MEKONG RIVER COMMISSION

THE COUNCIL STUDY

The Study on the Sustainable Management and Development of the Mekong River Basin, including Impacts of Mainstream Hydropower Projects

Biological Resource Assessment Technical Report Series

Volume 4: Assessment of Planned Development Scenarios

(Final Report)

29 December 2017

Disclaimer:

These Council Study reports are considered final drafts prepared by the technical experts and specialists of the Mekong River Commission, through a process of consultation with representatives of member countries. The contents or findings of the reports are not necessarily the views of the MRC member countries but will serve as knowledge base and reference in the work of the MRC and its member countries in their ongoing technical and policy dialogues in ensuring the sustainable development of the Mekong river basin.

The MRC is funded by contribution from its member countries and development partners of Australia, Belgium, European Union, Finland, France, Germany, Japan, Luxembourg, the Netherlands, Sweden, Switzerland, the United States and the World Bank.

Citation:

Mekong River Commission (MRC). 2017. The Council Study: Study on the sustainable management and development of the Mekong River, including impacts of mainstream hydropower projects. BioRA Final Technical Report Series. Volume 4: Assessment of Planned Development Scenarios. FINAL REPORT. Vientiane, Lao PDR. 145 pp.

Authors:

Cate Brown, Alison Joubert, Lois Koehnken, Ian Cowx, Hoang Minh Duc, Anthony Stones, Ian Campbell, James MacKenzie, Nguyen Thi Ngoc Anh, Duong Thi Hoang Oanh, Andrew MacDonald, Bounheng Soutichak, Toch Sophon, Luu Hong Truong, Kaviphone Phouthavong, Vu Vi An, Pich Sereywath, Phaivanh Phiapalath, Chea Tharith, So Nam, Henry Manguerra, Jackie King, Idsariya Wudtisin, Thananh Khotpathoom, Chavalit Vidthayanon and Chaiwut Grudpun.

Report prepared by Southern Waters ER&C cc

Contents

List of figures

List of tables

Document history

Version	Date	Report name	Comment
Draft 1	June 2017	Final Technical Report Series: Volume 4 – Planned Development Scenario Report - DRAFT	Incomplete draft containing first predictions for the main development scenarios
Draft 2	September 2017	Final Technical Report Series: Volume 4 – Assessment of Planned Development Scenarios - DRAFT	Predictions for the main development scenarios and sub-scenarios
Draft 3	October 2017	Final Technical Report Series: Volume 4 – Assessment of Planned Development Scenarios – FINAL DRAFT	Updated predictions for the main development scenarios and sub-scenarios following discussion with MT
Draft 4	November 2017a	Final Technical Report Series: Volume 4 – Assessment of Planned Development Scenarios – FINAL DRAFT	Additions and initial corrections based on feedback from the Member Countries
Draft 4	November 2017b	Final Technical Report Series: Volume 4 – Assessment of Planned Development Scenarios – FINAL DRAFT	
Final	December 2017	Final Technical Report Series: Volume 4 – Assessment of Planned Development Scenarios – FINAL REPORT	

Glossary, acronyms and abbreviations

Anadromous (fish)	Fish that migrate up rivers from the sea to spawn
ALU	Agricultural Landuse
BioRA	Biological Resource Assessment
Biota (of a river)	Plants and animals that live in, or are directly dependent on, a river
BDP	Basin Development Plan
Catadromous (fish)	Fish that migrate down rivers to the sea to spawn
Dam	An obstruction constructed on a river, usually for water storage and/or the production of electricity
DIW	Domestic and Industrial Water Use
DRIFT	A holistic EFA Method. Acronym for Downstream Response to Imposed Flow Transformations
DSF	Decision Support Framework
DSS	Decision Support System
EFlows	Environmental Flows
Eurytopic	A generalist species, i.e., on that is able to thrive in a wide variety of environmental conditions and can make use of a variety of different resources
FA	Focus Area
Flow regime	The volume and distribution of water that flows down a river in a particular period, e.g., a day, a month or a year
FP	Floodplain
FPI	Flood Protection Infrastructure
Generalist	A generalist species is able to thrive in a wide variety of environmental conditions and can make use of a variety of different resources[1]
Holt	An area where otters breed
HPP	Hydro-electric Power Plant
Hydrograph	A graph of water discharge against time
Hydrology	The study of movement of water on, under and above the land
IBFM	Integrated Basin Flow Management
Impoundment	The water stored behind a dam wall
IRR	Irrigation
ISIS	Hydrology, Hydraulics and Water Quality Modelling Programme
LMB	Lower Mekong Basin
MRC	Mekong River Commission
MCs	Member Countries
NAV	Navigation
NB	*Nota bene* (note well)
NMC	National Mekong Committee
Q	Discharge (m^3/s)
RC	Response curve

[1] Krebs, J.R. and Davies, N.B. 1993. An Introduction to Behavioural Ecology. Wiley-Blackwell. ISBN 0-632-03546-3.

Riparian	Pertaining to the banks of a river
River	In the context of this study, unless specifically stated otherwise, the term river is taken to encompass all biotic and abiotic components of inland freshwater ecosystems linked to the river, including its channel, wetlands, floodplains and estuary
River regulation	Modification of the natural flow regime of a river, usually by human interference
Reservoir	The area upstream of a dam wall where water is stored
OSP	Office of the Secretariat_Phnom Penh
OSV	Office of the Secretariat_Vientiane
PDR	People's Democratic Republic
SEA	Strategic Environmental Assessment
UMB	Upper Mekong Basin
WQ	Water Quality
WUP-FIN	Water Utilisation Programme – Finland
Water-resource development	Any development that involves the use of the water resources of a river. In the context of BioRA, the term is used to refer to developments that alter or block a river's natural flow, sediment and/or water quality regimes.

Acknowledgements

The BioRA Team wishes to thank all the **NMC members** who provided comment on various versions of this report. The feedback received was extremely useful, and has been incorporated into this update of the report.

The team also wishes to thank **Professor Jackie King** of Water Matters and the University of the Western Cape, South Africa for her thorough and invaluable internal review of this report.

Cate and Alison would like to thank the **BioRA specialists** for their diligent and tireless efforts, and unparalleled good humour, throughout the Council Study.

Executive summary

Introduction

The Council Study aimed to improve understanding of the impact of different water-related development opportunities within the whole Mekong River Basin, and to provide recommendations to facilitate development planning in the LMB. The stated objectives of the Council Study were to:

- further develop 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 Basin Development Plan process, and;
- promote capacity within, and ensure technology transfer to, the National Mekong Committees.

The Council Study involved:

- Six Thematic Teams each representing a development thematic area or sector, *viz*.:
  - Agricultural Landuse, Domestic and Industrial Water Use, Flood Protection Infrastructure, Hydropower, Irrigation and Navigation.
- Five cross-cutting Discipline Teams, *viz*.:
  - Climate change, Modelling, Bio-resources (BioRA), Social and Economic.

This report is BioRA Technical Report Series. Volume 4: Assessment of Planned Development Scenarios.

The main objective of BioRA was to provide clear and comparable information on the impacts of existing and proposed water-resource developments included in the scenarios on the aquatic resources of the study area. The report provides predicted ecological outcomes for four main development scenarios and a series of thematic sub-scenarios.

Main development and thematic sub-scenarios

The main development scenarios cover existing and planned water-resource developments for the past (2007 - Baseline), and the near (2020) and more distant (2040) future, plus climate change (2040CC).

The thematic sub-scenarios are variations on Scenario 2040CC, and their impacts on the ecosystem are assessed relative to that scenario. For each sub-scenario only one thematic sector is changed. The sub-scenarios are:

- Climate change sub-scenarios:
  - C2_2040Wet = 2040CC with wetter climate
  - C3_2040Dry =2040CC with drier climate
- Agricultural landuse sub-scenarios:
  - A1_noALU = 2040CC agriculture development at 2007 levels
  - A2_ALU = 2040CC with more agriculture development than in A1

- Irrigation sub-scenarios:
    - I1_noIRR = 2040CC with irrigation development at 2007 levels
    - I2_IRR = 2040CC with more agriculture development than in 2040CC
- Flood protection infrastructure sub-scenarios:
    - F1_noFPI = 2040CC with flood protection infrastructure at 2007 levels
    - F2_FPI = 2040CC with flood protection infrastructure at 'Level 2'
    - F3_FPI = 2040CC with flood protection infrastructure at 2020 levels, plus dam operations to reduce extreme flooding
- Hydropower sub-scenarios
    - H1a_noHPP = 2040CC with LMB hydropower development at 2007 levels
    - H1b_nomainHPP = 2040CC with the Lancang HPPs plus 2040 tributary HPPs
    - H3_HPP = 2040CC but with consideration of mitigation measures and operations at the HPPs.

BioRA zones

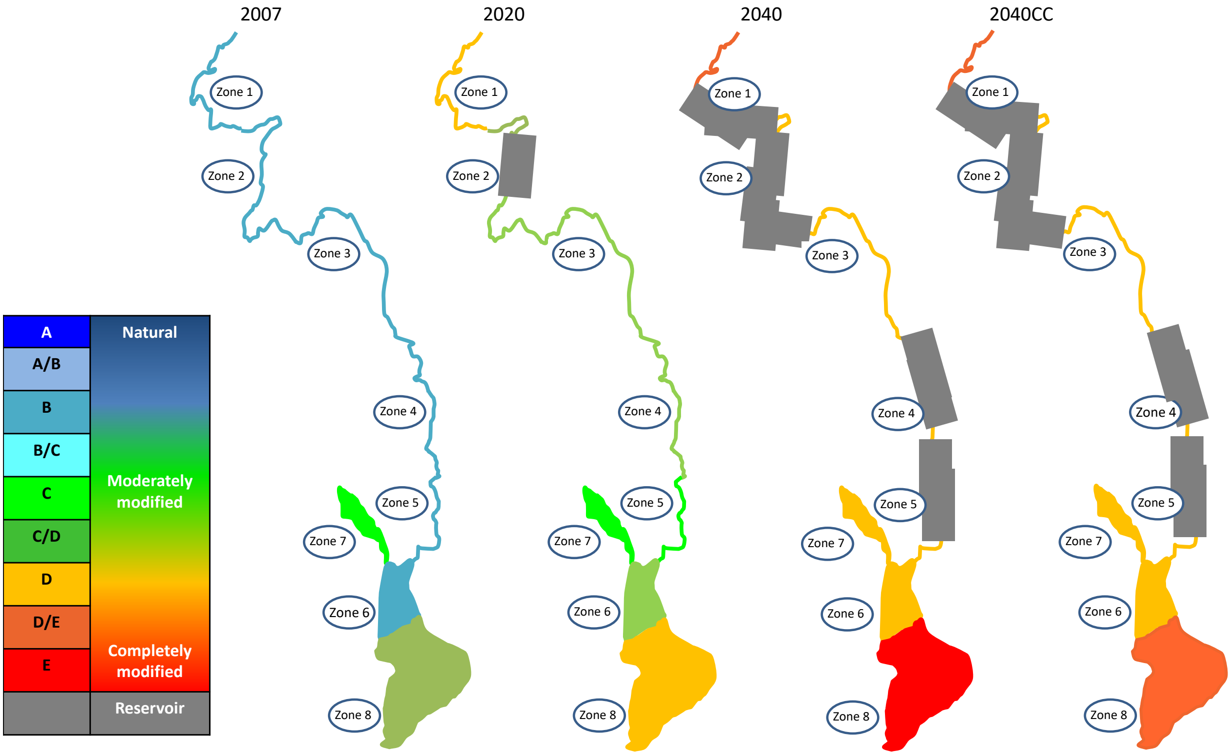
For BioRA, the LMR was divided into eight BioRA zones.

Main development scenarios: Overview of impacts

Changes in the physical environment (flow, sediments, nutrients, connectivity, salinity) driven by the developments in Scenario 2020 and 2040 are expected to affect the nature and availability of riverine habitats and the ability of species to complete their life cycles. The nett effect of these changes expressed using the key ecosystem indicators is provided below.

Zone	Indicator		2020	2040	2040CC
Zone 1	Erosion	river channel	+115	+115	+115
		impoundment	n/a	-100	-100
	Extent of indigenous riparian and wetland vegetation		-0	-35	-40
	Fish biomass		-35	-55	-55
	OAA biomass		-25	0	0
	Biodiversity		-35	-55	-60
Zone 2	Erosion	river channel	+45	+70	+65
		impoundment	-100	-100	-100
	Extent of indigenous riparian and wetland vegetation		-25	-80	-80
	Fish biomass		-40	-70	-75
	OAA biomass		+5	+35	+35
	Biodiversity		-50	-85	-85
Zone 3	Erosion	river	+25	+30	+20
		impoundment	n/a	n/a	n/a
	Vegetation biomass		-10	-10	-10
	Fish biomass		-40	-60	-65
	OAA biomass		-15	-15	-15
	Biodiversity		-30	-35	-35
Zone 4	Erosion	river channel	+35	+35	+40
		impoundment	n/a	-100	-100
	Extent of indigenous wetland vegetation		0	-30	-35
	Fish biomass		-15	-40	-40
	OAA biomass		-15	0	0
	Biodiversity		-40	-80	-80
Zone 5	Erosion	river channel	+60	+80	+80
		impoundment	n/a	-100	-100
	Extent of indigenous riparian and wetland vegetation		-10	-45	-45
	Fish biomass		-20	+5	+5
	OAA biomass		-15	+5	+10
	Biodiversity		-35	-75	-75
Zone 6	Floodplain sedimentation		-65	-95	-95
	Extent of indigenous riparian and wetland vegetation		-15	-30	-25
	Fish biomass		-20	-40	-35
	OAA biomass		-5	-10	-10
	Biodiversity		-25	-45	-45
Zone 7	Floodplain sedimentation		-25	-55	-55
	Extent of indigenous riparian and wetland vegetation		-10	-15	-10
	Fish biomass		-15	-25	-35
	OAA biomass		-10	-10	-15
	Biodiversity		-25	-50	-50
Zone 8	Floodplain sedimentation		-70	-95	-95
	Extent of indigenous riparian and wetland vegetation		-30	-40	-5
	Fish biomass		-15	-30	-10
	OAA biomass		-10	-15	0
	Biodiversity		-35	-50	-35

The predicted changes can be summarised in terms of the overall health of the riverine ecosystems in the LMB.



The basin-wide overview of changing river condition associated with each development level shows that river condition is predicted to decline through the development sequence, from 2007 Baseline when most parts of the river are in a Category B condition, to mostly Category C condition for Scenario 2020, and mostly Category D condition for Scenario 2040 and 2040CC.

The evaluation of the main development scenarios yielded the following important insights:

- The modelled data for the scenarios show that changes in the timing and volume of water flows will be minimal, but this is not borne out by recorded data measuring the influence of development in the UMB on the flows entering the LMB at Chaing Saen.
- Trapping of bed and suspended sediments in tributary and mainstream dams will increase bed and bank erosion in the downstream river, and reduce the deposition of nutrient rich sediment on the floodplains, even in Scenario 2020.
- The reservoirs associated with the mainstream dams in Scenarios 2040 and 2040CC will convert long stretches of the mainstream Mekong River from Chiang Saen to Kratie into deeper, lake-like habitat that is unsuitable for many of the species that inhabit the river but that will benefit others, such as bivalves, frogs and snails.
- The dams and reservoirs will disrupt migration routes essential for the continued occurrence of 30-40% of the species that comprise the Mekong fish community and 30-40% of the total caught fish biomass.

- The planned 2040 developments as modelled in the main development scenarios are expected to:
    - seriously reduce indigenous riparian and wetland vegetation, mostly through inundation associated with the 2040 planned level of development;
    - change the composition of algal and invertebrate communities that form the base of the aquatic food-chain, thereby affecting the viability of a wide range of animals and plants;
    - change the composition and reduce the biomass of fish in the LMB
    - eliminate white fish and promote invasion by non-native species.

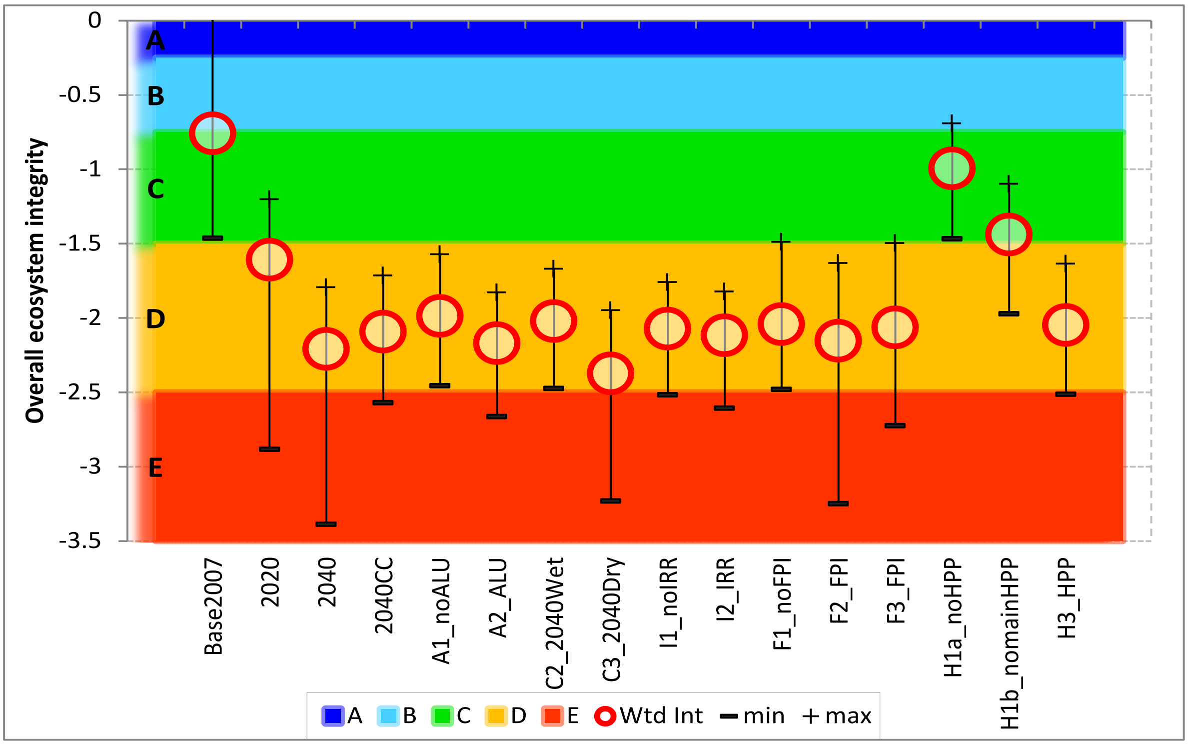
These changes will likely extend across the whole basin, but are expected to be felt first and most in the upper reaches of the LMB, in Zones 1 and 2. To some extent, the Tonle Great Sap Lake is buffered from development along the Mekong River by direct inflows and rainfall, provided reversal of the Tonle Sap River is preserved. The nature and functioning of the lake will be affected, however, by the reduction in sediments supplied by the Mekong River and the blocking of the migration paths of white fish. Similarly, the Viet Nam Delta would be cushioned from future changes by the fact that it is already highly modified and controlled, and the fact that higher flows in the dry season could aid fish recruitment. Nonetheless, it will be affected by, *inter alia*, the change in sediment supply and alterations in the make-up and dynamics controlling fish communities.

For the basin as a whole, and based on the modelled data for the mains development scenarios generated in the Council Study, the factors that will most impact the aquatic ecosystems associated with the Mekong River are:

- barriers to the upstream/downstream migration of biota;
- loss of sediments;
- change from flowing to still water habitats;
- reduction of floodplain flooding associated with floodplain protection infrastructure.

Thematic sub-scenarios: Overview of impacts

The relative impacts of the various thematic sub-scenarios on overall river condition are illustrated below.



The evaluation of the thematic sub-scenarios yielded the following important insights:

- The connectivity-related impacts, such as trapping of sediment, disruption of migration paths and alteration of flow regimes, related to mainstream hydropower dams are expected to be substantial and far-reaching, and to overshadow those of all other planned water-resource developments in the LMB.
- In comparison with those for hydropower development, the incremental impacts on ecosystem condition associated with the other sectors modelled in the Council Study development scenarios are difficult to distinguish, although it is recognised that it was not possible to capture the full extent of some of these.
- Of the other sectors:
  - a wetter climate future will mitigate some of the ecological impacts associated with the Scenario 2040, but only slightly;
  - a drier climate future will exacerbate the ecological impacts associated with the Scenario 2040, but mainly in the Tonle Sap system;
  - the resilience of the LMB aquatic ecosystems, particularly those in Cambodia, to a drier climate would be compromised by the developments in Scenario 2040;
  - the extent of floodplain protection infrastructure is expected to have a noticeable negative impact on ecosystem functioning, particularly in the lower parts of the LMB.

Recommended next steps

The information, tools and skills generated by the Council Study[2] provide much of the requisite structure and knowledge for a re-imagining of the development potential of the LMB that integrates environmental and associated social risk into the Internal Rate of Return (IRR) of planned and existing water-resource development projects. There is compelling evidence that this would ensure better ecological, social AND economic returns on individual water-resource investments. While it is accepted that the degree of river regulation associated with existing and under-construction HPP projects in the UMB and LMB precludes the adoption of large-scale basin-wide greenfield planning approaches, the Council Study resources lend themselves to strategic and systematic evaluation and coordination of design and operation of future developments to maximise possibilities for mitigation and to direct mitigation investment to where it will provide the greatest benefit.

The recommended next steps are:

1. Designate two to three BioRA champions in each member country to be the custodians of the DSS for the parts of the LMB in their country.
2. Align MRC ecosystem monitoring efforts to provide information for the most relevant of the relationships described in the BioRA DSS, e.g., those that describe the links between sediment supply, erosion, habitat availability, vegetation, OAAs and fish.
3. Encourage MSc or PhD studies focusing on testing and refining the response curves that define the relationships in the BioRA DSS.
4. Develop a quality assurance policy and a process for upgrading the response curves and the evidence base that supports them, and updating the BioRA DSS.
5. Increase investment in programmes aimed at enhancing awareness and understanding of the economic, cultural and spiritual values of the river systems of the LMB, and the underlying functioning that supports these.
6. Use the knowledge-base represented by the BioRA DSS to assist in guiding broad-scale planning and management of the aquatic ecosystems of the LMB, including the location of new infrastructure, and the design and evaluation of mitigation options and offsets for existing and future water-resource developments.

[2] In combination with other new and innovative tools.

