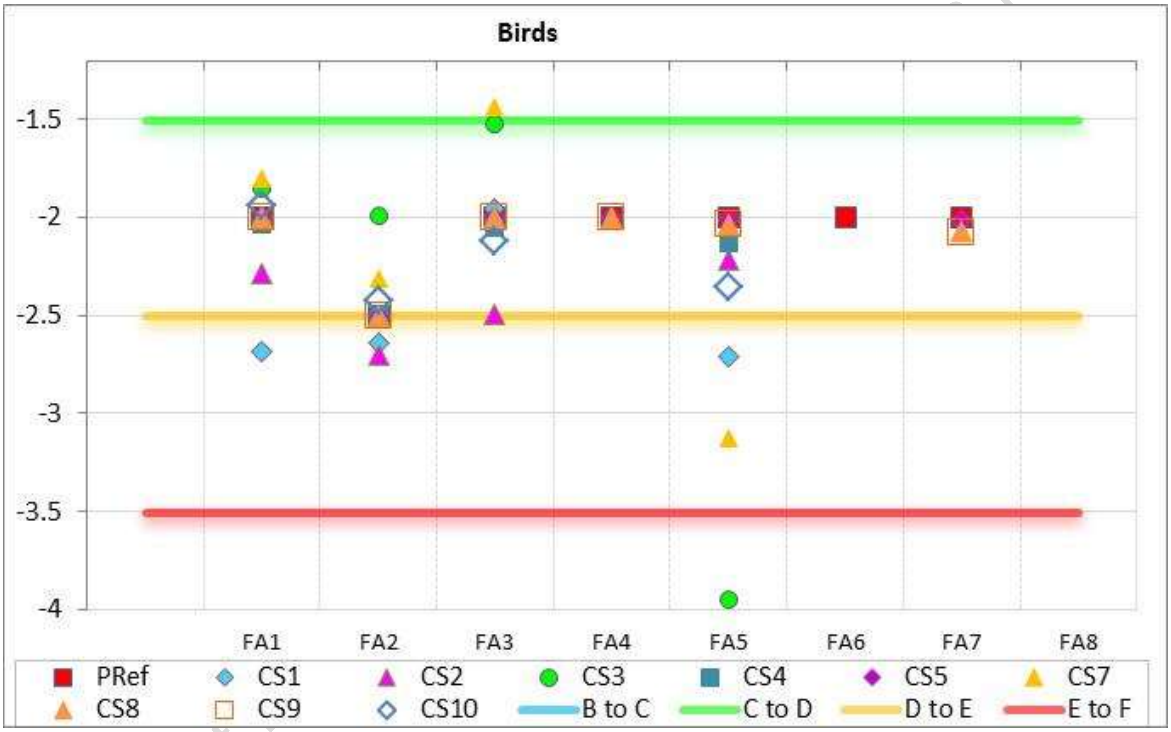


Figure 6.7 Bird integrity for all scenarios and sites

7 Conclusions on the predictions for the calibration scenarios and implications for calibration of the BioRA DSS

As mentioned in Section 1.3, the purpose of this document is to present the results of the preliminary calibration so that these can be discussed, analysed and, if necessary, the response curves driving the DSS can be adjusted. Ideally, there should be agreement that the DSS predictions for individual indicators are reasonable and, more importantly, explainable before using the DSS to make predictions for the Council Study cumulative and thematic development scenarios.

The process of compiling the report and describing the results has raised some questions about the DSS predictions, which will be used to stimulate the discussion in the next phase of BioRA. Some of these related to the input data used and some to the arrangement of linked indicators and response curves.