1 Introduction

1.1 Background

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[3]. The river rises in the high plateau of Eastern Tibet and flows in a south-east direction through/past China, Myanmar, Lao PDR, Thailand, Cambodia and Viet Nam. It drains an area of ~795 000 km^2 and discharges ~457 km^3 of water annually into the sea south-west of Ho Chi Minh City.

The Lower Mekong River (Figure 1.1) is ~3000 km long. It stretches from the China/Lao PDR border to the sea, and includes the Tonle Sap System and the Mekong Delta in southern Viet Nam. These two systems are dominant features of the Lower Mekong Basin (LMB), affecting its functioning and the people that 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 Tonle Sap Great Lake from ~2 600 to ~10 400 km^2. When the flood waters along the Mekong River recede, the flow in the Tonle Sap River reverses again and partially drains the lake. This natural phenomenon provides a unique and important water balance to the Mekong River, helping to ensure a flow of freshwater into the Delta during the Dry season that buffers the intrusion of salt water into the rich agricultural lands of the Delta[4].

Kratie is generally regarded as the point in the Mekong River where the hydrology and hydrodynamics change. Upstream of this point, the river flows within a clearly identifiable mainstream channel in all but the most extreme flood years, with only localised over-bank flooding. Downstream of Kratie, there is pronounced hydrodynamic complexity in both time and space as water moves freely over flat lands and it becomes impossible to measure channel discharge[5].

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 demonstrating and improving understanding of the functioning of the LMB aquatic ecosystems, and the links between 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.

3 Liu, J.P., Xue, Z., Ross, K., Wang, H.J., Yang, Z.S., Li, A.C. and Gao, S. 2009. Fate of sediments delivered to the sea by Asian large rivers: long-distance transport and formation of remote alongshore clinothems. SEPM-The Sedimentary Record 7 (4), 4–9.
4 MRC. 2005. Overview of the Hydrology of the Mekong Basin. Mekong River Commission, Vientiane, November 73pp.
5 MRC. 2005. Overview of the Hydrology of the Mekong Basin. Mekong River Commission, Vientiane, November 73pp.

Figure 1.1 The Lower Mekong River Basin

The MRC uses these data and models to aid decision making about possible water-resource developments in the LMB through the analysis of potential changes to river resources and the knock-on effects on the people that depend on them. Studies that have addressed this include

- Integrated Basin Flow Management (IBFM; 2004-2006[6])
- Basin Development Plan (BDP; 2006-2015[7])
- Strategic Environmental Assessment (SEA; 2010)[8].

1.2 The Council Study

Of the abovementioned studies, only IBFM involved detailed, systematic assessment of the impacts of developments on the river ecosystem. This was a preliminary study, however, in need of expansion, updating and a more systematic and systemic approach. At the 18th Council Meeting of the MRC[9], Prime Ministers of the National Mekong Commission agreed to implement a new study that would further support sustainable management and development of the Mekong River. This study would be called 'The Council Study'.

1.2.1 Aims

The Council Study aimed to improve understanding of the impact of different water-related development opportunities within the whole Mekong River Basin, and to provide recommendations that would facilitate development planning for the LMB.

The stated objectives of the Council Study were to:

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

1.2.2 Geographic focus

The Council Study focused on how water-resource developments across the whole Mekong River Basin would impact the mainstream Mekong River and its associated ecosystems from the Lao PDR/Chinese border to the sea in Viet Nam.

---

6 MRCS/IBFM. 2006. Flow regime assessment. Integrated Basin Flow Management Report No. 8. Vientiane, Lao PDR.
7 Mekong River Commission. 2011. Assessment of Basin-wide Development Scenarios and the BDS 2011-2015. Vientiane, Lao PDR.
8 International Centre for Environmental Management. 2010. MRC Strategic Environmental Assessment (SEA) of hydropower on the Mekong mainstream: Summary of the Final Report. Hanoi, Viet Nam.
9 Held in Bali, Indonesia, November 2011.

Thus, the developments evaluated include those on the Upper Mekong River (Lancang) and those in the tributaries and on the mainstream of the LMB. The analysis of *impacts* of these developments on the aquatic ecosystems and people, however, was limited to:

1. a 15-km corridor on both sides of the mainstream from the Chinese border to Kratie (Cambodia);
2. the Cambodia Floodplains including the Tonle Sap River, Great Lake and the river down to the Delta, and;
3. the Mekong Delta in Viet Nam.

1.2.3 Assessment framework

The overall unified assessment framework of the Council Study is illustrated in Figure 1.2. The Council Study involved:

- Six Thematic Teams each representing a development thematic area or sector, *viz*.:
    - Agricultural Landuse, Domestic and Industrial Water Use, Flood Protection Infrastructure, Hydropower, Irrigation and Navigation.
- Five cross-cutting Discipline Teams, *viz*.:
    - Climate change, Modelling, Bio-resources (BioRA), Social and Economic.

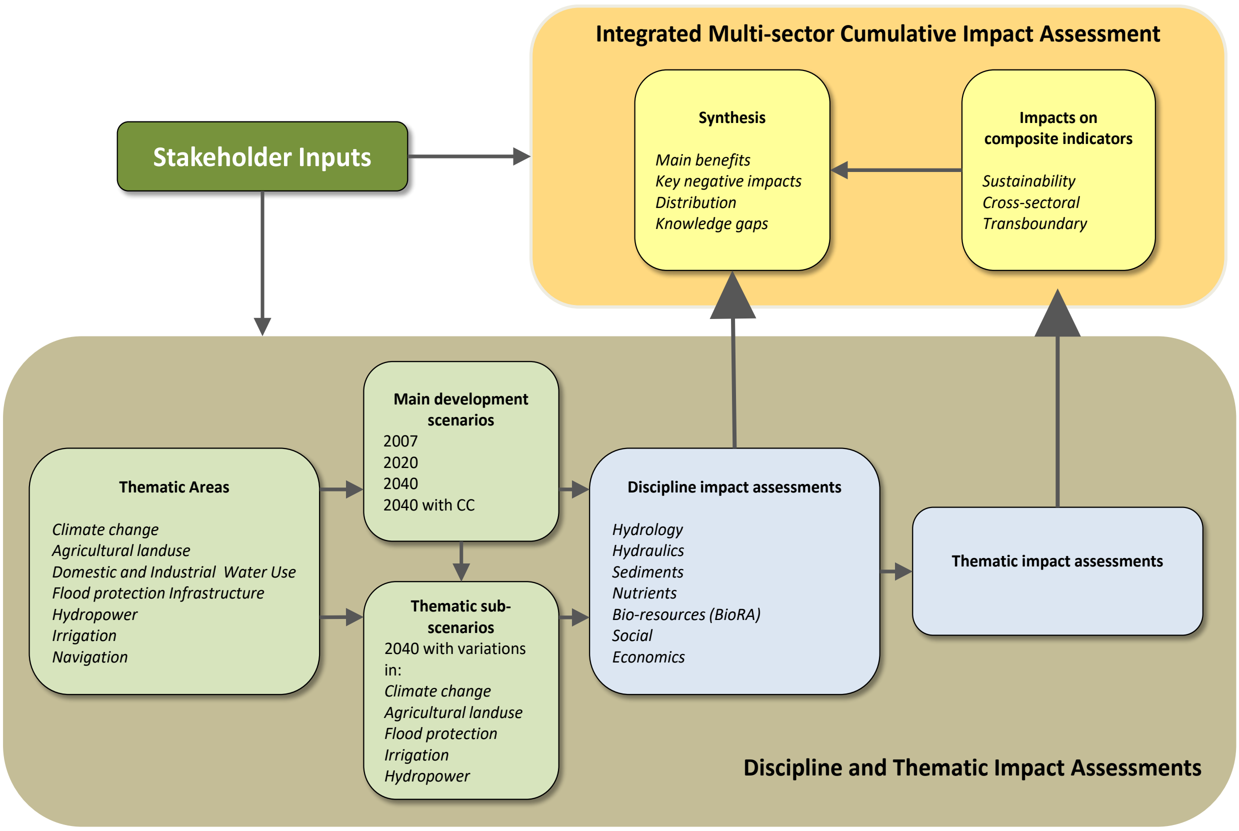


Figure 1.2 Council Study Assessment Framework

The framework required structured liaison between the Thematic and Discipline Teams in order to coordinate technical inputs and integrate outputs and deliverables. To facilitate this, the major activities in the Council Study were arranged in a general sequence, as follows:

- The Thematic Teams formulated a suite of scenarios that integrated existing/planned developments for all of the Thematic Areas. These comprised two types of scenarios: (see Section 3):
    - *Main development scenarios*, which encompass developments incorporated into the water-resource planning of Member Countries for the past (2007), and the near (*c*. 2020) and more distant (c. 2040) future. They also differ in terms of their climate (2040 and 2040CC) and the extent of floodplain settlement.
    - *Thematic sub-scenarios*, which incorporate sector-specific variations to the 2040 main development scenario for the purpose of assessing the positive and negative impacts associated with that sector.
- The Climate Change Team provided input on this aspect.
- The Modelling Team, through the use of the MRC Decision Support Framework (DSF), the Water Utilisation Program (WUP-FIN) and the eWater Source models, predicted the changes in flow, hydraulics, sediment transport, nutrients and salinity intrusion as a result of the developments in the scenarios, and produced daily time series of flow, hydraulics, sediment, nutrients and salinity for required locations along the river system (Figure 1.3).
- The Biological Resources (BioRA) Team, using the DRIFT EFlows process, used the outputs from the Modelling Team to predict the resulting changes in habitat, biodiversity and other indicators of the river ecosystem, producing seasonal time-series of change in geomorphology, vegetation, macroinvertebrates, fish, herpetofauna, birds and mammals (Figure 1.3).
- The Social Team used the outputs from the Thematic Teams, the Modelling Team and the BioRA Team to predict the resulting changes in selected socio-economic indicators such as livelihoods, public health and nutrition (Figure 1.3).
- The Economics Team used the outputs from the Thematic Teams, the Modelling, the BioRA and the Social Teams to predict resulting macro-economic impacts such as distributional analysis of benefits and costs for different communities, livelihood groups, countries and socio-economic strata (Figure 1.3).

The results were written up as a series of Thematic and Discipline Reports; and the bio-resources, social and economic impacts sections of the Thematic Reports were written by the relevant Discipline Teams.

This report summarises the scenario predictions of BioRA.

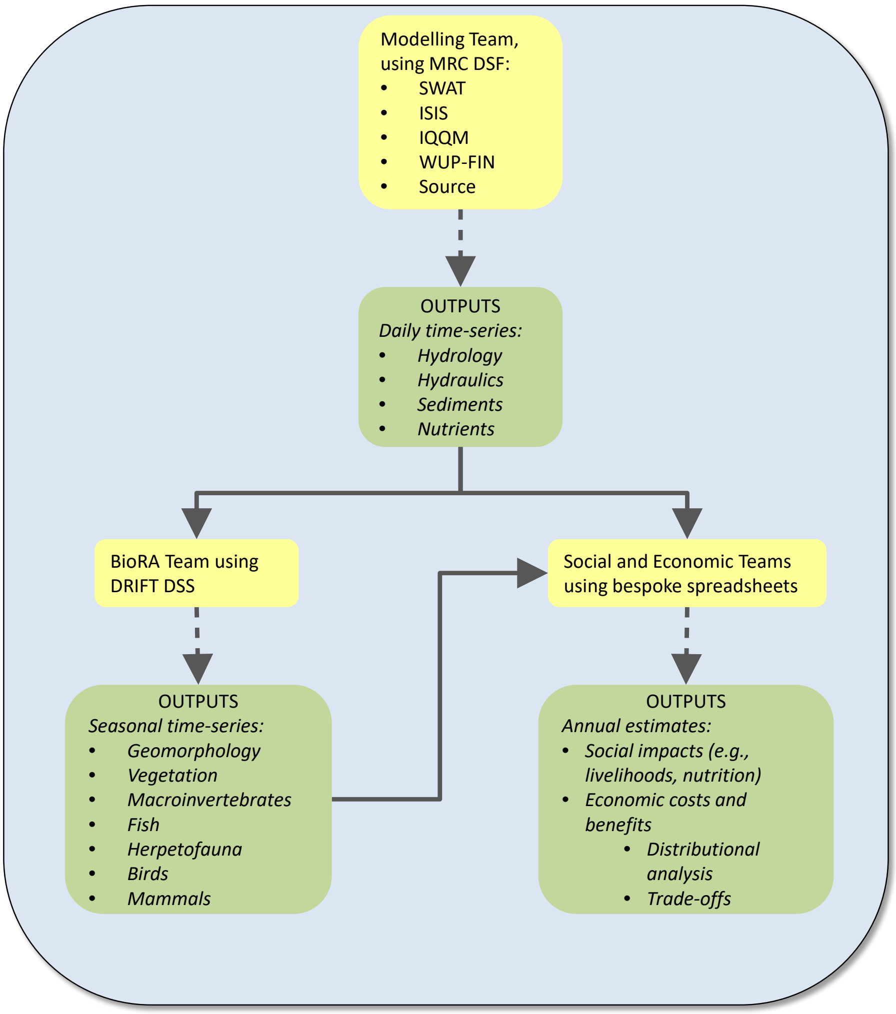


Figure 1.3 The flow of information for the discipline impact assessment

1.3 The Bio-resources Assessment (BioRA)

1.3.1 Objective

The main objective of BioRA was to provide clear and comparable information on the impacts of existing and proposed water-resource developments included in the scenarios on the aquatic resources of the study area.

1.3.2 Phasing

BioRA had two distinct phases:

Phase 1: January 2015 – March 2016

Phase 2: August 2016 – November 2017.

1.3.3 Process

The DRIFT EFlows process and Decision Support System (DSS[10]; Appendix A), referred to in the Council Study as the BioRA-DSS, were used to organise three main kinds of ecological information on the LMB: existing MRC data; relevant data in the international scientific literature, and; expert opinion from the highly-qualified and experienced team of river scientists employed in the Council Study (Table 1.1). This knowledge base was then used to:

- select the ecosystem indicators that would represent the mainstream river within the LMB;
- assess the ecological condition and trends of the ecosystem indicators in each of the scenarios, by predicting their change in abundance/area/concentration (relative to a 2007 Baseline);
- predict the overall ecological condition of the river ecosystem under each scenario.

1.3.4 Team members

The members of the BioRA team are listed in Table 1.1.

Table 1.1 BioRA Team

Role		Name	Country	Phase
BioRA Lead		Dr So Nam	Cambodia	1 and 2
Council Study Coordinator		Dr Henry Manguerra	Phillipines/USA	1
		Mr Suthy Heng	Cambodia	2
BioRA Technical Lead		Prof. Cate Brown	South Africa	1 and 2
DRIFT DSS Manager		Dr Alison Joubert	South Africa	1 and 2
Council Study Administrative Assistant		Ms Manothone Vorabouth	Lao PDR	1
		Ms Sokunthea Pheng	Cambodia	2
		Ms Vannida Chanpradith	Lao PDR	2
MRC-FP International Technical Adviser		Mr Peter Degen	Germany	1
Geomorphology and Water Quality	Lead Specialist	Dr Lois Koehnken	Australia/USA	1 and 2
	Regional Specialist	Mr Toch Sophon	Cambodia	1 and 2
	Regional Specialist	Dr Bounheng Soutichak	Lao PDR	1 and 2
	Regional Specialist	Dr Idsariya Wudtisin	Thailand	1 and 2
Vegetation	Lead Specialist	Dr Andrew MacDonald	USA	1
	Lead Specialist	Mr James MacKenzie	South Africa	2
	Delta Macrophytes	Dr Nguyen Thi Ngoc Anh	Viet Nam	1 and 2
	Delta Microalgae	Ms Duong Thi Hoang Oanh	Viet Nam	1 and 2
	Regional Specialist	Mr Thananh Khotpathoom	Lao PDR	1 and 2
	Tonle Sap Processes	Dr Dirk Lamberts	Belgium	1 and 2
Macroinvertebrate	Lead Specialist	Dr Ian Campbell	Australia	1 and 2
Herpetology	Lead Specialist	Dr Hoang Minh Duc	Viet Nam	1 and 2

[10] Brown, C.A., Joubert, A.R., Beuster, J., Greyling, A. and King, J.M. 2013. DRIFT: DSS software development for Integrated Flow Assessments. Final Report to the South African Water Research Commission. February 2013. Pretoria, South Africa.

Role		Name	Country	Phase
Bird and Mammals	Lead Specialist	Mr Anthony Stones	England	1 and 2
Biodiversity, excluding fish	Regional Specialist	Mr Pich Sereywath	Cambodia	1 and 2
	Regional Specialist	Dr Phaivanh Phiapalath	Lao PDR	1 and 2
	Regional Specialist	Dr Luu Hong Truong	Viet Nam	1 and 2
Fish	Lead Specialist	Prof. Ian Cowx	England	1 and 2
	Delta Specialist	Dr Kenzo Utsugi	Japan	1 and 2
	MRC Fish Specialist/ Regional specialist	Dr Chavalit Vidthayanon	Thailand	1 and 2
	MRC Fish Specialist	Mr Ngor Peng Bun	Cambodia	1
	Regional Specialist	Dr Chea Tharith	Cambodia	1 and 2
	Regional Specialist	Dr Kaviphone Phouthavong	Lao PDR	1 and 2
	Regional Specialist	Dr Chaiwut Grudpun	Thailand	1
	Regional Specialist	Mr Vu Vi An	Viet Nam	1 and 2

1.4 BioRA report volumes and the layout of this document

There are several volumes in the BioRA Technical Report Series:

- Volume 1: Specialists' Report[11]
    - *Status and trends assessment, the selection of focus areas, background to the ecosystem indicators, the response curves used in the predictions of change*
- Volume 2: Guide to BioRA Process and DSS
    - *Process, procedures and user manual for the BIORA DSS*
- Volume 3: Testing Report
    - *Validation of the DSS*
- Volume 4: Assessment of Planned Development Scenarios
    - *Predicted ecological outcomes for the main development scenarios and a series of thematic sub-scenarios.*

This report is BioRA Technical Report Series. Volume 4: Assessment of Planned Development Scenarios.

The report is laid out as follows:

- Section 1 (this section) describes BioRA in the *context of the Council Study* as a whole.
- Section 2 presents the BioRA *assessment sites and the indicators* used to describe change.
- Section 3 is an overview of the various *water-resource scenarios* that were assessed.
- Section 4 presents the predictions of change for the full suite of individual BioRA indicators in the parts of the river in each BioRA zone that remain *unimpounded* under the main development scenarios;

[11] This comprises chapters for each of geomorphology, vegetation, macroinvertebrates, fish, herpetofauna, birds and mammals.

- Section 5 presents the predictions of change for the individual BioRA indicators for the parts of the river in each BioRA zone that will become *inundated* under the main development scenarios;
- Section 6 combines and summarises the predictions in Sections 4 and 5 to provide an *overview of impacts to the aquatic ecosystems* in each BioRA Zone as a whole for the main development scenarios;
- Section 7 provides the same information as Section 6, but for the *thematic sub-scenarios*.
- Section 8 presents the main *conclusions* of the BioRA scenario assessments and highlights some of the key *knowledge gaps* in this assessment, and the options available for addressing these.

1.5 Major assumptions and limitations

Predicting the effect of flow, sediment and connectivity changes on rivers is difficult because the actual trajectory and magnitude of the change is dependent on so many other variables, such as climate, sediment supply and human use of the system. Thus, several assumptions and limitations applied to BioRA.

A major assumption was that the modelled Reference Period (1985-2008) time-series of flow, sediment and water quality closely approximated the actual conditions in the river over the period of record, and for the development levels selected (2007). Should this not be the case, then the baseline for the scenarios would be different to that used and so the scenario predictions could change.

The main limitation was the paucity of data. This is a universal problem, as ecosystems are complex and we will probably never have complete certainty of their present and possible future characteristics. Instead it is essential to push ahead cautiously and aid decision-making, using best available information. The alternative is that water-resource development decisions are made without consideration of the consequences for the supporting ecosystems, eventually making management of sustainability impossible. Data paucity was addressed in the BioRA process by accessing every kind of knowledge available - general scientific understanding, international scientific literature, local wisdom, traditional knowledge and specific data from the river under consideration or from similar ones – and capturing these in a structured process that is transparent, with the BioRA DSS inputs and outputs checked, workshopped and approved at every step. The response curves (and the reasoning used to construct them) are available for scrutiny within the DSS and they, as well as the BioRA DSS, can be updated as new information becomes available.

Other limitations were:

- The predictions were based on a 23-year horizon (1985-2008). This is insufficient time to capture the full extent of some changes, particularly those related to sediment budgets.
- It was neither known what the river was like in its pristine condition nor exactly how abundant each ecosystem aspect (sand bars, fish, etc.) was then or at the time of the study.

To address this, all predictions were made relative to a 2007 Baseline (i.e. all indicators were predicted to increase or decrease by a small, medium or large amount relative to their status in 2007).

These inherent uncertainties mean that attention should be mostly directed toward trends in the sequence of scenarios and the position of scenarios relative to each other, rather than to absolute values.

2 Zones and indicators

2.1 BioRA zones and Focus Areas

For BioRA, the LMR was divided into eight BioRA zones (Figure 2.1 and Table 2.1), each represented by a Focus Area (FA; Table 2.1).

Figure 2.1 **BioRA zones**

Table 2.1 BioRA zones and Focus Areas

BioRA zones		Representative Focus Areas		
No.	Location	No.	Location	FA coordinates (longitude; latitude)
Zone 1	Mekong River from the border with China to Pak Beng (confluence with Nam Beng)	FA1	Mekong River upstream of Pak Beng	19.8589; 101.0797
Zone 2	Mekong River from downstream of the Nam Beng to upstream of Vientiane	FA2	Mekong River upstream of Vientiane	18.2079; 102.1260
Zone 3	Mekong River from Vientiane to Nam Kam town (near confluences with Xe Bang Fei and Nam Kam)	FA3	Mekong River upstream of Xe Bang Fai	17.2066; 104.8061
Zone 4	Mekong River from Nam Kam to Stung Treng (Se San / Se Kong confluences)	FA4	Mekong River upstream of Stung Treng	13.5559; 105.9511
Zone 5	Mekong River from Stung Treng to Kampong Cham	FA5	Mekong River upstream of Kampong Cham	12.2980; 105.5926
Zone 6	Tonle Sap River at Prek Kdam, plus the Cambodian Floodplains excluding Zone 5 and 7	FA6	Whole area	11.87.87; 104.7827
Zone 7	Tonle Sap Great Lake	FA7	Whole area	12.8673; 104.0837[12]
Zone 8	The Vietnamese Delta from the Cambodian/Viet Nam border to the sea	FA8a	FA8a: A heavily flooded area at the head of the Delta	10.6000; 105.4000[13]
		FA8b	FA8b: A lightly flooded area between FA8a and FA8c	
		FA8c	FA8c: The coastal area	

The BioRA zones were selected using a systematic approach that considered:

- the need to limit the number of zones to a manageable number[14] and to identify transboundary effects;
- existing geomorphological and social delineations of the LMB;
- key biological features, such as fish migration routes;
- differences in aquatic habitats across the river system;
- availability and spatial resolution of hydrological, water quality and sediment data;
- the need to link predicted ecosystem changes to potential impacts on people.

The general approach was to identify a network of nodes along the system, each of which represented a change in terms of one or more of the criteria above, and to group these nodes using similarity analysis. Each group of nodes identified in this way became a BioRA zone[15].

The location of the FA in each zone was based on where suitable hydrological, hydraulic, sediment and water quality modeled data were available for the assessment. FA1, FA2 and FA4 were located at a river cross-section that was deemed representative of the zone, guided by the outcome of a

[12] Marks centre point in Tonle Sap Great Lake
[13] Marks centre point in FA8a
[14] The Council Study Inception Report made provision for six BioRA zones and six FAs
[15] BioRA Technical Report Series. Volume 1: Specialists' Report

multivariate analysis[16]. FA3 and FA5 were located adjacent to existing floodplain areas for which hydrodynamic (WUP-Fin) models had been set up. The spatial divisions for FA6, FA7 and FA8 (a, b and c) were based on coverages of existing hydrodynamic (ISIS and WUP-Fin) models for the floodplains.

2.2 BioRA indicators

Some of the BioRA indicators selected represented physical and chemical aspects of the river ecosystem and their predicted changes emerged from the modelling exercises. Others were ecosystem indicators whose predicted changes were provided through response curves created by the BioRA team.

2.2.1 Modelled physical and chemical indicators

The Modelling Team provided to BioRA daily simulated time series of discharge; hydraulic parameters, such as depth, velocity, shear stress and inundated area; sediment concentration/load; and nutrient concentration. *Sub-daily data were not provided and so within-day changes, such as those associated with peaking-power generation, have not been possible to address*.

The supplied time series were summarised to annual values or to values for one or more of the four hydrobiological flow seasons recognised by the ecologists (Figure 2.2):

1. **Dry Season**. Flows are much less than the annual average and there is relatively little *natural* flow variability from day to day.
2. **Transition Season 1**. A time of transition between the end of the Dry Season and the start of the Flood Season. Flows increase but not necessarily rapidly. A number of spates or 'freshets' might typically signify a number of false starts to the Flood Season, with flows receding again after each one.
3. **Flood/Wet Season**. This is initially characterised by a number of periods of accelerated rates of increasing flow until the annual peak discharge is reached. There may be a number of pulses in this process but overall there is a clear single flood-pulse hydrograph.
4. **Transition Season 2**. A second transition season between the end of the Flood Season and the start of the Dry Season, during which time the rate of flow recession remains higher than in the Dry Season. In some years there may be late but relatively minor spate events.

The discharges used to define the seasonal thresholds in BioRA, such as the Dry/T1 threshold and the T1/Flood threshold, were similar to those defined by Adamson for IBFM[17]. For example, the T1/Flood threshold is the value of the mean annual discharge, and thus the first up-crossing above this defines the start of the Wet/Flood Season (Figure 2.2).

---

[16] Clarke, K. R. and Gorley, R. N. 2006. PRIMER V6: User Manual/Tutorial. Plymouth.

[17] As per Adamson, P.T. 2006. Hydrological and water resources modelling in the Mekong Region: A brief overview. In: Mekong Region Waters Dialogue. Co-convened by IUCN, TEI, IWMI, M-POWER. Vientiane, Lao PDR, 6 to 7 July 2006.

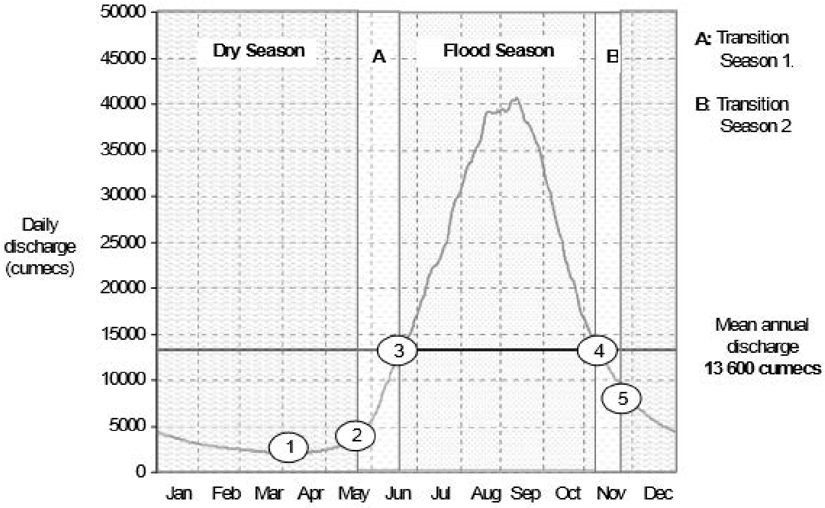


Figure 2.2 The definition of the onset of the four flow seasons based on the mean annual hydrograph (1924 to 2006) for the Mekong River at Kratie, Cambodia. The annual minimum daily discharge usually occurs in early April (1). The doubling of this discharge, usually in late May, defines the start of Transition Season 1 (2). This ends when the Flood Season starts (3). Transition Season 2 is between the end of the Flood Season (4) and the start of the Dry Season (5). The Dry Season starts when the rate of daily flow decrease becomes typical of 'baseflow' recession. According to this definition, the average Dry Season onset is late November [18].

The BioRA modelled indicators and the seasons for which they were calculated are provided in Table 2.2.

Table 2.2 BioRA modelled indicators

Discipline		Indicator	Units
Hydrology	All	Mean annual runoff	m^3/s
	Dry Season	Onset	calendar week
		Duration	days
		Minimum 5-day discharge	m^3/s
		Average daily volume	$m^3 \times 10^6$
		Within-day range in discharge	m^3/s
	Transition Season 1	Average daily volume	m^3/d
		Within-day range in discharge	m^3/s
	Flood/Wet Season	Onset	calendar week
		Duration	days
		Maximum 5-day discharge	m^3/s
		Average daily volume	$m^3 \times 10^6$
		Flood volume	$m^3 \times 10^6$
		Within-day range in discharge	m^3/s

[18] Adamson, P.T. 2006. Hydrological and water resources modelling in the Mekong Region: A brief overview. In: Mekong Region Waters Dialogue. Co-convened by IUCN, TEI, IWMI, M-POWER. Vientiane, Lao PDR, 6 to 7 July 2006.

Discipline		Indicator		Units
	Transition Season 2	Average daily volume		$m^3 \times 10^6$
		Within-day range in discharge		m^3/s
Channel hydraulics (Annual, Flood, T1, T2 and Dry)		Average velocity		m/s
		Maximum depth		m
		Minimum depth		m
		Average depth		m
		Shear stress		Pa
		Wetted Perimeter		m
Floodplain hydraulics (Annual, Flood, T1, T2 and Dry)		Onset of inundation		calendar week
		Duration of inundation		days
		Inundated area		km^2
		Average velocity		m/s
		Maximum velocity		m/s
		Average depth		m
		Maximum depth		m
		Minimum depth		m
Vegetation depth/duration classes[19]		Zone 7	Zone 6 and 8	
	Area of floodplain that corresponds with selected water depth/duration classes depth/duration classes			
	Annual	Not specified	Depth = 0.3-0.55 m for <110 days	km^2
			Average max depth > 2.75 m	
			Depth of 0.3-0.55 m for >110 days	
			Depth of 0.3-0.55 m for >110 days	
			Inundated for >200 days	
	Flood Season	Depth <3.5 m	Depth 0.05-0.3 m	km^2
		Depth >3.5 m, excl. open water		
	Dry Season	Depth >3.5 m	Depth >0.55m in Dry Season	km^2
Sediments and nutrients (Annual, Flood, T1, T2 and Dry)		Sediment concentration/load		mg/l tonnes/day
		Sediment pulse duration		days
		Sediment pulse onset		calendar week
		Floodplain sedimentation		t/day
		Total SiltClay		t/day
		Average Silt/Clay		g/m2/d
		Average Secchi depth		m
		Total nitrogen		mg/l (T/d Delta)
		Total phosphorus		mg/l (T/d Delta)
		Average productivity		tC/day
Salinity (Annual)		Average salinity		g/l
		Maximum salinity		g/l
		>1 g/l all year		km^2
		>4 g/l all year		
		>4 g/l for 1-4 months		
		>4 g/l for 4-6 months		
		>4 g/l for >6 months		
		>20 g/l for >1 month		

[19] The depth/duration classes were established using published vegetation maps of the different FAs (e.g., MRC 2003 landuse map) and then using the WUP-Fin model to define the flooding characteristics of the broad vegetation types (see Specialists' Report – Volume 1).

2.2.2 Ecosystem indicators

Ecosystem indicators are a set of habitat and biotic indicators that reflect important aspects of the riverine ecosystem. They are deemed to be sensitive to a change in the flow, sediment or water quality regimes (described by the indicators in Table 2.2) by changing in one of the following ways:

- abundance/size, e.g., fish.
- extent (area), e.g., cover of riparian tree community on upper dry bank.
- concentration, e.g., sediments and nutrients.

In BioRA, up to ten ecosystem indicators were selected to represent each one of the disciplines (Table 2.3), with due consideration of their relevance for other disciplines. For instance, the geomorphological indicator 'Availability of exposed sandy habitat in the Dry season' was selected because it represents a prominent channel attribute as well as an important habitat for herpetofauna and birds.

The indicators may change with water-resource developments, and in doing so, drive other indicators to change. For instance, responders to one driver (e.g., sandy beds disappearing as sediment loads decrease) can become drivers themselves (e.g., change in sandy bed habitat affects some fish species), thus driving further change (e.g., loss of fish affects fish-eating birds). The simplified linkages between disciplines shown in Figure 2.3 thus mask the full suite of driver-response links used in the BioRA analyses (Figure 2.4). Each line in Figure 2.4 represents a response curve drawn by the BioRA specialist team and housed in the DRIFT software[20].

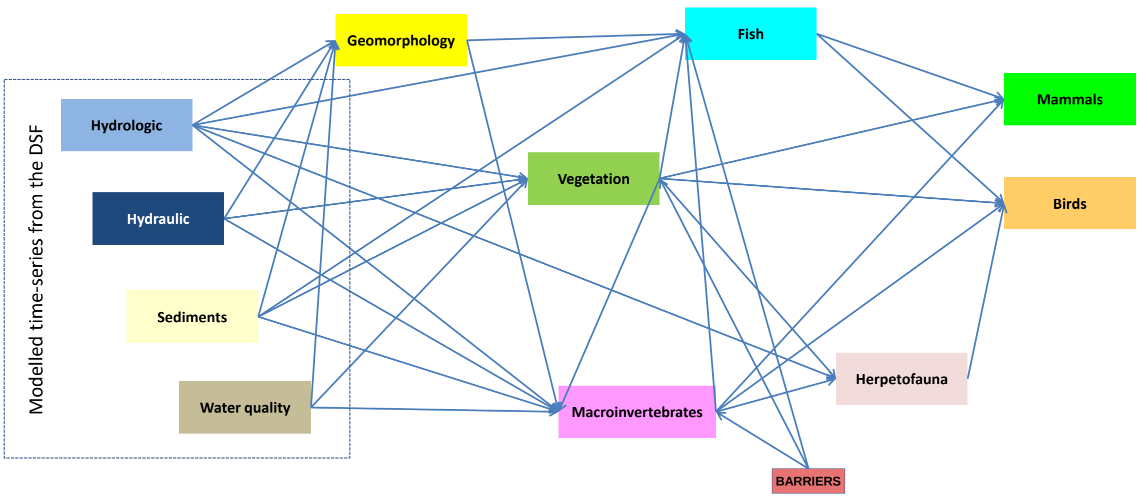


Figure 2.3 Discipline-level assessment framework for BioRA

The resultant BioRA database thus formed a knowledge base contributed to by the entire BioRA team. It was interrogated in this project to predict the changes to the river ecosystem under each scenario and remains a resource for future use by the MCs.

[20] BioRA Technical Report Series: Volume 1: Specialists' Report

Table 2.3 BioRA ecosystem indicators showing applicable BioRA zones for each. NA = not applicable. Grey shading denotes presence in a zone.

Indicator Groups		Taxa	BioRA zones							
			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	NA								
	Extent of lower bank vegetation	NA								
	Extent of herbaceous marsh	NA								
	Weeds and grasses on sandbanks and sandbars	NA								
	Biomass freshwater algae (periphyton, plankton, benthic)	NA								
Floodplain	Extent of flooded forest	NA								
	Extent of herbaceous marsh	NA								
	Extent of grassland	NA								
	Biomass freshwater algae (periphyton, plankton, benthic)	NA								
	Extent of invasive riparian vegetation	*Mimosa pigra*								
	Extent of floating and submerged vegetation	Hyacinth								
Delta	Extent of flooded forest	NA								
	Extent of herbaceous marsh	NA								
	Extent of grassland	NA								
	Biomass freshwater algae (periphyton, plankton, benthic)	NA								
	Extent of invasive riparian vegetation	*Mimosa pigra*								
	Extent invasive floating/submerged vegetation	Water Hyacinth, *Eichhornia crassipes*								
	Biomass marine algae	NA								
All	Indigenous vegetation biomass	NA								
	Overall vegetation biomass	NA								

Indicator Groups	Taxa	BioRA zones							
		1	2	3	4	5	6	7	8
Macroinvertebrates									
Insects on stones	Heptageniid mayflies	■	■	■	■				
Insects on sand	Baetid mayflies	■	■	■	■	■	■		■
Burrowing mayflies	Palingeniid mayflies	■	■	■	■	■	■		
Snails	NA	■	■	■	■	■	■	■	■
Aquatic snail diversity	NA	■	■	■	■	■	■	■	■
Neotricula aperta	*Neotricula aperta*			■	■	■			
Bivalves	NA	■	■	■	■	■	■	■	■
Polychaete worms	NA								■
Shrimps and crabs	NA	■	■	■	■	■	■	■	■
Macrobrachium prawns	NA				■	■	■	■	
Littoral invertebrate diversity	NA	■	■	■	■	■	■	■	■
Benthic invertebrate diversity	NA	■	■	■	■	■	■	■	■
Zooplankton abundance	NA	■	■	■	■	■	■	■	■
Zooplankton diversity	NA							■	
Benthic invertebrate biomass	NA	■	■	■	■	■	■	■	■
Composite: Benthic invertebrate abundance	NA							■	
Composite: Emergence	NA	■	■	■	■	■	■	■	■
Fish									
Rhithron 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	■	■	■	■	■	■	■	■

Indicator Groups	Taxa	BioRA zones							
		1	2	3	4	5	6	7	8
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*			■	■	■	■	■	■
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				■				

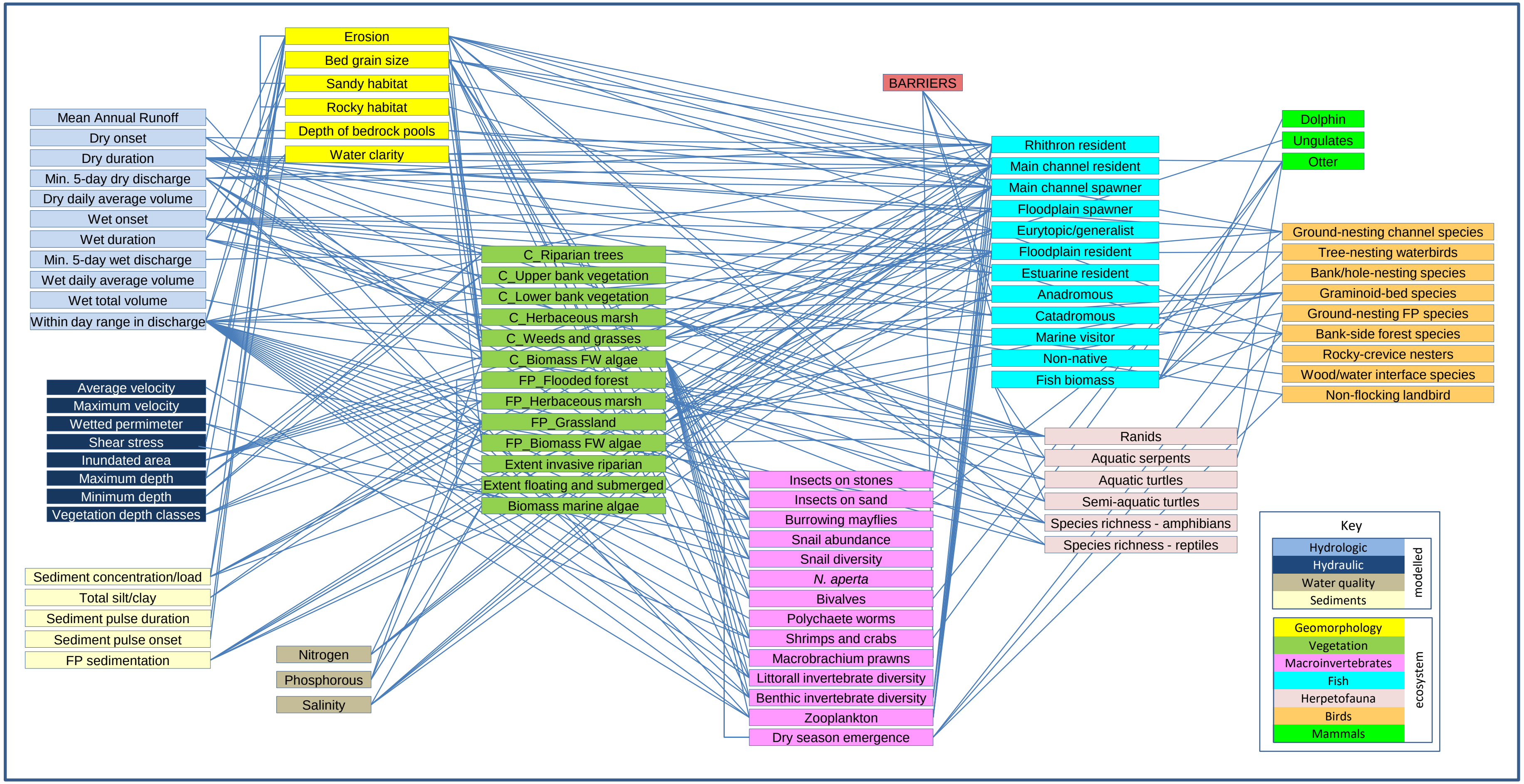


Figure 2.4 Links in the BioRA DSS. . Each line represents a response curve drawn by the BioRA team.

3 The water-resource scenarios

The water-resource scenarios adopted in the Council Study and investigated in BioRA fall into two main groups:

- *Main development scenarios*, which incorporated the existing and/or planned infrastructure and other water-resource developments for the reference years 2007, 2020 and 2040, plus a 2040 scenario that included expected climate change (2040CC);
- *Thematic sub-scenarios*, which incorporated sector-specific variations to the 2040CC main development scenario for the purpose of assessing the positive and negative impacts associated with that sector.

3.1 Main development scenarios

The main development scenarios for the past (2007 - Baseline), and the near (*c*. 2020) and more distant (c. 2040) future include:

- physical changes associated with:
  - land use;
  - water-resource infrastructure (i.e., hydropower dams);
  - flood-protection works;
- management regimes, such as operating rules for dams with respect to flows and sediments, flood zoning and protection standards;
- exogenous developments such as urbanisation and demographics.

They also differ from one another in terms of their climate (2040 and 2040CC) and the extent of development on the floodplains included in each (Table 3.1). The climate in scenarios 2040 and 2040CC differs as follows: in the 2040 scenario, rainfall run-off modelling (SWAT) used the climatic condition that prevailed between 1985 and 2008; in the 2040CC scenario it used warmer and wetter conditions than those between 1985 and 2008. Detailed descriptions of the main development scenarios are provided in the Modelling Report.

Time horizons for river change

The assessments done in this Council Study aimed to predict, to the extent possible with available knowledge, the likely condition of the river ecosystem with developments expected for 2020 and 2040 in place. All rivers are continuously changing, but much of this change is around a dynamic equilibrium so that although they may appear to differ from season to season or year to year, they remain much the same over many years. Water-resource developments can disturb this dynamic equilibrium, driving a new trajectory of change that can become apparent in days (e.g., new effluents changing water quality) to years (e.g., fish populations declining as migration routes disappear) to decades (e.g., capture of sediments in reservoirs changing downstream channels and habitats). The descriptions for the scenarios 2020 and 2040 should therefore be seen as points at which many short-term changes may have happened and some of the medium and longer-term changes could still be ongoing.

Table 3.1 Parameters for the main development scenarios

Scenario			Level of Development for water-related sectors[21]						Climate	Floodplain settlement
			ALU	DIW	FPI	HPP	IRR	NAV		
M1	2007	Baseline Scenario 2007	2007	2007	2007	2007	2007	2007	1985-2008	2007
M2	2020	Definite Future Scenario 2020	2020	2020	2020	2020	2020	2020	1985-2008	2020
M3	2040	Planned Development Scenario 2040	2040	2040	2040	2040	2040	2040	1985-2008	2040
M4	2040CC	Planned Development Scenario 2040	2040	2040	2040	2040	2040	2040	Mean warmer & wetter	2040

The scenarios encompass a series of potential mainstream and tributary dams and their impoundments for hydropower generation. In the 2007 Baseline, most of the existing dams are located outside the study area, in China with ~14 tributary dams in the LMB (Table 3.2), but for Scenario 2020 there are ~63 possible tributary barriers (Table 3.2), and two possible barriers on the mainstream Mekong River in the LMB (Xayabury and Don Sahong HPPs; Figure 3.1; Table 3.3). For Scenario 2040, another ~57 tributary dams are added (Table 3.2) as well as nine more mainstream dams in the LMB (Figure 3.1; Table 3.3). The developments associated with Scenario 2040 would alter water levels along the Lower Mekong so that for most upper river reaches these no longer reflect bed topography but rather a step-drop sequence of dam reservoir levels (Figure 3.2).