As part of the completion of DSS calibration, the DSS will be updated with the full suite of modelled data for the Reference Scenario 2007. In all likelihood, many of the issue related to the input data will be resolved by switching to the full suite of DSF modelled input data, in particular the water quality, sediments and sub-daily operation of infrastructure. Issues related to these data include:

- There were no modelled calibration data for FA7, and thus only partial calibration undertaken for FA7.
- Within day ranges, which not yet properly calibrated for various reasons:
    1. Changes in discharge will reflect differently in terms of water levels depending on the geometry of the channel, i.e. for this reason water level is a better linked indicator to use. However, without the modelled data from the DSF it was not possible to use water level.
    2. There is as yet no clear indication of the likely magnitude of peaking.
    3. None of the CSs included peaking, and so the outcome for calibration peaking scenarios has not yet been investigated.
    4. Not all of the specialists have reached the point where they have linked to within day variations in discharge.
- Each of the calibration scenarios focused on a single aspect – e.g., flow change, barrier or sediment reduction. In reality one would not occur without the other, and the impact on the ecosystem would be a result of the combined effects of both. For instance, if a dam is constructed for hydropower generation, it is likely that it will affect migration, sediment supply, and change the flows.

Issues related to the arrangement of linked indicators and response curves are raised in the relevant sections of the report. Many of these may indeed be correct, or moay related idiosyncrasies in the preliminary dataset but nonetheless they all require further checking and explanation. They include:

- There are some inconsistencies in indicators, linked indicators and response curves between FAs. Most of these are related to difference between the FAs, but they all need to be checked in the light of the predictions.

- The x-axes for within-day fluctuations in discharge for geomorphology require checking. These did not affect the CS results – but may affect the outcome of a scenario that includes releases for peaking power generation.
- A reduction in duration of wet season is expected to reduce the number of tree-damaging floods each year and thus allow for encroachment of terrestrial forest to the detriment of riparian upper bank vegetation. This assumption should be checked against the benefit for the riparian vegetation of not being knocked-back by floods, and the outcome reported in the evidence-based motivation for the relevant response curves(s).
- Macroinvertebrates were not affected by any of the scenarios, which may be correct but should be substantiated through evidence-based explanations.
- At FA5, *Neotricula aperta* is predicted to increase under CS1. This is entirely in response to an increase in dry season wetted perimeter, which is expected to provide an indication of total habitat area. Habitat area is expected to correlate with snail population size. However, wetted perimeter is not a linked indicator at FA3. This requires checking – and if correct, additional explanation/evidence.
- The weights for the fish contribution to integrity are based on guild contribution to composition of catch (Interim Technical Report 1: Volume 1 – Specialists' Report) and it may be that this would be better based on contribution to diversity.
- The Main channel resident, Rithron residents and Main channel spawners all increase markedly under CS1. These changes are driven by several factors. Of these, possibly the most relevant is increase in dry season flows, which can assist recruitment by flushing spawning beds and maintaining dry season pool depths, which the fish use as refuge areas. It may be, however, that these improvements are a little exaggerated in the current DSS.
- Eurytopic fish do less well than other guilds CS1.
- There is some residual double-accounting in the links, for instance "discharge" and "water depth", which requires resolution.
- Overall the DSS is sensitive to duration of wet season and to flooded area on floodplains. Thus, the curves linked to these two aspects will need to be interrogated to ensure that they are not over-estimating the response.
- All the results need careful evaluation in the light of the preliminary calibration scenarios – particularly given that some of these do not represent dramatic changes from the Preliminary Reference Scenario.

Other issues will arise, and be resolved, through the examination and subsequent discussions of the results presented in this report and revisions of the DSS.

8 Literature

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Appendix A. BIORA TEAM MEMBERS FOR KNOWLEDGE CAPTURE AND CALIBRATION WORKSHOPS