Table 3.2 The number of tributary HPPs included in 2007 Baseline, Scenarios 2020 and 2040 from the Hydropower Thematic Report

No	Country	Number of HPPs in tributaries	
2007, 2020 and 2040	Lao PDR	5	14
	Thailand	4	
	Cambodia	0	
	Vietnam	5	
2020 and 2040	Lao PDR	39	49
	Thailand	0	
	Cambodia	0	
	Vietnam	10	
2040	Lao PDR	54	57
	Thailand	0	
	Cambodia	0	
	Vietnam	1	
Total			120

21 ALU = Agric/Landuse Change; DIW = Domestic and Industrial Water Use; FPI = flood protection infrastructure; HPP = hydropower; IRR = irrigation; and NAV = Navigation.

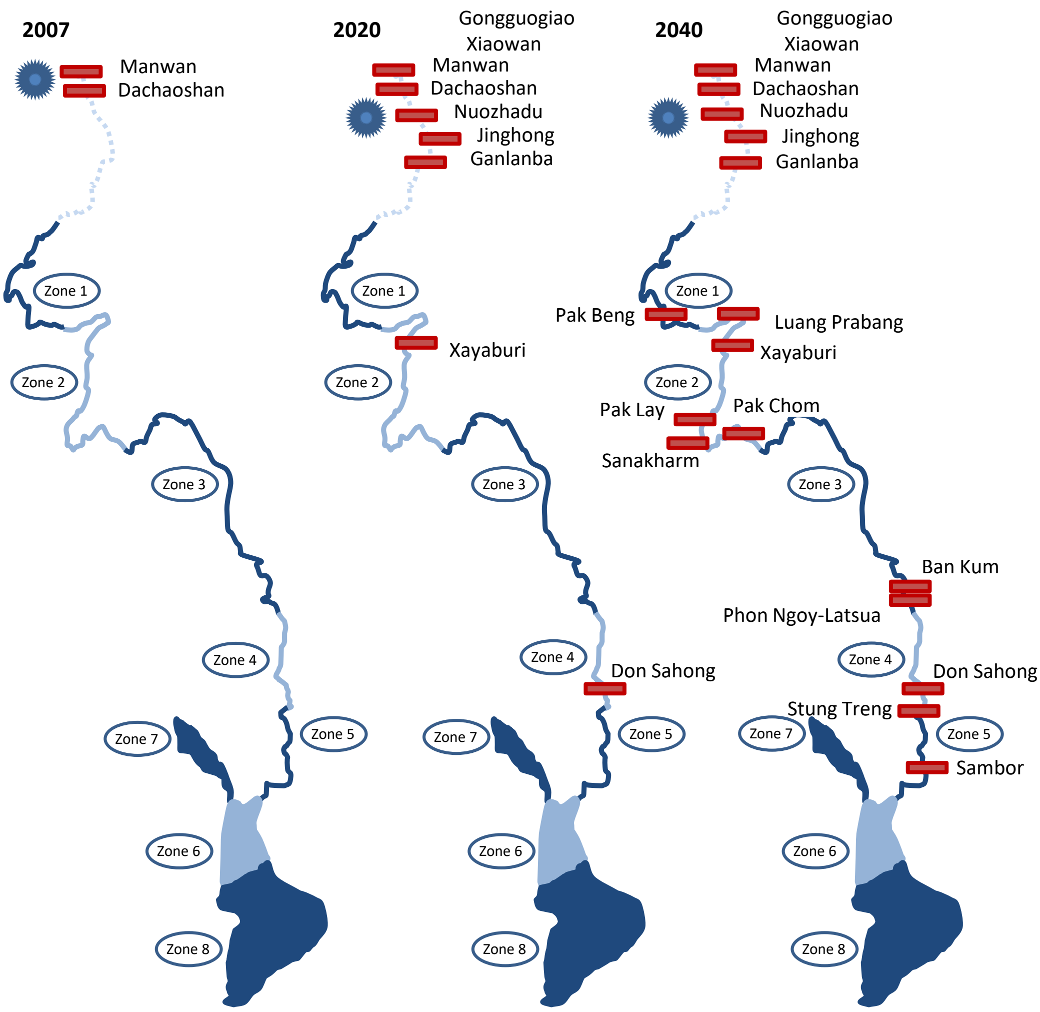


Figure 3.1 Schematic of mainstream (maroon rectangles) infrastructure included in the 2007 Baseline and Scenarios 2020 and 2040

Table 3.3 Mainstream HPPs included in each main development scenario

HPP	2007 Baseline	2020	2040
Langcang Cascade (in Figure 3.1)	Yes	Yes	Yes
Pak Beng			Yes
Luang Prabang			Yes
Xayabury		Yes	Yes
Pak Lay			Yes
Sanakharm			Yes
Pak Chom			Yes
Ban Kum			Yes
Phon Ngoy-Latsua			Yes
Don Sahong		Yes	Yes
Stung Treng			Yes
Sambor			Yes

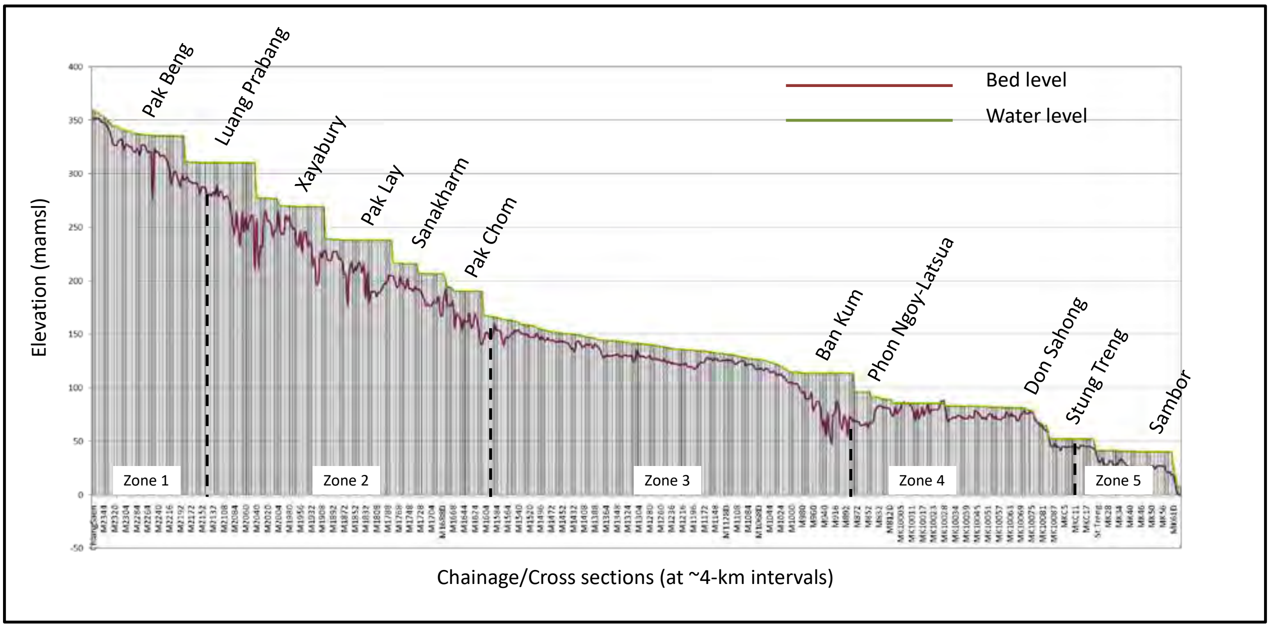


Figure 3.2 Long profile of the Mekong River from Chiang Saen to Kratie showing predicted water levels associated with potential HPP reservoirs included in the 2040 scenarios

Details of the developments included in the scenarios, including the design and generation capacity of the mainstream hydropower plants, are provided in the relevant Thematic Reports.

The incorporation of the effects of floodplain protection into the scenarios required a pragmatic approach as no details were available to aid specification of areas that would have floodplain protection. For the river channel, the actual defenses present in 2007 and 2015 were used to inform the hydraulic modelling for the scenarios, but for the floodplains in Zone 3, 5, 6, 7 and 8 the inundation mapping done for BioRA assumed no flood defenses. Thus, for these areas, 'floodplain protection' was incorporated into the scenarios using proportions of expected change in flooding for rural or urban sections of the river.[22]

The proportions of expected change in floodplain inundation as a result of floodplain protection infrastructure applied for the main scenarios are given in Table 3.4, and were based on the following general reasoning[23]:

Zone 3: In Scenarios 2007, Xe Bang Fai floodplain has little or no protection, but by 2015 it was embanked on one side, so Scenario 2020 assumed the same. For Scenario 2040, it is expected that the whole floodplain would have flood protection to a rural standard of ~1:10.

[22] In general, 'full protection', which means year-round protection from floods, is rare and confined to heavily urbanized areas, which make up a small portion of the LMB. Most rural defenses are expected to provide protection again events with a 1:5 to 1:10 return period.

[23] Anthony Green, .Flood Protection Thematic Team, pers. comm.

Table 3.4 The proportions of expected change in floodplain inundation as a result of floodplain protection infrastructure applied for the main scenarios[24]. Level 2 FPI is discussed in Section 3.2.[25]

Scenario	Zone 3	Zone 5	Zone 6	Zone 7	Zone 8
2007	None	None	None	None	None
2020	Reduce by ~15%	Reduce by ~2%	None	Reduce by ~2%	Reduce by ~2%
2040	Reduce by ~20%	Reduce by ~5%	None	Reduce by ~5%	Reduce by ~5%
2040CC	Reduce by ~35%	Reduce by ~5%	None	Reduce by ~5%	Reduce by ~5%
Level 2 FPI	Reduce by ~30%	Reduce by ~40%	None	Reduce by ~40%	Reduce by ~10%

Zone 5/6: In Scenarios 2007 and 2020, the Cambodia reaches have little in the way of rural defenses but have some urban protection. In Scenario 2040, the situation is expected to change, particularly in Zone 6, with a noticable loss of floodplain inundation.

Zone 7: Tonle Sap Great Lake does not have any limitation or defenses proposed under the main scenarios. Should there be further encroachment into the Tonle Sap Authority outer zones it may affect flooding, but this was not accounted for.

Zone 8: In 2007 Baseline scenario, flooding in much of the Viet Nam Delta was already controlled by a system of embankments and gates. These are expected to provide early flood protection only except for certain areas that have 'full protection' which means year round but not necessarily to a high standard. These increased slightly between 2007 and 2015, and so Scenario 2020 incorporates this, but further defenses were not included in Scenario 2040, i.e., 2020 and 2040 assume the same level of flood defense.

The main land-use changes are: reduction in deciduous forest (~-8%); increase in built-up areas (~+2%), and; increases in paddy fields (~+6%)[26]. For agricultural landuse, much of the change is expected to occur outside the corridor for the Council Study but will affect flow and sediment supply to the main river. There are also concentrated direct effects that are related to conversion of aquatic habitats expected in the study area, although many of these probably pre-dated 2007. In addition, floodplain infrastructure and agricultural landuse are correlated, as the one often leads to the other, particularly in the in the rural areas and, although there were details on specific areas that would be converted this were not incorporated directly into the hydraulic modelling on the floodplains, and so a rough proportional response was used to try and capture transformation of habitats for agriculture over and above those lost through floodplain infrastructure[27]. The estimated proportions of change in indigenous vegetation in the study corridor as a result of landuse change alone that were applied for the main scenarios are given in Table 3.5.

---

[24] Please note: These are ***modelling parameters*** and can be changed in later runs of the DSS to see the effect of difference assumptions.

[25] Changes in inundated area should also affect sedimentation and nutrient delivery to the floodplains, but these were not reduced as BioRA responds to proportional change rather than absolute values, and proportional change was deemed to be minor.

[26] Agricultural Landuse Thematic Report

[27] This was done using the exogenous function in the BioRA DSS.

Table 3.5 The proportions of expected direct conversion of aquatic habitats to other forms of landuse applied for the main scenarios[28]. A2_ALU is discussed in Section 3.2.[29]

Scenario	Zone 1-6	Zone 7	Zone 8
2007	None	None	None
2020	Reduce by ~4%	Reduce by ~4%	Reduce by ~4%
2040	Reduce by ~6%	Reduce by ~6%	Reduce by ~6%
A2_ALU	Reduce by ~8%	Reduce by ~7%	Reduce by ~8%

3.2 Thematic sub-scenarios

The thematic sub-scenarios are variations on Scenario 2040CC (Table 3.6), and their impacts on the ecosystem are assessed relative to that scenario. For each sub-scenario only one thematic sector is changed. For agricultural landuse and irrigation, the sub-scenarios incorporate two or three variations on the extent of developments envisaged in 2040CC. Where the variant is climate change, they represent different climatic conditions (rainfall and temperature, which drive evaporation) than used in 2040CC, to produce a different time-series of flows. Where the variant is hydropower, the sub-scenarios incorporate different levels of hydropower development as well as assumptions about operations, such as sediment flushing and/or alternative designs for some of the mainstream hydropower plants. Where the variant is flood protection infrastructure, the bulk of the flood protection is offered by the tributary and mainstream dams included in 2040CC for other sectors, such as hydropower. Thus, the floodplain protection sub-scenarios deal with variations in the levels of flood protection infrastructure, such as revetments and dikes in urban areas, and joint operation among mainstream dams and selected tributary dams for flood management and protection. Each of these sub-scenarios produces a different set of predictions of the physical, chemical and ecological consequences for the river ecosystem. Sub-scenarios were not developed for navigation and domestic and industrial water use.

For instance, there are two irrigation thematic sub-scenarios:

I1_noIRR: where all other developments are held at the same levels as in Scenario 2040CC, but irrigation is at 2007 levels.

I2_IRR: where all other developments are held at the same levels as in Scenario 2040CC, but there is more irrigation than was included in Scenarios 2040 or 2040CC.

[28] Please note: These are ***modelling parameters*** and can be changed in later runs of the DSS to see the effect of difference assumptions.

[29] Changes in inundated area should also affect sedimentation and nutrient delivery to the floodplains, but these were not reduced as BioRA responds to proportional change rather than absolute values, and proportional change was deemed to be minor.

In BioRA, the physical, chemical and ecological consequences of the different levels of irrigation were compared against those predicted for the 2040CC scenario in order to evaluate the extent to which irrigation either aggravated or alleviated the expected impacts on the river ecosystem.

Table 3.6 Thematic sub-scenarios

Designation	Code	Description
Climate change sub-scenarios	C2_2040Wet	2040CC with wetter climate
	C3_2040Dry	2040CC with drier climate
Agricultural landuse sub-scenarios	A1_noALU	2040CC with agriculture development at 2007 levels
	A2_ALU	2040CC with more agriculture development than in A1
Irrigation sub-scenarios	I1_noIRR	2040CC with irrigation development at 2007 levels
	I2_IRR	2040CC with more agriculture development than in 2040CC
Flood protection infrastructure sub-scenarios	F1_noFPI	2040CC with flood protection infrastructure at 2007 levels
	F2_FPI	2040CC with flood protection infrastructure at 'Level 2' (Table 3.4)
	F3_FPI	2040CC with flood protection infrastructure at 2020 levels and joint operation among mainstream dams and selected tributary dams to reduce flooding
Hydropower sub-scenarios	H1a_noHPP	2040CC with LMB hydropower development at 2007 levels
	H1b_nomainHPP	2040CC with the Lancang HPPs plus 2040 tributary HPPs
	H2_HPP	Same as 2040CC
	H3_HPP	2040CC but with consideration of mitigation measures and operations at the HPPs

In all, 16 scenarios were explored: three main development scenarios (2007, 2020 and 2040), plus 2040 level of development under a warmer and wetter climate (2040CC), and 12 sub-scenarios covering variations in each of five thematic areas (Table 3.6).

4 Predictions of change for river reaches under the main development scenarios

Some of the mainstream Mekong River in the LMB will be converted to impounded waters by the planned dam developments. This section focusses on the reaches that would remain as flowing river-like stretches under the main development scenarios, with the impounded areas addressed in Section 5, and the summary impacts for each river zone as a whole in Section 6. The predictions of change are provided for the indicators listed in Section 2.2.

River connectivity is discussed first as this has major implications for the movement of water, sediments, fish and other organisms through the LMB, as well as for water quality. Thereafter, the predicted changes in the hydrological and hydraulic regimes are addressed, followed by predictions of how this would affect: the movement of sediments and nutrients[30]; channel erosion; aquatic habitats; vegetation; aquatic macroinvertebrates; fish; herpetofauna; birds, and; mammals.

4.1 Effects on connectivity

Rivers ecosystems are interconnected and interact across four dimensions (Amoros *et al.* 1987 in Finlayson and McMahon 2004; Ward and Tockner 2001): longitudinally - upstream to downstream progression; laterally – across the main channel and riparian area including floodplains; vertically – between the surface and groundwater, and; temporally – daily, seasonal and annual changes in river dynamics and ecosystem functioning. These interactions define and dictate much of the character and function of the ecosystems, which means that changes in one part of a river ecosystem can affect the character and function many other parts of the ecosystems. The disruptions considered in the Council Study are those on the longitudinal and lateral movement of water and sediments and those on the longitudinal and lateral movement of fish and prawns.

4.1.1 Effects on movement of water and sediments

Dams in a river alter the movement of water and sediments through the system. The extent of this alteration varies depending on the extent of the barrier, the size of the impoundment and the characteristics of the sediment and flo*w* regimes. Impoundments that store the annual flow and more can change the whole flow regime, whereas those with small storage capacity relative to annual flow may only affect Dry season flows. Hydropower dam operations can also affect daily patterns of flow by, for instance, releasing large amounts for peak power generation in the morning and evening[31].

[30] The changes in discharge, sediment and nutrients are derived directly from the modelled time-series for these parameters. The models and the assumptions used in to produce these are described in the Modelling Report.
[31] For instance, the recently completed Delta Study modelled elevated flows in day and reduced flows at night.

In general, dams are highly effective at trapping sediments because they are physical barriers to downstream movement. Also, because flow velocities in impoundments are lower than in the free-flowing river, sediments fall from suspension. Courser materials such as sand, gravel, cobbles and boulders tend to be deposited at the head of the reservoir, creating a delta that can extend down the length of the impoundment over time. Silts and clays may be deposited closer to the dam wall in impoundments with low velocities and long residence times, but can be transported through some impoundments and past the dam. The amount and size of sediments trapped varies with season, with Dry low-flow conditions generally increasing the trapping of finer sediments.

Nutrient transport through a river system is also affected by barriers, as nutrients are typically associated with sediments and thus can also be trapped in the reservoir. The rate of nutrient trapping in an impoundment tends to be lower relative to overall sediment trapping, because the nutrients are associated with the finer-grained sediments that are less likely to be trapped.

Nutrients and sediments trapped in reservoirs represent a reduction in the supply to the downstream river, which is discussed in following sections.

4.1.2 Effects on fish migration

The LMB fish communities are characterised by a high diversity of species[32]. Many exhibit complex life cycles that involve migration between different areas of the river and may include upstream migration to spawning areas. The dams in the main scenarios would be a barrier to their movement, denying them access to refuges, breeding and nursery areas. The reservoirs associated with these dams would convert long stretches of flowing riverine habitat to relatively still lake-like waters (Table 5.1), potentially disorientating migrating fish and further inhibiting successful migrations, even where fish by-passes have been constructed at dam walls.

The efficacy of fish passages intended to facilitate up- and downstream migration of fishes past in-channel HPP weirs and impoundments is a matter of considerable debate[33], with the prevailing view among specialists that existing types and sizes of fish ladders will have difficulty accommodating the intensity and diversity of fish attempting to migrate up the mainstream Mekong River, and provide little or no assistance with downstream migration (and larval drift)[34].

---

32 Mekong River Commission (MRC). 2003. State of the Basin Report. Mekong River Commission, Phnom Penh. Cambodia; Poulsen A.F., Hortle K.G., Valbo-Jorgensen J., Chan S., Chhuon C.K., Viravong S., Bouakhamvongsa K., Suntornratana U., Yoorong N., Nguyen T.T., and Tran B.Q. (2004). Distribution and Ecology of Some Important Riverine Fish Species of the Mekong River Basin, MRC Technical Paper No. 10.

33 Agostinho, A.A. Marques, E.E., Agostinho, C.S., de Almeida, D.A., de Oliveira, R.J. de Melo, J.R.B. 2007. Fish ladder of Lajeado Dam: migrations on one–way routes?. Neotropical Ichthyology, 5(2). On-line version ISSN 1982-0224.; Dugan, P., Barlow, C., Agostinho, A.A. and Winemiller, K.O. 2010. Fish Migration, Dams and Loss of Ecosystem Services in the Mekong Basin. AMBIO A Journal of the Human Environment 39(4):344-8; Nunn, A.D. and Cowx, I.G. 2012. Restoring River Connectivity: Prioritizing Passage Improvements for Diadromous Fishes and Lampreys. Ambio, 41(4): 402–409.

34 International Centre for Environmental Management (ICEM) 2010. MRC Strategic Environmental Assessment (SEA) of hydropower on the Mekong mainstream: summary of the final report, Hanoi, Viet Nam.

Fish migrations in the LMB

The LMB has one of the largest and most productive inland fisheries on Earth. The commercially valuable fish species are generally divided between 'black fish', which inhabit low oxygen, slow moving, shallow waters, 'white fish', which inhabit well-oxygenated, fast moving, deeper waters, and 'grey fish', which fall somewhere between the other two.

The black fish tend to reside on floodplains, with limited lateral migrations from the river onto floodplains and no migrations upstream and downstream; they account for ~13% of the Lower Mekong's species richness and ~50% of capture fisheries.

The white fish account for ~37% of species richness and ~36% of fish catch[35]. Many of the 'white fish' are either long- or short-distance migrators. Long-distant migrants tend to be large in size because they need stamina to swim to their distant spawning grounds, feeding habitats and/or refuges. Short-distant migrants are usually smaller and spawn in the main channel or tributaries upstream of floodplain feeding and nursery habitats. Both sets of white fish fetch higher prices on the market than do other fish guilds. To complete their migrations they require unobstructed passage upstream, and the capacity for adults, larvae and juveniles to migrate or drift downstream[36]. The timing of these migrations is variable depending on species; migration appears to occur throughout the year but is highest in spring (February-March), at the onset of the flood season (June-July), and when the water is receding (November)[37].