Name	Discipline
Dr So Nam	BioRA Task Leader: MRC Fisheries Programme
Dr Henry Manguerra	Council Study Coordinator
Prof. Cate Brown	BioRA Team Technical Lead
Dr Alison Joubert	DRIFT DSS Manager
Manothone Vorabouth	Council Study Administrative Assistant
Dr Lois Koehnken	Geomorphology and Water Quality Lead Specialist
Dr Andrew MacDonald	Vegetation Lead Specialist
Prof. Nguyen Thi Ngoc Anh	Delta Macrophytes Lead Specialist
Ms Duong Thi Hoang Oanh	Delta Microalgae Lead Specialist
Dr Ian Campbell	Macroinvertebrate Lead Specialist
Prof. Ian Cowx	Fish Lead Specialist
Dr Dirk Lamberts	Tonle Sap Process Lead Specialist
Dr Chavalit Vidthayanon	MRC Fisheries Programme
Mr Ngor Peng Bun	MRC Fisheries Programme
Dr Hoang Minh Duc	Herpetology Lead Specialist
Anthony Stones	Bird and Mammal Lead Specialist
Toch Sophon	Geomorphology Cambodia Specialist
Pich Sereywath	Biodiversity, excl. fish Cambodia Specialist
Dr Chea Tharith	Fish Cambodia Specialist
Dr Idsariya Wudtisin	Geomorphology Thailand Specialist
Chaiwut Grudpun	Fish Thailand Specialist
Dr Hong Truong Luu	Biodiversity, excl. fish Vietnam Specialist
Vu Vi An	Fish Viet Nam Specialist
Dr Bounheng Soutichak	Geomorphology Lao PDR Specialist
Thananh Khotpathoom	Vegetation Lao PDR Specialist
Dr Phaivanh Phiapalath	Fauna, excl. fish Lao PDR Specialist
Dr Kaviphone Phouthavong	Fish Lao PDR Specialist

Appendix B. KNOWLEDGE CAPTURE AND CALIBRATION

A Knowledge Capture and Calibration Workshop was held in MRC Secretariat in Phnom Penh (OSP) from 17th to 24th September 2015.

KNOWLEDGE CAPTURE AND CALIBRATION WORKSHOP

The schedule for the Knowledge Capture and Calibration Workshop from 17th to 24th September 2015 is given in Appendix Table 1.

Appendix Table 1 Schedule for the Knowledge Capture and Calibration Workshop from 17th to 24th September 2015 in Phnom Penh

Day	Date	Activity (please note – FA focus changed between disciplines)
THURSDAY	17-Sept	Team Meeting 1 – see agenda below
FRIDAY	18-Sept	KCW: FA3 and FA4
SATURDAY	19-Sept	Calibration: FA 1, 2, 3 and 4
SUNDAY	20-Sept	Calibration: FA 1, 2, 3 and 4
MONDAY	21-Sept	KCW: FA 5, 6, 7
TUESDAY	22-Sept	KCW: FA 5, 6, 7
THURSDAY	23-Sept	AM: Team Wrap Up PM: Home

TEAM MEETING AGENDAS

The agendas for the team meetings and the wrap-up are provided in Appendix Table 2 and Appendix Table 3.

Appendix Table 2 Agenda: Team meeting – 17th September 2015 (OSP)

Time	Item	Presenter/Facilitator
8:00 AM	Welcome and Introductions	So Nam
8:15 AM	Presentation of AGENDA	Cate Brown
8:30 AM	BioRA Progress and Way Forward	Cate Brown
9:00 AM	Modelled data availability and plan for the week	Cate Brown
9:30 AM	Calibration Scenarios	Alison Joubert
10:00 PM	TEA	
10:30 AM	Specialist Reports	Cate Brown
10:45 AM	Process and data for Tonle Sap	Dirk Lamberts
11:00 AM	DRIFT Handover and reminder of the process	Alison Joubert
12:30 PM	LUNCH	
2:00 PM	KCW: FA1, FA2, FA3 and FA4	All
3:00 PM	TEA	
3:30 PM	KCW: FA1, FA2, FA3 and FA4	All
5:00 PM	Close for the day	

Appendix Table 3 Agenda: Team wrap-up – 24th September 2015 (OSP)

Time	Item	Presenter/Facilitator
8:00 AM	KCW – Finalisation of outstanding tasks	All
9:30 AM	Hand over DSS – and plans for finalisation	Alison Joubert
10:00 PM	TEA	
10:30 AM	BioRA – Way forward and deadlines	Cate Brown
11:45 AM	Closing address	So Nam
12:00 PM	Close of OSP KCW	
12:30 PM	LUNCH	

Appendix Figure 1 Members of the BioRA Team in Phnom Penh (September 2015)