The river fragmentation resulting from an increase from two main-channel hydropower plants (Scenario 2020) to 11 main-channel plants (Scenario 2040) is expected to result in a marked, and more than likely irreversible, negative impact on the LMB ecosystem (Figure 4.1). The composition of the scenarios makes it impossible to disaggregate the incremental impacts of these dams. Work done in the earlier stages of BioRA suggested, however, that from the perspective of blocking migrations, the lower dams Stung Treng or Sambor HPPs (in Zone 4 and Zone 5, respectively), will have a greater incremental impact on ecosystem health and indigenous fish communities in the LMB as a whole, while Xayabury HPP in Zone 2, for instance, would have a lesser effect. By way of illustration, Figure 4.1 gives the predicted mean percentage of migrating fish remaining at each zone with hypothetical barriers at different points. The BioRA DSS predicts that the effect on migrating fish populations in the LMR, increases the more downstream that barrier is located. For instance, a barrier between Zone 1 and Zone 2 (A in Figure 4.1) is predicted to have little or no effect on migrating fish populations downstream of Zone 2, whereas as a barrier between Zone 4 and Zone 5

[35] Halls, A.S., Paxton, B.R., Hall, N., Peng Bun, N., Lieng, S., Pengby, N. and So, N. 2015. The Stationary Trawl (Dai) Fishery of the Tonle Sap-Great Lake, Cambodia. MRC Technical Paper No. 32, Mekong River Commission, Phnom Penh.

[36] Lucas, M.C. and Baran, E. 2001. Migration of Freshwater Fishes. Blackwell Science. 420 pp; Hogan, Z., Baird, I., Vander Zanden, J. and Radtke, R. 2007. Long distance migration and marine habitation in the Asian catfish, *Pangasius krempfi*. *Journal of Fish Biology*, 71: 818-832; Halls, A.S. and Kshatriya, M. 2009. Modelling the cumulative barrier and passage effects of mainstream hydropower dams on migratory fish populations in the Lower Mekong Basin. MRC Technical Paper No. 25. Mekong River Commission, Vientiane. 104 pp; Meynell, P-J. 2012. Ecological significance of Mekong tributaries. Report prepared for the MRC. 155 pp.; Fukushima, M., Jutagate, T., Grudpan, C., Phomikong, P. and Nohara, S. 2014. Dam development in the Mekong River Basin on the migration of Siamese mud carp (*Henicorhynchus siamensis* and *H. lobatus*) elucidated by otolith microchemistry. *PLOS One* 9 (8), e103722 Halls, A.S. 2014. The Lower Sesan 2 Dam in the Sekong-Sesan-Srepok (3S) Basin: Potential impacts on fish supply for consumption in Cambodia. Project Technical Report prepared for IUCN, 104 pp.

[37] Sverdrup-Jensen, S. 2002. Fisheries in the Lower Mekong Basin, Status and Perspectives. MRC technical Paper No. 6. Mekong River Commission, Phnom Penh, Cambodia, 84 pp.

(C in Figure 4.1) is predicted to severely reduce migrating fish species in the LMR as a whole. Two barriers (D in Figure 4.1) will have a greater negative effect than one but once a barrier is in place, additional barriers upstream are predicted to have a lesser effect on migrating fish populations (Figure 4.1).

In the assessment of the main development scenarios, a fish-passage success rate of 50% was used for ten of the 11 main stream dams, with the eleventh, Don Sahong, which does not block the whole river channel, assigned a success rate of 90% (Table 4.1).

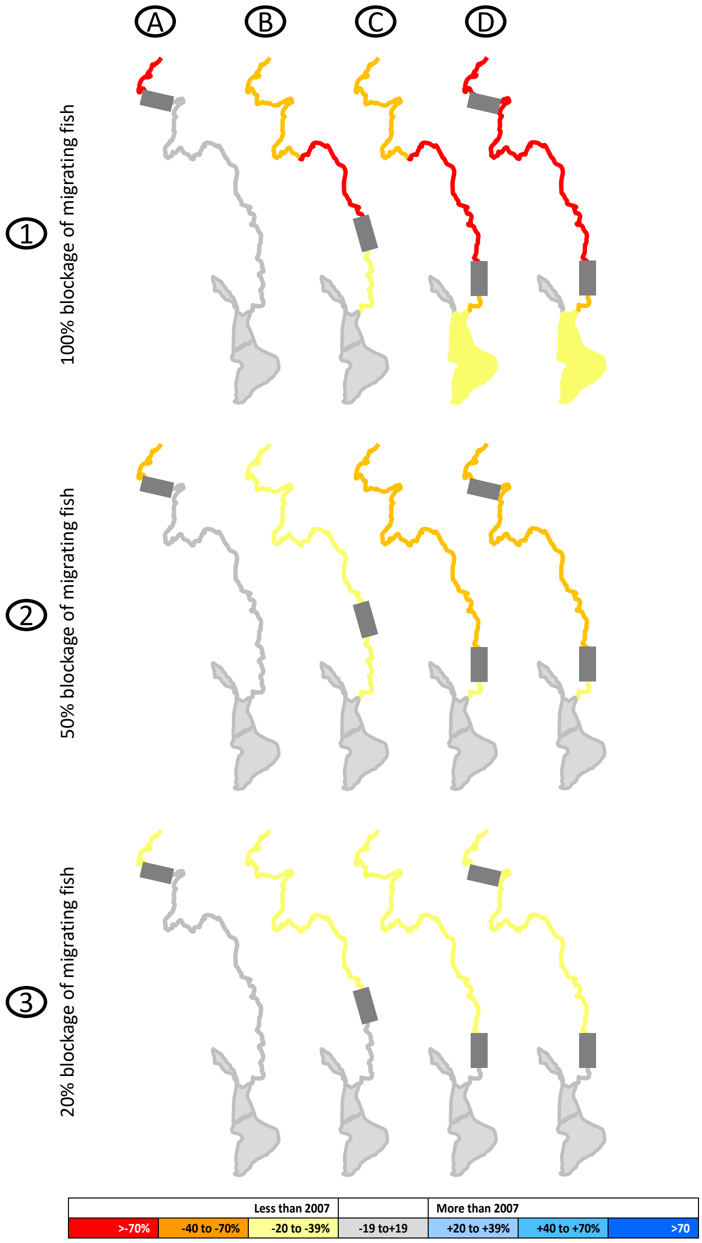


Figure 4.1 Estimated percentage of migrating fish remaining if barriers at different hypothetical points along the system block 100%, 50% or 20% of fish movement, all else being equal. Barriers indicated by rectangles.

Table 4.1 Modelled effect of the mainstream dams on fish migration[38]

Development	White fish	Freshwater prawns
	Percent of 2007 Baseline able to pass	
Langcang Cascade	Not included	n/a[39]
Pak Beng	50%	
Luang Prabang	50%	
Xayabury	50%	
Pak Lay	50%	
Sanakharm	50%	
Pak Chom	50%	
Ban Kum	50%	
Phon Ngoy-Latsua	50%	
Don Sahong	90%	95%
Stung Treng	50%	50%
Sambor	50%	50%

For the tributary HPPs, the effect on migration depends on the number of dams, the location of the lowest dam and whether fish passage facilities are provided. For BioRA, the change in tributary connectivity linked to the proposed developments was estimated for each zone as a whole. The values used are given in Table 4.2. For instance, with two HPPs included in tributaries feeding Zone 2 in 2007, ~13 in 2020 and ~31 in Scenario 2040 (many of which are on the same tributaries as the HPPs in Scenario 2020), the nett effect on migration used in BioRA was a 50% reduction in fish in Zone 2 in Scenario 2020 and a 60% reduction under Scenario 2040, compared to the 2007 Baseline. The effects of these changes in connectivity are incorporated into the response curves that drive the predictions of change in the BioRA fish (and prawn) indicators in Section 4.3.4. The predicted impact on migrating fish guilds will be smaller if higher success rates for fish passage are used as input parameters (Figure 4.1), but there is little doubt that, overall, the sheer number of tributary and mainstream dams included in the Scenario 2020 and 2040 would reduce fish migrations in the LMB.

Table 4.2 Estimated change in tributary connectivity for each zone used in the BioRA DSS for migratory white fish[40]

Zone	2020	2040
Zone 1	-70%	-70%
Zone 2	-50%	-60%
Zone 3	-40%	-50%
Zone 4	-20%	-50%
Zone 5-8	0	0

[38] For 2040, dams that occur in a sequence are lumped on a single arc, with ~50% efficiency applied to each, i.e., three weirs/reservoirs = 12.5% nett efficiency.
[39] Outside of distribution range
[40] Please note: These are ***modelling parameters*** and can be changed in later runs of the DSS to see the effect of difference fish-passage efficiencies on the prediction. ***They are not a comment on the actual efficiencies of any fish passages in any dams existing or planned***.

4.2 Inputs from the Modelling Team

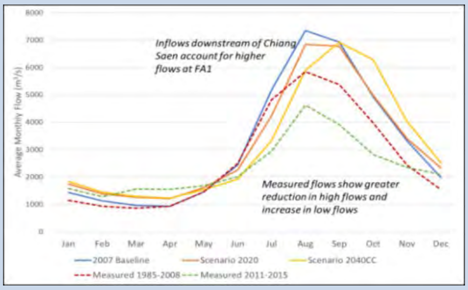
In accordance with the design of the Council Study (Section 1.2.3), the BioRA outcomes are based on the modelled time-series data received from the Modelling Team (also see text box). Ecologically-relevant summaries of these data for the sub-scenarios are provided and discussed in this section as they provide the context for the BioRA predictions. The reasoning behind the modelling outputs in provided in the Modelling Report.

On the whole, the modelling for the main development scenarios yielded:

- relatively small changes in the seasonality of river flows and floodplain hydraulics, which increased from 2007 Baseline, through Scenarios 2020 to 2040;
- large changes in sediment and nutrient supply, which increased from 2007 Baseline, through Scenarios 2020 to 2040.

DRIFT responds to ***modelled*** changes

DRIFT responds to modelled differences in flow, hydraulics, sediments and water quality between a baseline and a developed condition, here represented by the scenarios. Actual flow and other changes associated with developments frequently differ from modelled results because of the complexities of natural river systems and differences between actual and modelled design and operation of developments.



A comparison between averaged monthly modelled flows for Zone 1 (at FA1) for the main development scenarios and measured discharge at Chiang Saen before and after development of the Lancang Cascade show how actual changes may differ from modelled changes[41]. In the figure, Scenario 2020 shows an increase in Dry season flow relative to the 2007 Baseline as a result of operation of the dams in the UMB. Measured flow results before (1985-2008) and after (2011-2015) development of the cascade show a greater change in the Dry season than those predicted by the model used in the Council Study. This is partly attributable to the measured data containing several consecutive dry years, but probably also reflects the complex reality of hydropower operation in the UMB.

The differences between modelled and actual changes should be kept in mind when interpreting the BioRA results, which predict ecosystem changes based on differences between *modelled* flow, hydraulic, sediment and water quality time-series. Thus, if the modelled changes are under- or over-estimated, then the predicted responses in DRIFT will be under- or over-estimated.

[41] Lu, X.X. Jian-Jun, W., Grundy-Warr, C. 2008. Are the Chinese dams to be blamed for the lower water levels in the Lower Mekong? Modern Myths of the Mekong. 39-51; Piman, T., Cochrane, T.A., Arias, M.E., Green, A., Dat, N.D. 2012. Assessment of flow changes from hydropower development and operation in the Sekong, Sesan and Srepok rivers of the Mekong Basin. J. Water Resour. Plann. Manage. 139 (6), 723-732.

4.2.1 Hydrology and hydraulics

"The flow regime is of central importance in sustaining the ecological integrity of flowing water systems. The five components of the flow regime-magnitude, frequency, duration, timing, and rate of-change influence ecological integrity both directly, and indirectly, through their effects on other primary regulators of integrity. Modification of flow thus has cascading effects on the ecological integrity of rivers"[42].

The modelled flow changes associated with the main development scenarios are small, as shown in Figure 4.2. Relative to 2007 Baseline, Scenarios 2020 and 2040 have slightly higher Dry season flows; and flood seasons with slightly shorter durations and delayed onsets for all river zones. The flow regime for Scenario 2040CC is similar to those for Scenario 2020 and 2040, except for higher flows late in the flood season.

Ecological functions of the natural flow regime

All parts of the flow regime play a role in sustaining the riverine ecosystem: floods replenish groundwater, maintain the channel and support floodplains, leaving nutrient-rich sediments as they subside; flow fluctuations between Dry and Wet seasons and years define the perenniality and degree of seasonality of the river and thus the biota it can support. Plant and animal life cycles are linked to the onset, duration and the magnitude of flow in each flow season. Changing these can alter flow cues so that life-cycles are disrupted and species decline.

Thus, changing any part of the flow regime can trigger changes in the ecosystem. The relationships between cause and effect may not be linear because of the complex interactions that characterise these systems, but experience has shown that the more the natural flow/sediment/water quality regimes are changed, the more the river ecosystem will change[43][44].

The median Baseline (2007) values for hydrology and hydraulics are given in Table 4.3. They illustrate, for instance, that under baseline conditions, flood volume increases dramatically from Zone 1 to Zone 5 on account of the contribution to Wet season flow from the tributaries in Lao PDR, Thailand and Cambodia. Note also that depending on the zone, the parameter and units reported differ. For instance, 'Dry Min 5day Q/depth/area' is a discharge (Q) in the river channels, a depth on the floodplains and an area in Tonle Sap Great Lake (Zone 7) and the Delta (Zone 8).

The predicted changes from these median values under Scenarios 2020, 2040 and 2040CC are given in Table 4.4. The values are colour coded from colourless (negligible change) to red (very large negative change) and blue (very large positive change) for easy identification of levels of impact. The positive and negative signs in the table denote a numerical increase or decrease and do not indicate if the change is or is not beneficial for the river ecosystem or people. Table 4.4 shows that, for instance, relative to the 2007 Baseline, Dry

[42] Karr, J,R. 1991. Biological integrity: a long-neglected aspect of water resource management. Ecological Applications 1: 66-84.
[43] Brown, C.A., King, J.M., Hughes, J. and Zakaria, V. 2017. Good Practice Handbook: Environmental Flows for Hydropower Projects. WorldBank Group, Washington. 82pp.
[44] Poff, N.L., Allan, D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., Sparks, R.E. and Stromberg, J.C. 1997. The Natural Flow Regime A paradigm for river conservation and restoration. BioScience Vol. 47 No. 11.

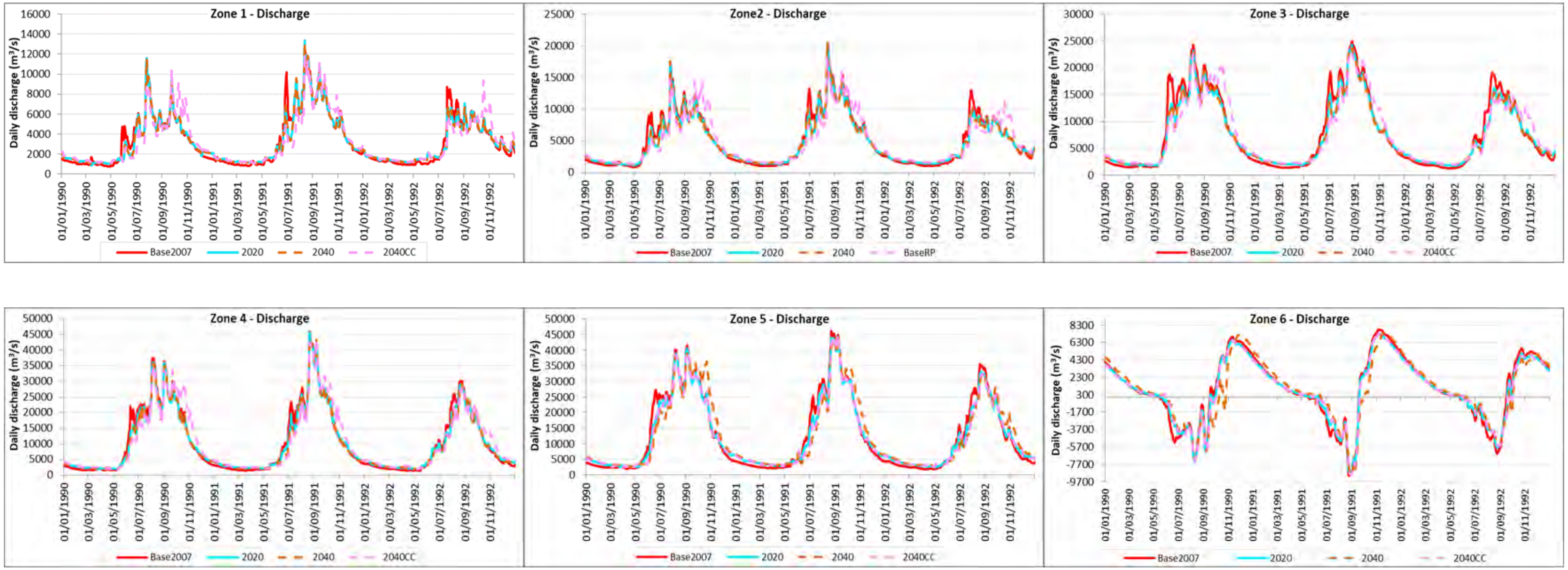


Figure 4.2 Modelled hydrographs for 2007, 2020, 2040 (without climate change) and 2040CC (with climate change) in Zone 1-6.

Table 4.3 Median values for the modelled hydrology and hydraulic indicators for 2007 Baseline in the river sections.

2007	Units	Zone									
		1	2	3	4	5	6	7	8a	8b	8c
Mean annual runoff	m^3/s	3232	4792	7852	10593	13048					
Dry onset	week	49	49	49	49	49	49	50	50	47	47
Dry duration	days	194	181	171	174	178	192	203	231	250	205
Dry Min 5day Q/depth/area	m3/s; m; m^2	861	996	1345	1461	1938	9	1	154	74	3112
Wet onset	week	28	27	23	25	25	31	34	31	32	39
Wet duration	days	123	125	150	136	138	136	122	131	109	133
Wet Max 5day Q/depth/area	m3/s; m; m^2	10384	15457	23394	35265	39847	17	9	10257	6436	6926
Flood volume	m^3	68664	103023	191675	257288	311638					
T1: T1 onset	week	25	22	21	22	22	25	26	31	32	37
D: Average Channel Velocity	m/s	1	0	1	1	0	0				
W: Average Channel Velocity	m/s	1	1	1	2	1	0				
D: Average Channel Depth	m	13	5	4	2	24	10				
W: Average Channel Depth	m	22	12	10	5	32	16				
D: Average Wetted perimeter	m	340	1205	1460	1298	565	567				
D: Average Shear Stress	Pa	51	3	3	7	1	2				
T1: Average Channel Shear Stress	Pa	79	5	4	15	3	1				
W:Average Channel Shear Stress	Pa	107	8	5	16	7	3				
T2: Average Channel Shear Stress	Pa	76	5	4	13	2	6				
Average FP Area inundation	km^2			26		305	7481	8137	7267	4242	4987
Average FP Onset inundation	week			20		23	27	26	31	32	25
FP Duration inundation	days			222		184	182	195	131	119	147

Table 4.4 Predicted percentage change from 2007 Baseline in hydrology and hydraulic indicator values for Scenarios 2020, 2040 and 2040CC

Scenario	Indicators	Zone									
		1	2	3	4	5	6	7	8a	8b	8c
Scenario 2020	Mean annual runoff	0	-3	-4	-1	-1					
	Dry onset	0	2	2	2	4	0	-2	0	2	0
	Dry duration	-4	-2	-4	-5	-2	3	3	2	1	0
	Dry Min 5day Q/depth/area	35	35	38	42	41	3	8	2	8	-1
	Wet onset	5	6	9	4	8	0	3	3	3	5
	Wet duration	-8	-11	-7	-2	-5	-3	-6	-3	-10	-2
	Wet Max 5day Q/depth/area	-4	-4	-6	-1	-3	-2	-3	-3	-2	1
	Flood volume	-11	-11	-13	-8	-5					
	T1: T1 onset	-2	7	2	2	5	2	4	3	3	0
	D: Average Channel Velocity	12	10	5	9	21	-7				
	W: Average Channel Velocity	-4	-3	-4	-1	-4	-2				
	D: Average Channel Depth	6	7	11	14	3	2				
	W: Average Channel Depth	-3	-4	-5	-4	-1	-2				
	D: Average Wetted perimeter	1	0	0	6	16	9				
	D: Average Shear Stress	8	16	2	22	46	-13				
	T1: Average Channel Shear Stress	-17	-6	-11	-10	-23	-28				
	W:Average Channel Shear Stress	-4	-4	-6	0	-5	-9				
	T2: Average Channel Shear Stress	4	3	-1	8	16	-14				
	Average FP Area inundation			-22		-10	-9	-4	-6	-7	0

Scenario	Indicators	Zone									
		1	2	3	4	5	6	7	8a	8b	8c
Scenario 2040	Mean annual runoff	0	-4	-5	-3	2			-8	-6	-1
	Dry onset	0	0	2	2	4	0	-2	0	2	0
	Dry duration	-2	-4	-3	1	-3	5	5	3	4	0
	Dry Min 5day Q/depth/area	34	44	47	38	33	3	7	0	1	-2
	Wet onset	5	6	11	8	14	2	3	3	5	5
	Wet duration	-8	-12	-7	-5	-8	-4	-8	-4	-11	-2
	Wet Max 5day Q/depth/area	-5	-5	-6	-2	-1	-2	-4	-4	-2	1
	Flood volume	-11	-12	-14	-10	-3					
	T1: T1 onset	-2	7	0	7	9	6	4	3	3	0
	T2: T2 onset	0	0	1	0	4	1	-1	1	0	0
	D: Average Channel Velocity	12	10	6	9	21	-7				
	W: Average Channel Velocity	-4	-3	-5	-1	-5	-2				
	D: Average Channel Depth	6	7	11	14	3	1				
	W: Average Channel Depth	-3	-4	-6	-4	-2	-2				
	D: Average Wetted perimeter	1	0	0	6	15	7				
	D: Average Shear Stress	8	16	3	22	44	-14				
	T1: Average Channel Shear Stress	-17	-6	-10	-10	-37	-35				
	W:Average Channel Shear Stress	-4	-4	-7	0	-6	-8				
	T2: Average Channel Shear Stress	4	3	-1	8	15	-16				
	Average FP Area inundation			-38	#N/A	-17	-32	-3	-16	-16	-10
Scenario 2040CC	Mean annual runoff	0	0	1	1	-2			-3	-1	0
	Dry onset	5	3	5	4	3	2	2	1	8	0
	Dry duration	-3	-4	-6	-2	-3	2	0	1	-3	6
	Dry Min 5day Q/depth/area	38	47	55	36	36	4	12	-1	-3	-2
	Wet onset	9	7	13	8	8	3	6	3	5	5
	Wet duration	-4	-4	-4	1	-10	-1	-6	-2	-1	-2
	Wet Max 5day Q/depth/area	3	1	-4	3	-2	0	0	-1	0	1
	Flood volume	-8	-6	-5	-3	-8					
	T1: T1 onset	14	12	5	7	5	10	8	3	3	0
	T2: T2 onset	4	4	7	4	0	4	3	3	4	9
	D: Average Channel Velocity	12	10	8	9	25	5				
	W: Average Channel Velocity	-4	-3	-4	-1	-2	-3				
	D: Average Channel Depth	6	7	14	14	3	4				
	W: Average Channel Depth	-3	-4	-4	-4	-1	-1				
	D: Average Wetted Perimeter	1	0	0	6	20	16				
	D: Average Shear Stress	8	16	4	22	55	7				
	T1: Average Channel Shear Stress	-17	-6	-14	-10	-52	-49				
	W:Average Channel Shear Stress	-4	-4	-6	0	-2	-8				
	T2: Average Channel Shear Stress	4	3	8	8	49	-7				
	Average FP Area Inundation			-22	#N/A	-10	-26	-5	-0	19	50

Less than 2007				More than 2007		
<-70%	-40 to -70%	-20 to -39%	-19 to+19	+20 to +39%	+40 to +70%	>70

season discharges will be 35-42% higher in Zone 1-5 for Scenarios 2020 and 2040, and the onset of the Wet season will be one to two weeks later.

The change in flow to the Tonle Sap Great Lake (Zone 7) is believed to be strongly influenced by the timing of the onset of the Wet season and the relative differences in water levels between the lake and the Mekong River[45]. Importantly, however, according to the modelled data, the seasonal flow reversal of the Tonle Sap River is expected to endure (Modelling Report; Figure 4.3), although the volume entering Tonle Sap Great Lake is expected to drop by ~8% (2020), ~5% (2040) and ~9% (2040CC), with more extreme dry years suffering a more severe reduction of up to 10% compared with the 2007 Baseline (Figure 4.3).

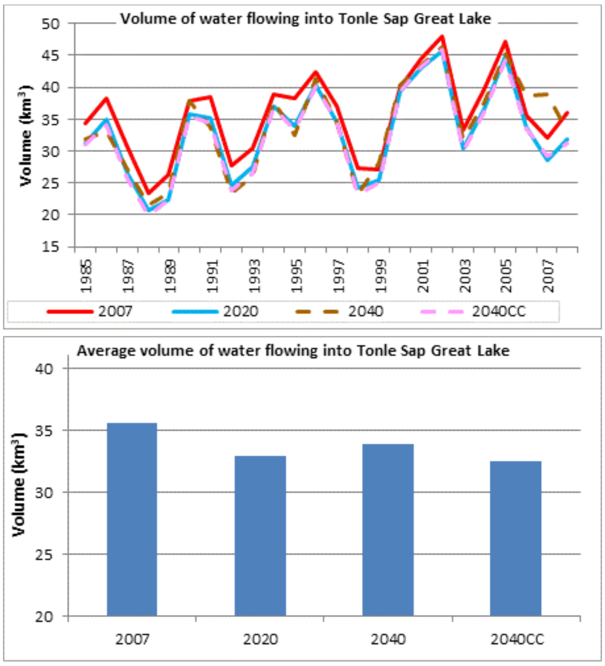


Figure 4.3 Annual volumes of flow from the Mekong River up the Tonle Sap River predicted in the main development scenarios. Top: annual volumes. Bottom: annual average based on the 24-year modelled time-series.

The onset, duration and extent of floodplain inundation were also modelled and show that because the magnitude and volume of the Wet season high flows would be reduced in Scenarios 2020 and 2040, the predicted floodplain areas that will be inundated will be lower (Figure 4.4). These changes are relatively minor, but the fact that they occur year after year means that they will elicit change in the ecosystem. Under Scenario 2040CC, the inundated areas are similar to those in 2007 Baseline, but with a slightly later timing.

4.2.2 Sediments and nutrients

The Mekong River carries sediment and nutrients from upstream to downstream and across national borders, influencing the shape of the channel, creating a diverse array of habitats for animals and

[45] Adamson, P.T. 2006. Hydrological and water resources modelling in the Mekong Region: A brief overview. In: Mekong Region Waters Dialogue. Co-convened by IUCN, TEI, IWMI, M-POWER. Vientiane, Lao PDR, 6 to 7 July 2006.

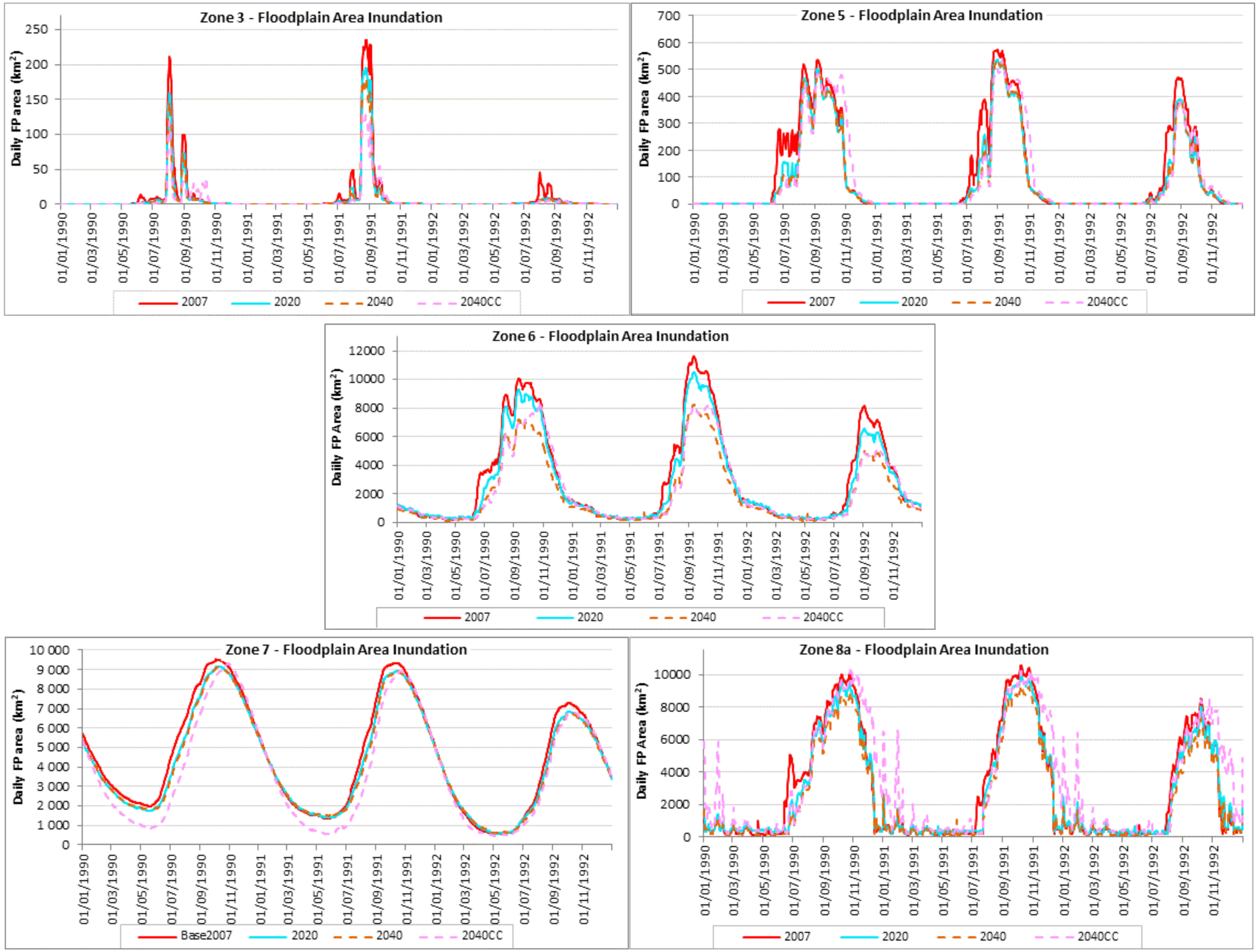


Figure 4.4 **Examples of modelled inundated areas for 2007, 2020, 2040 (without climate change) and 2040CC (with climate change) at Zone 3, 5, 6, 7 and 8.**

plants[46], replenishing banks and enriching the floodplain. These sediment and nutrient loads are fundamental in shaping and maintaining the river channels and sustaining the ecological integrity of the river and surrounding landscapes [47].

The modelled 2020 and 2040 scenarios predict a substantial loss of sediments moving through the system relative to 2007 Baseline (Figure 4.5). The reduction in sediment delivery to the Delta is predominantly due to their being trapped in impoundments, with an additional reduction caused by a reduced capacity of weakened flood flows to carry sediment loads. The Modelling Report concludes: "*The most significant change anticipated is the 97% reduction in sediment flux*[48] *to the Delta under … the 2040 Scenarios with or without climate change …. A large part of this reduction is the trapping of sediments in dams of the Upper Basin and in tributary dams of the LMB. Proposed mainstream dams, especially Sambor in Cambodia, reduce the total amount of sediment that is free to pass downstream even more*." This is in line with recent predictions that under a level of development similar to the 2040 scenario, only 4% of the pre-dam sediment load would reach the Delta once in-channel stored sediment was exhausted[49].

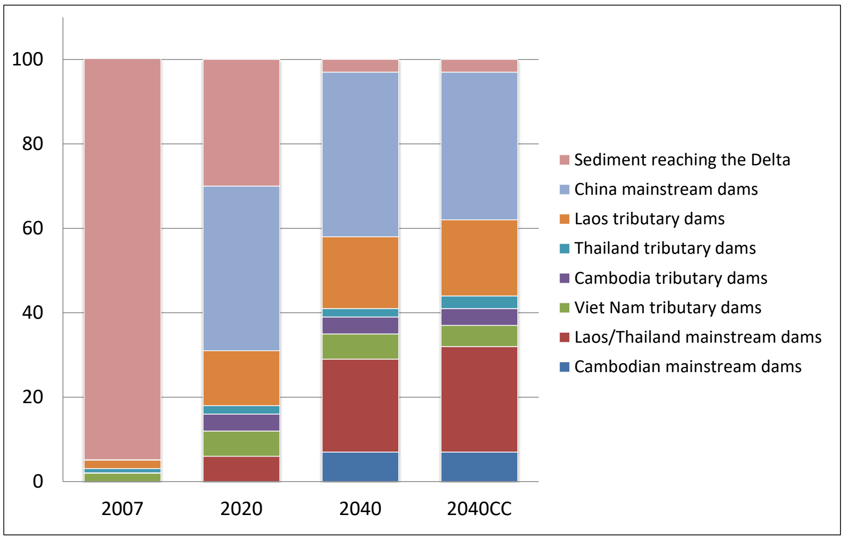


Figure 4.5 Distribution of estimated percentage of sediment that would be trapped between the mainstream and tributary dams and the remaining sediment flux to the Delta[50]

The median baseline values for BioRA sediment and water quality indicators for free-flowing river reaches (Table 4.5) highlight the existing scale and seasonality of sediment delivery to the LMB.

46 Richter, B.D., Baumgartner, J.V., Wigington, R. and Braun, D.P. 1997. How much water does a river need? Freshwater Biology 37, 231-249.
47 Kummu, M., Penny, D., Sarkkula, J. and Koponen, J. 2008. Sediment: Curse or Blessing for Tonle Sap Great Lake? Ambio, 37(3): p 158.
48 i.e., flow.
49 Kondolf, M., Rubin, Z.K. and Minear, J.T. 2014. Dams on the Mekong: Cumulative sediment starvation. Water Resources Research. 50 (6). 5158–5169.
50 Source: Council Study Modelling Report.

Under baseline conditions, an average of ~237 813 and ~557 956 kg of sediment per day was delivered to Zone 1 in the Transition 1 and Wet seasons, respectively. At Zone 5, these values increased to 303 476 and 871 537 kg/day, respectively. Such high sediment loads would have meant highly turbid waters with near-zero light penetration. By contrast the sediment loads in Transition season 2 and the Dry season were more than an order of magnitude lower, resulting in clearer water.

Table 4.5 Modelled median Baseline 2007 values for sediment and nutrient indicators in the river sections.

Indicators	Units	Zone									
		1	2	3	4	5	6	7	8a	8b	8c
D: ave Sediment load	kg/day	21 002	11877	12 903	25227	45402	27460				
T1: ave Sediment load	kg/day	237813	64028	110 934	368171	303476	78669				
Wt: ave Sediment load	kg/day	557956	397088	572 058	861725	871537	85328				
T2: ave Sediment load	kg/day	86672	72919	98658	76811	62 677	22608				
W: Average sediment Onset	weeks	30	31	30	29	29	14.0				
W: Average sediment Duration	days	68	64	64	67	69	157.5				
D: Average Total Phosphorous	mg/l	0.02	0.02	0.02	0.04	0.04	1.2		1.12	0.80	9.60
W: Average Total Phosphorous	mg/l	0.06	0.09	0.08	0.08	0.09	27.8		24.48	13.85	5.91
D: Average Total Nitrogen	mg/l	0.28	0.29	0.25	0.22	0.22	2.0		1.74	1.29	13.26
W: Average Total Nitrogen	mg/l	0.74	0.77	0.58	0.55	0.49	40.5		37.74	21.60	10.86
W: FP TOT SiltClay	g/m2/d			1296		14740	1393746		942893	353464	57341
FP Sedimentation	t/day						2242302	12858	1288461	480540	92814
Average salinity	g/l								6.5	1.4	18.0

The predicted percentage changes relative to 2007 Baseline in each scenario (Table 4.6) indicate the magnitude of the anticipated loss in sediments and nutrients as a result of trapping in tributary and mainstream dams. Large reductions in sediment loads could be expected across all zones and seasons. For instance, Wet season sediment loads passing through Zone 5 are predicted to decline by ***59%*** under Scenario 2020 and by ***97%*** under Scenario 2040.

Overall, time-series of sediment loads at Zone 1 through to Zone 6 for each of the scenarios (Figure 4.6) show the following characteristics:

- there is a high 'natural' variability in the sediment loads in the 2007 Baseline;
- there is a trend of increasing sediment loads over time in the 2007 Baseline in most zones;
- the largest sediment loss in Zones 1 through 4 occurs between the 2007 Baseline and Scenario 2020, mainly through trapping in the dams in the Lancang cascade (UMB) and the dams in the tributaries draining Lao PDR (Figure 4.5), with Zone 5 showing an additional large reduction between the 2020 and 2040 scenarios as a result of additional sediment trapping in the mainstream dams in Lao PDR and Cambodia;
- the reduction in sediments as a result of dams in the tributaries draining Thailand is small (Figure 4.5), because the dams in these tributaries were constructed earlier than 2007, and thus pre-date the 2007 Baseline;
- the reductions in sediment load are not uniform over time within zones. In Zones 2 and 3 the differences between 2007 Baseline and the development scenarios increase over time

presumably because the supply of existing sediments in the river channel downstream of hydropower projects are 'eroded' away, and;

- the wetter conditions associated with 2040CC result in small increases in sediment loads in some zones.

Table 4.6 Sediment and nutrient indicators: Predicted percentage change from Baseline for Scenarios 2020, 2040 and 2040CC in the river sections

Scenario	Indicators	Zone									
		1	2	3	4	5	6	7	8a	8b	8c
Scenario 2020	D: Average sediment load	-99	-45	25	-83	-79	-58				
	T1: Average sediment load	-100	-65	-41	-75	-45	-60				
	W: Average sediment load	-91	-73	-47	-60	-66	-58				
	T2: Average sediment load	-98	-73	-23	-68	-92	-71				
	W: Average sediment onset	7	-2	0	3	-5	11				
	W: Average sediment duration	-41	5	9	-11	-7	-4				
	D: Average Total Phosphorous	-51	-42	-28	-9	-18	-7		-33	-29	-26
	W: Average Total Phosphorous	-19	-20	-14	-11	-28	-35		-29	-32	-15
	D: Average Total Nitrogen	-23	-29	-21	-17	-17	-6		-15	-29	-30
	W: Average Total Nitrogen	-17	-19	-19	-22	-53	-35		-32	-35	-18
	W: FP TOT SiltClay			-9		-66	-63		-68	-65	-74
	FP Sedimentation						-65	-24	-68	-65	-73
	Average salinity								28		
Scenario 2040	D: Average sediment load	-99	-77	23	-85	-93	-91				
	T1: Average sediment load	-100	-82	-41	-79	-98	-98				
	W: Average sediment load	-91	-87	-56	-60	-97	-95				
	T2: Average sediment load	-98	-88	-31	-69	-97	-94				
	W: Average sediment onset	7	0	0	3	-3	-18				
	W: Average sediment duration	-41	-3	12	-13	8	13				
	D: Average Total Phosphorous	-51	-67	-42	-9	-60	-58		-69	-68	-70
	W: Average Total Phosphorous	-19	-9	-11	-11	-66	-69		-66	-68	-53
	D: Average Total Nitrogen	-23	-44	-27	-17	-20	-17		-39	-42	-52
	W: Average Total Nitrogen	-17	14	10	-22	-52	-61		-59	-58	-25
	W: FP TOT SiltClay			-9		-97	-97		-97	-97	-94
	FP Sedimentation						-97	-56	-97	-97	-94
	Average salinity								20		
Scenario 2040CC	D: Average sediment load	-99	-54	9	-85	-96	-93				
	T1: Average sediment load	-100	-61	-38	-73	-98	-98				
	W: Average sediment load	-93	-75	-48	-59	-96	-95				
	T2: Average sediment load	-98	-71	-20	-70	-92	-97				
	W: Average sediment onset	10	2	3	7	3	2				
	W: Average sediment duration	-40	11	18	-11	1	37				
	D: Average Total Phosphorous	-51	-70	-46	-10	-61	-40		-15	27	-61
	W: Average Total Phosphorous	-19	-16	-14	-11	-67	-65		-57	-48	-3
	D: Average Total Nitrogen	-23	-55	-40	-17	-20	8		73	136	-31
	W: Average Total Nitrogen	-17	-21	-25	-20	-62	-49		-43	-28	42
	W: FP TOT SiltClay			-13		-97	-96		-96	-96	-91
	FP Sedimentation						-96	-54	-96	-96	-91
	Average salinity								36		

Less than 2007				More than 2007		
<-70%	-40 to -70%	-20 to -39%	-19 to+19	+20 to +39%	+40 to +70%	>70

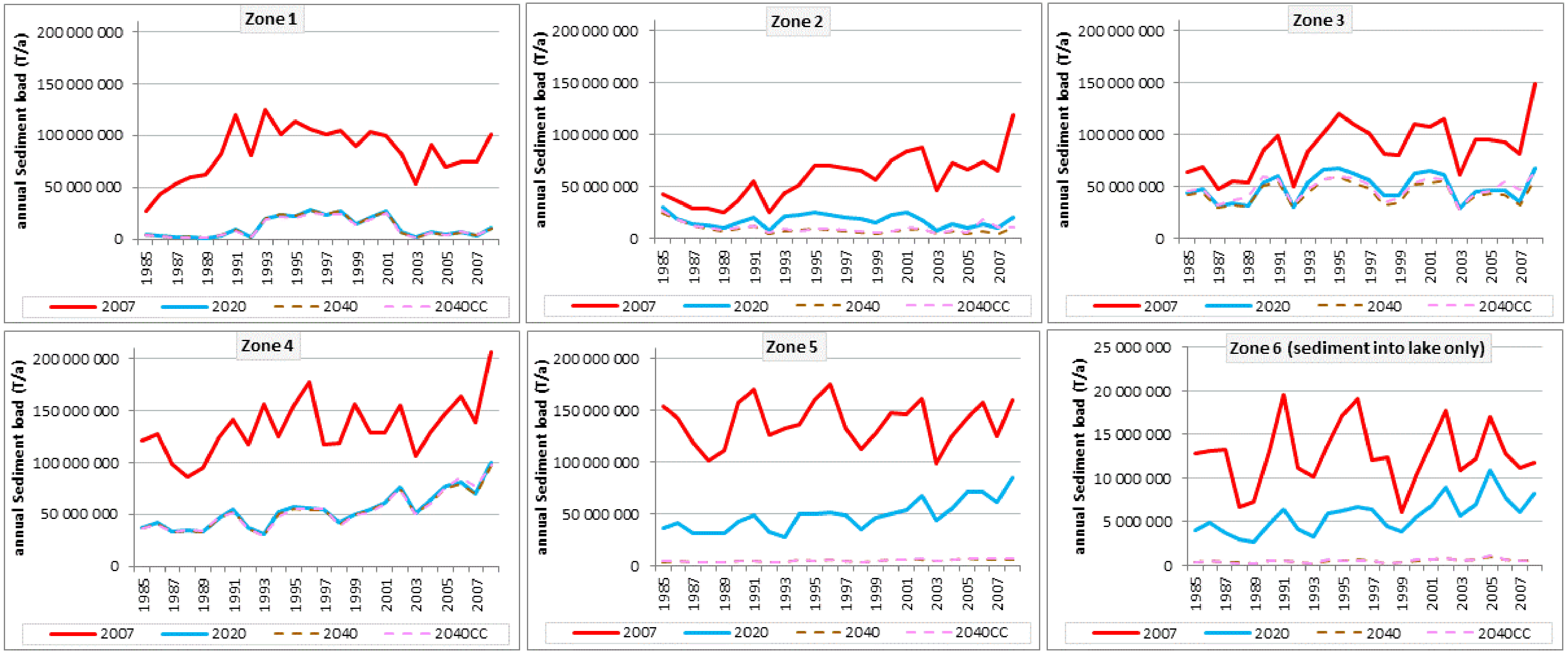


Figure 4.6 Modelled sediment loads in Zone 1 - 6 for 2007, 2020, 2040 and 2040CC. Note: The y-axis for Zone 6 has a different scale from the y-axis on the other plots, and shows the amount of sediment delivered into the lake under the different scenarios.

Scenario 2020 sediment results show the predicted effects of the Lancang cascade, Xayabury and over 70 tributary hydropower projects[51]. The mainstream projects of Xayabury and Don Sahong, as well as many of the tributary projects included in Scenario 2020, will be commissioned after 2017. Thus, Scenario 2020 does not reflect present (2017) conditions in the LMB, but predicts the large decreases in sediment transport that will occur from 2017 to 2020 as these projects come on line.

Roles of sediment in river systems

Fine and coarse sediments have different roles in the Mekong River and different transport regimes. Fine-sediments (silts and clays) transport the majority of nutrients through the river system, and once suspended in the river's flow tend to stay in suspension unless deposited on floodplains. Once discharged to the sea, this fine material underpins the productivity of coastal ecosystems. Fine sediments also control the amount of light that can penetrate into the water column, and thus indirectly control the growth of algae and other aquatic plants. This fine-grained material is more readily transported through impoundments, but the Council Study modelling results suggest that most will be captured in impoundments under Scenario 2040.

In contrast, coarse sediments (sands and gravels) are only transported episodically when river energy is high enough to carry the larger grain sizes, and can take many years to reach the Delta. During this journey to the sea, the sands and gravels maintain channel stability, and provide a mosaic of aquatic habitats, such as the gravel beds where fish spawn and the sandbanks where reptiles and birds build their nests. The continuous delivery of coarser material to the Delta is also critical for maintaining Delta and coastal stability.

The additional decrease in sediment loads in Zone 5 in Scenario 2040 is attributable to the nine additional mainstream dams, three of which are located in the lower reaches of Zone 4 or upper reaches of Zone 5, and additional tributary projects. The large impoundment associated with the proposed Sambor HPP is projected to have a highly efficient sediment trapping rate, and will remove fine grained (silt-sized) material as well as sand (Figure 4.5).

Nutrients in the LMR are closely linked to sediment supply[52], and the Council Study modelling team assumed ~66% of the total nutrient load would be captured in the impoundments along with the sediments because much of the nutrients are adsorbed onto the sediments. As a result, the nutrient concentrations in the river follow similar trends to those reported for sediments (Table 4.5).

The weight of material deposited on floodplains is also projected to decrease under the development scenarios at similar levels to the sediment loads (Table 4.5; Figure 4.7). The 2020 development scenario will cause the greatest loss of sediment tonnage on floodplains, with a further decrease under Scenario 2040, similar to the changes recorded in sediment loads in Zone 5. The amount of time that sediments will be depositing on floodplains is also predicted to decrease. Together, these will reduce the amount of nutrients arriving on floodplains and the productivity of the floodplains, and thus affect both wild ecosystems and floodplain agriculture.

51 With no sediment mitigation measures in place.

52 Kummu, M., Penny, D., Sarkkula, J. and Kopenen, J. 2008. Sediment: Curse or Blessing for Tonle Sap Great Lake? Ambio, 37(3): p 158; Koehnken, L. 2012. IKMP Discharge and Sediment Monitoring Program Review, Data Analysis and Recommendations. MRC Report. 75pp.

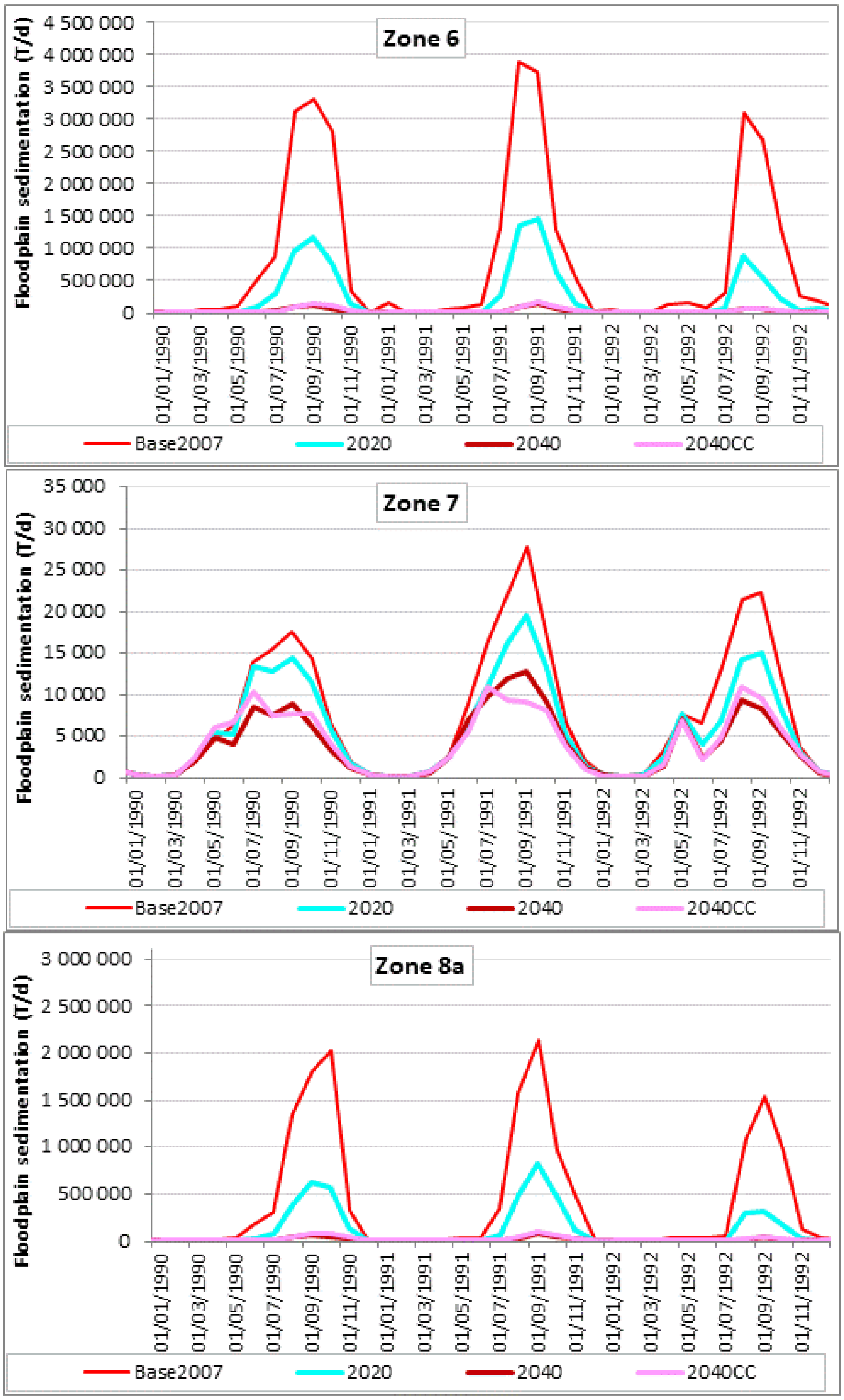


Figure 4.7 Three years of modelled floodplain sedimentation at Zone 6-8a for 2007, 2020, 2040 and 2040CC

4.2.3 Salinity

Salinity is a key driver of plant and animal distributions, and many freshwater species are highly intolerant of salt content in the water.

Salinity is expressed in two ways in (Table 4.5 and Table 4.6), as average annual salinity (expressed g/l) and as areas with different salinity characteristics (expressed in km^2), such as the area where salinity concentrations are never greater than 1 g/l (Salinity<1g/l all yr). As expected, Table 4.5, shows that the bigger areas with the higher salinity concentrations tend to be located in Zone 8c, nearest to the sea.

In the modelled inputs, the ***extent*** of the Delta suitable for habitation by different species changes across the three main scenarios, for instance, freshwater habitats (Area Salinity<1g/l all yr) increase by ~12%, ~3% and ~4%, whereas more saline areas (e.g., Area Salinity>4g/l (1-4 month)) decrease by ~17%, ~10% and ~12%, respectively.

4.3 BioRA results

Up until now discussion has focused on the modelled changes to the flow, hydraulics, sediment and water quality as provided by the Modelling Team. The BioRA DSS 'responds' to the difference between the modelled values for the baseline and those for the water-resource development scenarios. Every change predicted by the BioRA DSS can be linked back to one or more of these modelled changes, so the accuracy of the modelled results is paramount to the accuracy of the BioRA predictions.

The following sub-sections present the mean predicted outcome for each BioRA indicator under the main development scenarios for the unimpounded sections of the mainstream Mekong. The estimated uncertainty ranges for the predictions presented here are provided in Appendix C. These inherent uncertainties meant that the trends and relative position of the scenarios are more reliable predictors of the impacts of the scenarios than are their absolute values (see Appendix A).

Section 5 presents the predicted outcome for each BioRA indicator the reaches of the river that will be inundated by the main channel dams included in the scenarios.

Section 6 summarises the nett changes in response to the main development scenarios (i.e., for river and impounded reaches combined in the form of changes in key composite indicators, and changes in overall condition (health) of the river ecosystem.

4.3.1 Indicators dealing with erosion and the availability of habitats

The presence, size and location of river and floodplain habitats, such as bedrock outcrops, sand banks and bars, mud flats and marshes, are determined by the interactions between the flow of water, the sediment load and the characteristics of the zone (e.g., geology, slope, land use).

Sediments, erosion and habitat availability

The predicted changes in habitats are largely driven by the expected increase in erosion, which directly affects, for instance, the amount of sandy versus rocky habitat and the depth of pools. In the context of the LMB, erosion is primarily driven by shear stress which is the force of flowing water acting on the river bed that mobilises sediment. Shear stress in the river changes slightly with increased development in response to changes in the distribution of Wet and Dry season flows, but the big change is the dramatic reduction in sediment supply across all scenarios but greatest in Scenario 2040 (Section 4.2.1). The amount of sediment being transported in suspension affects the availability of sediment for deposition or the potential for erosion. Water that is transporting high sediment loads has less energy to erode and transport additional sediment, and there is a greater likelihood that sediment will be available for deposition as shear stress decreases. Based on this, there is a negative relationship between sediment loads and erosion, with erosion increasing as sediment loads decrease. Sediment supply exerts a greater influence on erosion during the wet, T1 and T2 seasons as these are the periods when the majority of the sediment is transported and shear stresses are highest.

Sediment concentration, and hence load, is substantially altered between the 2007 Baseline and the development Scenarios 2020 and 2040, as the modelling predicts little change to the flow regime but major decreases in sediment supply. As described in the text box, these changes will lead to increased erosion of sediment from river banks and channels as similar amounts of river energy will be available to transport sediment, but the amount of sediment available transport will be greatly reduced.

The changes are captured in the erosion predictions in Table 4.7, which show increases in erosion in all zones. The inter-zone variability in the erosion results is attributable to the differences in shear stress and the relative rate of sediment decline in the different zones. For example, in Zone 1, shear stress is very high (Table 4.5) and the decline in sediment is also very high (Figure 4.5), where as in Zone 3 the initial shear stresses are low and the decline in sediment is much less, and even increases in the Dry season.

Bed sediment grain size is closely linked to sediment supply and erosion, and is expected to increase between 2007 Baseline and Scenarios 2020 and 2040 because sediment moved downstream by the river will not be replaced from upstream.

The changes in erosion will affect sandy and rocky habitats in and alongside the river channel. Table 4.7 indicates that under Scenarios 2020 and 2040, the exposure and availability of rocky habitats are predicted increase and sandy habitats to decrease because the enhanced erosion is will erode sediments, such as sand and silt, exposing the underlying bedrock or large boulders. This is expected to be greatest in Zone 1, which is by far the steepest section of the study area. In Zone 1, sandy habitats are expected to drop by between ~55 and ~75%, and rocky habitats are expected to increase by between ~45 and ~60% (Table 4.7). The extent of exposure of both (sandy and rocky) habitats in the Dry season will reduce slightly under Scenarios 2020 and 2040 because of the increased Dry season flows increasing water levels and inundating more of these habitats as compared to 2008. Concomitantly, the availability of inundated habitats is expected to increase. However, the effects of water-level changes are secondary compared to the impacts of erosion.

Table 4.7 Geomorphological indicators: Mean predicted change for Scenarios 2020, 2040 and 2040CC as a percentage of 2007 Baseline in the river sections

Zone	Indicator	Zone 1	2	3	4	5	6	7	8
Scenario 2020	Erosion (bank / bed incision)	120	40	25	35	60	-5		
	Average bed sediment size in the Dry season	135	65	45	65	70	-10		
	Availability exposed sandy habitat in Dry season	-55	-20	-15	-15	-30			
	Availability inundated sandy habitat in Dry season	-75	-15	-10	-15	-20			
	Availability exposed rocky habitat in Dry season	60	30	10	20				
	Availability inundated rocky habitat in Dry season	45	20	10	20				
	Depth of bedrock pools in Dry season	15	10	0	15	20			
	Water clarity	60	10	0	15	10	15		
Scenario 2040	Erosion (bank / bed incision)	120	70	25	35	80	45		
	Average bed sediment size in the Dry season	135	95	55	65	110	-5		
	Availability exposed sandy habitat in Dry season	-55	-35	-10	-15	-45			
	Availability inundated sandy habitat in Dry season	-75	-25	-10	-15	-30			
	Availability exposed rocky habitat in Dry season	60	45	10	20				
	Availability inundated rocky habitat in Dry season	45	30	10	20				
	Depth of bedrock pools in Dry season	15	15	0	10	20			
	Water clarity	60	55	0	15	75	50		
Scenario 2040CC	Erosion (bank / bed incision)	120	65	20	40	80	55		
	Average bed sediment size in the Dry season	135	90	50	65	115	-15		
	Availability exposed sandy habitat in Dry season	-55	-35	-15	-20	-45			
	Availability inundated sandy habitat in Dry season	-75	-25	-10	-20	-30			
	Availability exposed rocky habitat in Dry season	60	40	10	20				
	Availability inundated rocky habitat in Dry season	45	30	10	25				
	Depth of bedrock pools in Dry season	15	15	-5	15	25			
	Water clarity	60	55	0	15	75	50		

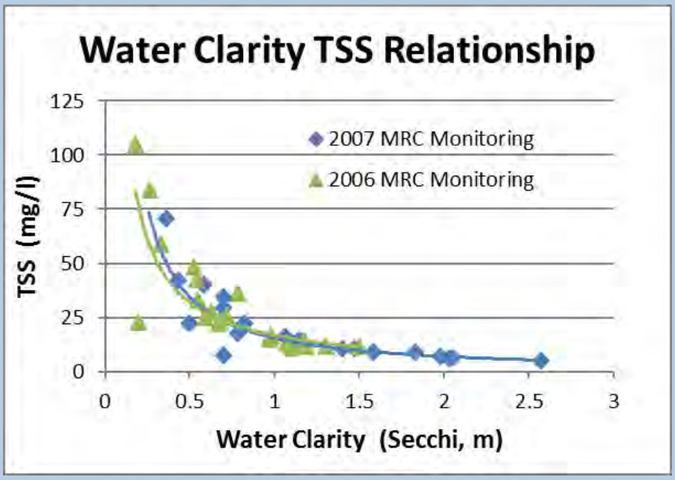
Less than 2007				More than 2007		
<-70%	-40 to -70%	-20 to -39%	-19 to+19	+20 to +39%	+40 to +70%	>70

The predictions of lower sediment supply combined with relatively unchanged river energy will combine to maintain and possibly deepen the deep pools that provide dry season refuge for fish and other species (Table 4.7). The slightly greater deepening in the Zones 4 and 5 under Scenario 2040CC is attributable to the increased flow in the late Wet season that would increase shear stress and erode additional sediment from the pools, and increase water depth.

The large reduction in sediment concentrations is predicted to increase water clarity in all zones under Scenarios 2020 and 2040 (Table 4.7), which will affect processes such as algal growth (see Section 4.3.2).

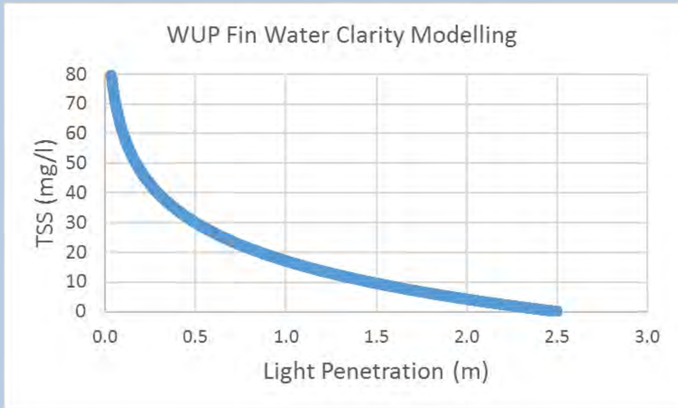
Water clarity and sediment concentration

Water clarity is important for ecosystem process as it controls the penetration of light that can affect plant growth and water temperature. Water clarity is determined by the concentration and characteristics of suspended material in the water column. Fine-grained sediments with high surface area will decrease water clarity at a proportionately greater rate as compared to the same quantity of coarser sediment.



The MRC Model did not provide water clarity for zones 1 through 6 so a general relationship between water clarity and sediment concentration was derived based on MRC monitoring results from the Aquatic Health monitoring program, and a regionally derived conversion factor for converting turbidity to Total Suspended Solids[53].

The graph shows this relationship, and it is evident that water clarity decreases rapidly at TSS concentrations below ~50 mg/L. The BioRA water clarity results are based on this relationship, with a threshold value of 50 mg/l sediment concentrations used to determine changes to water clarity; once sediment concentrations from the MRC model decrease below this threshold, water clarity increases rapidly. This accounts for the very large increases predicated in some zones.



In Zones 7 and 8, water clarity was provided by the Modelling Team. The relationship between sediment concentration and light penetration in these zones is shown in the graph to the right, and is consistent with large increases in light penetration occurring once sediment concentrations drop below 50 mg/L.

4.3.2 *Indicators dealing with riverine and wetland vegetation*

The predicted changes in physical and chemical attributes of the river ecosystem are expected to affect plants growing in and alongside the Mekong River, and on its floodplains, in a complex way that will benefit some groups of plants and prejudice others.

---

53 Zeigler, A.D. Benner, S.G. Tantasirin, C. Wood, S.H. Sutherland, R.A., Sidle, R.C. Jachowski, N. Nullet, M.A. Xi, L.X. Snidvongs, A. Giambelluca, T.W. and Fox, J.M. 2014. Turbidity based sediment monitoring in northern Thailand: Hysteresis, variability and uncertainty. Journal of Hydrology. 519:2020-2039.

The predicted changes in abundance from 2007 Baseline for the vegetation in the non-inundated parts of the river under the main scenarios are shown in Table 4.8. One of the most noteworthy predictions for these reaches is the loss of floodplain vegetation, particularly in Zones 5 and 6. Under Scenario 2020, for instance, a ~35% reduction in herbaceous marsh is predicted for Zone 5, and a ~50% reduction under Scenario 2040. The changes would be driven by the reduced flooding of the floodplains, but also by flood protection infrastructure and conversion of riparian areas for cultivation. Wetland vegetation needs periodic flooding and those areas that no longer flood annually will become drier with increased invasion of terrestrial vegetation including non-native species such as *Mimosa pigra* (represented by the indicator 'Extent invasive riparian vegetation' in Table 4.8; Figure 4.8). This is potentially problematic as these plants have been known to completely dominate areas, reducing their usefulness as natural habitats and as agricultural areas.

Figure 4.8 *Mimosa pigra*[54]

Predictions of how freshwater algae could change are difficult at any time and especially with the level of information available here. Algae could increase in abundance if the water becomes clearer and light penetrates deeper, but also tend to decrease if nutrients are reduced as could happen with lower sediment loads.

On balance, it is highly likely that the reduction in suspended sediments, together with an increase in water clarity and thus light penetration, would favour higher levels of algal growth in Zones 1 and Zone 5. There, baseline sediment concentrations are already near to the threshold below which water clarity increases rapidly (see text box). In Zones 3 and 4[55], however, water clarity is not expected to be greatly enhanced by the reduction in sediments and so the expected increased erosion and loss of nutrients should lead to a decline in algae[56]. Since algae are the base of the food chain for many animals, changes in their abundance are expected to affect, for instance, snails, fish and birds.

[54] Nguyen Thi Thu Hong, Vo Ai Quac, Tran Thi Kim Chung, Bach Van Hiet, Nguyen Thanh Mong and Phan The Huu 2008 *Mimosa pigra* for growing goats in the Mekong Delta of Vietnam. Proceedings MEKARN Regional Conference 2007: Matching Livestock Systems with Available Resources (Editors: Reg Preston and Brian Ogle), Halong Bay, Vietnam:25-28 November 2007 http://www.mekarn.org/prohan/hong_agu.htm.

[55] And to a lesser extent Zone 2.

[56] This assumes that nutrients will decline in line with the modelled predictions and that nutrients are a limiting factor in algal growth in those zones.

Table 4.8 Vegetation: Mean predicted change for Scenarios 2020, 2040 and 2040CC as a percentage of 2007 Baseline in the river sections

Zone	Indicator	Zone							
		1	2	3	4	5	6	7	8
Scenario 2020	C: Riparian trees	5	5	5	5				
	C: Extent upper bank vegetation	-10	-15	-15	-15				
	C: Extent lower bank vegetation	10	-10	-5	-15				
	C: Extent herbaceous marsh		5	5					
	C: Weeds, grasses on sandbanks and sandbars	-10	0	5	0	-5			
	C: Biomass freshwater algae	20	-5	-10	-5	-5	5		
	FP: Extent of flooded forest			-20		-5	-10	-10	-40
	FP: Extent of herbaceous marsh			-15		-20	-15	-10	-15
	FP: Extent of grassland			-10		-20	-20	-5	-25
	FP: Biomass freshwater algae			-10		0	0	0	-5
	Biomass marine algae								0
	Extent invasive riparian vegetation	10	10	15	5	20	20	15	50
	Extent invasive floating/submerged vegetation	0	0	10	10	10	10	5	0
	Indigenous vegetation biomass	0	-10	-10	0	-15	-15	-10	-35
	Overall vegetation biomass	0	-10	5	0	0	-5	-5	-5
Scenario 2040	C: Riparian trees	5	5	5	5				
	C: Extent upper bank vegetation	-10	-20	-20	-20				
	C: Extent lower bank vegetation	10	-5	-5	-15				
	C: Extent herbaceous marsh		5	10					
	C: Weeds, grasses on sandbanks and sandbars	-10	-5	5	0	-10			
	C: Biomass freshwater algae	20	20	-10	-5	45	15		
	FP: Extent of flooded forest			-25		-10	-30	-15	-50
	FP: Extent of herbaceous marsh			-20		-25	-30	-20	-30
	FP: Extent of grassland			-10		-30	-25	-15	-35
	FP: Biomass freshwater algae			-10		25	-5	0	-15
	Biomass marine algae								-5
	Extent invasive riparian vegetation	10	10	20	5	25	35	20	55
	Extent invasive floating/submerged vegetation	0	0	15	10	10	10	5	0
	Indigenous vegetation biomass	0	-5	-10	0	-20	-30	-15	-45
	Overall vegetation biomass	0	-5	5	5	-5	-10	-10	-10
Scenario 2040CC	C: Riparian trees	0	0	0	0				
	C: Extent upper bank vegetation	-10	-15	-15	-15				
	C: Extent lower bank vegetation	10	-5	-5	-15				
	C: Extent herbaceous marsh		10	10					
	C: Weeds, grasses on sandbanks and sandbars	-15	-5	0	-5	-10			
	C: Biomass freshwater algae	20	15	-15	-5	45	15		
	FP: Extent of flooded forest			-25		-5	-20	-10	10
	FP: Extent of herbaceous marsh			-15		-25	-25	-15	5
	FP: Extent of grassland			-5		-25	-25	-10	-30
	FP: Biomass freshwater algae			-15		25	-5	0	-15
	Biomass marine algae								-40
	Extent invasive riparian vegetation	15	20	20	10	20	30	20	-15
	Extent invasive floating/submerged vegetation	0	0	10	10	10	10	0	5
	Indigenous vegetation biomass	0	0	0	0	-20	-25	-10	-10
	Overall vegetation biomass	0	-10	5	0	-5	-10	-5	-5

Less than 2007						More than 2007
<-70%	-40 to -70%	-20 to -39%	-19 to+19	+20 to +39%	+40 to +70%	>70

4.3.3 Indicators dealing with aquatic macroinvertebrates

Aquatic macroinvertebrates are small animals without backbones, and include insects, crustaceans, snails, mussels and various types of worms. Many macroinvertebrates are benthic, living on the bed of the river, from the edges (littoral) through to the bottom of even the deepest pools. Others are planktonic, floating freely in the water column. They are a vital component of the food chain in the river ecosystem, providing food for many fishes, frogs, birds and other animals. They are also a major component of aquatic animals other than fish (other aquatic animals or OAAs) that underpin many economic and social activities in the LMB[57].

The mean predicted percentage changes from 2007 Baseline of macro-invertebrates under the main development scenarios are linked to habitat and food availability (Table 4.9). For instance, many insects and other invertebrates, such as aquatic snails feed mainly on algae[59] and so they are expected to increase in response to the predicted increase in algae (Section 4.3.2). At the same time, many invertebrates will be negatively affected by erosion, which will remove them and their habitats.

Macrobrachium prawns are expected to increase under Scenario 2020 for this reason, but to decrease in abundance sharply in Zone 4 under Scenario 2040 because downstream dams in this scenario will block their breeding migration to brackish water.

Macrobrachium prawns

Macrobrachium is a genus of freshwater prawns of which there are at least seven species in the LMB. One of the species, *Macrobrachium lanchesteri*, is abundant from above the Delta to Khone Falls. It is widely used by people as food, and completes its lifecycle entirely within freshwater. A second, larger species, *Macrobrachium rosenbergii*, is known as the giant river prawn. Adults can grow to a length of 32 cm and are highly prized by fishers. The species occurs naturally only downstream of Khone Falls as the females must move downstream to brackish waters in the Delta to reproduce or the larvae will not survive[58]. The need for a reproductive migration makes them susceptible to disruption by barriers between Khone Falls and the Delta. Temporary populations, populated by escapees from upstream aquaculture farms (mainly in Thailand), have established.

Similarly bivalves, which require sediment-rich environments to thrive, are predicted to decline due to the reduction in habitat availability and quality.

57 Hortle, K.G. 2007. Consumption and the yield of fish and other aquatic animals from the Lower Mekong Basin: Mekong River Commission, Vientiane, Lao PDR.
58 D'Abramo, L.R. and Brunson, M.W. 1996. Biology and Life History of Freshwater Prawns. SRAC Publication No. 483.
59 Cummins, K.W. and Klug, M.J. 1979. Feeding ecology of stream invertebrates. Ann. Rev. Ecol. Syst., 10:147-172.

Table 4.9 Macroinvertebrates: Mean predicted change for Scenarios 2020, 2040 and 2040CC as a percentage of 2007 Baseline in the river sections

Zone	Indicator	Zone							
		1	2	3	4	5	6	7	8
Scenario 2020	Insects on stones	15	10	0	0	-5			
	Insects on sand	5	5	0	0	5			
	Burrowing mayflies	-70	-15	-20	-35	-20			
	Aquatic snails	10	0	-5	0	5	-5	-5	-5
	Aquatic snail diversity	-50	-10	-15	-5	-20	0	-5	-5
	Neotricula aperta			-5	0	15			
	Bivalves	-90	-35	-30	-40	-55	-5	-5	-5
	Polychaete worms								-5
	Shrimps and crabs	5	15	0	-5	-5	-5	-10	-5
	Macrobrachium prawns				-15	15	5	-5	
	Littoral invertebrate diversity	-40	25	10	-5	-10	0		-5
	Benthic invertebrate diversity	-45	-5	-10	-20	-30	-5	-10	-5
	Zooplankton abundance	5	0	-5	-5	-10	-10	-10	-5
	Benthic invertebrate abundance							-10	
Scenario 2040	Insects on stones	15	15	0	5	-10			
	Insects on sand	5	10	0	0	15			
	Burrowing mayflies	-70	-35	-25	-35	-40			
	Aquatic snails	10	5	-5	5	10	-5	-5	-10
	Aquatic snail diversity	-50	-10	-20	-5	-25	-25	-5	-10
	Neotricula aperta			-5	0	25			
	Bivalves	-90	-55	-40	-35	-100	-10	-5	-10
	Polychaete worms								-10
	Shrimps and crabs	5	5	0	-5	5	-10	-5	-10
	Macrobrachium prawns				-90	20	5	-5	
	Littoral invertebrate diversity	-40	20	10	-5	-15	-20		-10
	Benthic invertebrate diversity	-45	-30	-15	-20	-50	-5	-5	-10
	Zooplankton abundance	5	0	-5	-5	0	-20	-5	-10
	Benthic invertebrate abundance							-5	
Scenario 2040CC	Insects on stones	15	15	0	0	-10			
	Insects on sand	5	10	0	0	15			
	Burrowing mayflies	-70	-30	-25	-35	-40			
	Aquatic snails	10	5	-5	0	15	-5	-10	0
	Aquatic snail diversity	-50	-10	-20	-5	-20	-30	-15	0
	Neotricula aperta			-5	0	25			
	Bivalves	-95	-50	-40	-40	-100	0	-15	0
	Polychaete worms								5
	Shrimps and crabs	5	10	0	-5	5	-5	-25	0
	Macrobrachium prawns				-90	25	5	-15	
	Littoral invertebrate diversity	-40	30	5	-5	-15	-25		0
	Benthic invertebrate diversity	-40	-20	-15	-20	-50	-5	-25	0
	Zooplankton abundance	5	5	-5	0	0	-10	-20	0
	Benthic invertebrate abundance							-20	

Less than 2007				More than 2007		
<-70%	-40 to -70%	-20 to -39%	-19 to+19	+20 to +39%	+40 to +70%	>70

4.3.4 Indicators dealing with fish

Many fish species are sensitive to changes that can occur with development. They are affected by changes in the timing of the flow seasons as these provide important cues in their life cycles; and by reductions in the area of inundated floodplains where their young feed and grow. Changes in the size or distribution of sediments could compromise breeding and feeding habitats, changes in the abundance of algae and macroinvertebrates could affect some fish species for whom these are primary food sources[60], and changes in salinity profiles could affect the presence of marine and estuarine fishes. Migratory species unable to move freely along migration routes can show catastrophic declines in numbers (as previously discussed in Section 4.1.2). The kinds of developments that could lead to these impacts are all represented in the Council Study scenarios.

The predicted change in fish relative to 2007 Baseline in the non-inundated parts of the mainstream Mekong River under the main development scenarios are shown in Table 4.10 and Figure 4.10. The characteristic species comprising the fish indicators are listed in Table 4.11.

White fish of the LMB

Fish species that spend most of their lives in turbid (white) river water are known as white fishes. Many of these white fishes migrate long distances to Dry-season refuges. These species tend to be large, fetch higher prices than other fish at market and are thus much prized by fishermen.

The more common white fishes include species such as the river catfish (*Pangasius hypophthalmus*), red-tailed tinfoil (*Barbonymus altus*), lowland river catfish (*Hemibagrus nemurus*), small-scaled croaker (*Boesemania microlepis*), marbled goby (*Oxyeleotris marmorata*) and the giant sheatfish (*Wallago attu*)[61]. They also include less common species such as Julian's golden carp (*Probrabus jullieni*; Figure 4.9.)

Overall, indigenous fish species will decline in numbers while some non-native ones (such as carp and tilapia) will increase. In general, the migratory species are expected to be the worst affected, with some groups almost or completely eliminated upstream of mainstream dams. For instance, Main channel resident (long distance white) species are predicted to decline by ~100% in Zone 1 under Scenario 2020 as a result of the combined barriers effects on sediments and fish of the Lancang Cascade, Xayabury (which was modelled as a 50% barrier to fish- see Section 4.1.2) and >70 tributary dams[62]; but will persist in the lower parts of the LMB. However, they are expected to decline by ~85 to ~100% throughout the system once there are eleven mainstream dams and an addition ~35 tributary dams[63] in place (Scenarios 2040 and 2040CC). Similarly, the anadromous fish are

Figure 4.9 White fish: Julian's golden carp

[60] Migratory species are sensitive to a reduction in nutrients because the juveniles eat algae and the adults each benthic macroinvertebrates that graze on algae.
[61] Hortle, K.G., Lieng, S. and Valbo-Jorgensen, J. 2004. An introduction to Cambodia's inland fisheries. Mekong Development Series No. 4. Mekong River Commission, Phnom Penh, Cambodia. 41 pages. ISSN 1680-4023.
[62] Which is ~double the number present in 2015.
[63] More than 100 in total.

expected to be affected by Scenario 2020, mainly because of changes to their habitat as a result of reduced sediment loads, but are predicted to be eliminated from Zones 3 and 4 under the 2040 scenarios because of blockages to their migration (see Section 4.1 on longitudinal connectivity).

Table 4.10 Fish: Mean predicted change for Scenarios 2020, 2040 and 2040CC as a percentage of 2007 Baseline in the river sections

Zone	Indicator	Zone							
		1	2	3	4	5	6	7	8
Scenario 2020	Rhithron resident	-5	0	10	-5	-20			
	Main channel resident (long distance white)	-100	-90	-80	-65	-60	-50	-30	-60
	Main channel spawner (short distance white)	-85	-45	-45	-25	-30	-30	-20	-55
	Floodplain spawner (grey)			-25	-20	-35	-40	-30	-50
	Floodplain resident (black)			-30	-40	-55	-40	-20	-45
	Eurytopic (generalist)	-15	5	15	-10	-25	-5	-5	0
	Estuarine resident						-30	-20	-20
	Anadromous			-45	-25	-15	-10	-5	-15
	Catadromous				-55	-15	-15	-15	-25
	Marine visitor								0
	Non-native	80	60	30	25	40	40	40	50
Scenario 2040	Rhithron resident	-5	-5	25	-5	-35			
	Main channel resident (long distance white)	-100	-100	-100	-100	-100	-95	-90	-95
	Main channel spawner (short distance white)	-100	-95	-80	-100	-95	-70	-65	-95
	Floodplain spawner (grey)			-15	-25	-45	-60	-60	-80
	Floodplain resident (black)			-15	-35	-70	-70	-40	-85
	Eurytopic (generalist)	5	40	50	30	-5	-10	10	10
	Estuarine resident						-55	-45	-35
	Anadromous			-100	-100	-55	-40	-20	-35
	Catadromous				-95	-35	-30	-20	-40
	Marine visitor								-5
	Non-native	115	110	80	85	90	80	80	95
Scenario 2040CC	Rhithron resident	-5	-5	10	-10	-30			
	Main channel resident (long distance white)	-100	-100	-100	-100	-100	-90	-85	-85
	Main channel spawner (short distance white)	-100	-100	-85	-100	-95	-65	-65	-80
	Floodplain spawner (grey)			-30	-25	-45	-55	-70	-40
	Floodplain resident (black)			-30	-35	-65	-65	-55	-35
	Eurytopic (generalist)	10	40	45	35	-5	-5	0	35
	Estuarine resident						-55	-55	-25
	Anadromous			-100	-100	-55	-30	-15	-15
	Catadromous				-95	-30	-25	-20	-20
	Marine visitor								5
	Non-native	115	115	95	80	85	75	70	70

Less than 2007				More than 2007		
<-70%	-40 to -70%	-20 to -39%	-19 to+19	+20 to +39%	+40 to +70%	>70

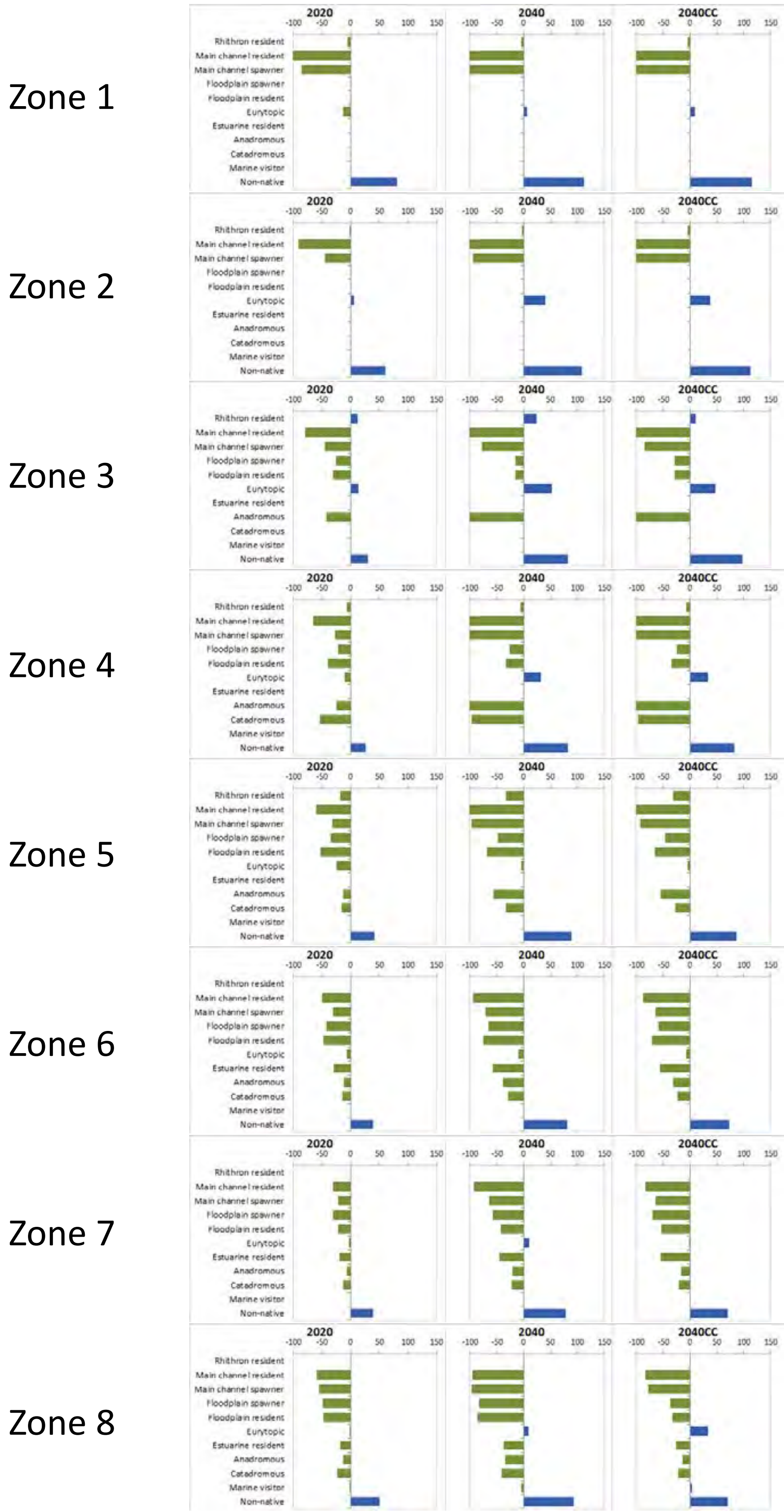


Figure 4.10 Relative predicted change from 2007 Baseline in fish in the BioRA zones (*no response = indicator does not occur in that zone*)

Table 4.11 Characteristic species comprising fish indicators

Indicator Guilds	Indicator species/groups of species
Rhithron resident species	*Chitala blanci; Garra* spp., *Brachydanio* spp., *Devario* spp., *Poropuntius* spp., *Tor spp., Neolissocheilus spp., Osteochilus waandersii, Raiamas guttatus, Opsarius* spp., *Lobocheiros* spp., *Onychostoma* spp.(Lao PDR), *Scaphidonichthys acanthopterus* (Lao PDR), *Mekongina erythrospila* (Zone 1 - 4), *Mystacoleucus* spp., *Homaloptera* spp., *Balitora* spp.; *Nemacheilus* spp., *Schistura* spp., *Akysis* spp., *Pseudobagarius* spp., *Gryptothorax* spp., *Bagarius* spp., *Datnioides undecimradiatus, Rhinogobius mekongianus* (upstream of Stung Treng), *Pao baileyi, P. turgidus.*
Main channel resident (long distant white) species	*Cirrhinus microlepis, Cyclocheilos enoplos, Cosmochirus harmandi, Probarbus jullieni, Pangasianodon hypophthalmus, Pangasius larnardii, P. mekongensis, P. bocourti, P. concophilus.*
Main channel spawner (short distance white) species	*Clupeichthys aesarnensis* (all zones), *Clupeoides borneensis* (all zones), Corica laciniata (Zone 6-8), *Tenualosa thibeaudei, Cirrhinus prosemion, C. jullieni, Hypsibarbus* spp., *Puntioplites falcifer* (upstream of Kratie), *Labeo chrysophekadion, L. pierrei, Sikukia* spp., *Incisilabeo behri, Scaphognathops* spp. (upstream of Kratie), *Barbichthys laevis, Leptobarbus rubripinna, Amblyrhynchichthys micracanthus, Syncrossus* spp., *Yasuhikotakia* spp., *Pangasius macronema, Pseudolais pleurotaenia, Helicophagus leptorhynchus, Walago attu, Phalacronotus* spp., *Kryptopterus* spp., *Acantopsis* spp., *Acanthopsoides* spp. (prefers sandy bottom), *Boesemania microlepis* (Zone 5 and Zone 8 common, upstream of Khone Falls very rare), Gyrinocheilidae, *Auriglobus nefastus.*
Floodplain spawner (grey) species	*Barbonymus altus, B. schwanefeldii, Cyclocheilichthys* spp (*Rasbora* spp., *Paralaubuca* spp., *Parachela* spp., *Thynnichthys thynnoides, Pangio* spp., *Ompok siluroides, Doryichthys boaja* (Zone 5-8), *D. contiguus* (confirmed between Vientiane-Ubon Ratchathani, does not exist downstream of Khone Falls), *Mystus* spp., *Parambassis wolfii, P. apogonoides*, *Pao cambodgiensis, P. suvattii* (upstream of Khone Falls only).
Eurytopic (generalist) species	*Notopterus notopterus*[64], *Chitala ornate, Channa gachua, Gymnostomus* spp., *Barbonymus gonionotus, Systomus orphoides, Crossocheirus* spp., *Osteochirus vittatus, O. microcephalus, Hampala* spp., *Labiobarbus* spp., *Cyclocheilichthys* spp. *Mystacoleucus* spp., *P. proctozysron* (Zone 5, 6 and Zone 8), *Hemibagrus* spp., *Pristolepis fasciata, Mastacembelus* spp. (e.g., *M. favus, M. armatus*), *Macrognathus siamensis, Parambassis siamensis, Oxyeleotris marmorata, Osphronemus exodon*.
Floodplain resident (black)	*Esomus spp., Lepidocephalichthys hasselti, Clarias macrocephalus, C.* cf *batrachus, Oryzias mekongensis, O. songkramensis, O. minutillus, Dermogenys siamensis, Channa striata, C. lucius, C. micropeltes, Anabas testudineus, Trichopodus* spp., *Trichopsis* spp., *Monopterus albus, Macrognathus* spp., *Pao cochinchinensis, P. palustris, P. suvatii*
Estuarine resident species	Plotocidae, Ariidae, Adrianichthidae, Gobiidae, Polynemidae, Cynoglossidae, Soleidae
Anadromous species	*Pangasius krempfi, P. elongatus*, Ariidae
Catadromous species	*Anguilla marmorata, A. Bicolor, Pisodonophis boro*
Marine visitor species	Scombridae, Gerreidae, Ambassiidae, Terapontidae, Sciaenidae, Gobiidae
Non-native species	*Labeo rohita, Cirrhinus cirrosus, Cyprinus rubrifuscus, Piaractus brachypomus, Clarias gariepinus, Pterygoplichthys* spp., *Oreochromis* spp.

[64] *Notopterus notopterus* and *Chitala ornate* occur everywhere. They are often collected in small canals associated with rice fields and even in stagnant water with *Mystus* spp. Thus, they were defined as eurytopics.

The predicted decline in the white fish species will be offset to a degree by a noticeable increase in non-native species and a smaller increase in eurytopic species as these can thrive in a wide range of environments and will also benefit from a drop in white fish numbers. For instance, in Zone 5, non-native species are expected to increase by ~40% under the 2020 scenario and by ~90% under Scenario 2040. This switch from white species to non-native species is already occurring in response to existing developments in the LMB: in 2014/15, in Zone 1, although white fish as a whole still dominated the catch, the most prevalent *species* was the non-native *Cyprinus carpio* (~21% of the catch); and in the Delta, the non-native, *Oreochromis niloticus,* comprised ~7% of the catch[65] (see BioRA Technical Report. Volume 1: Specialists' Report for more detail). It is unlikely, however, that increases in the non-native fish will completely counterbalance the loss of the large indigenous fish, and a reduction in fish biomass, and thus catch, is anticipated in most zones under Scenario 2040. Also, the non-native species are less valuable on the markets than their large indigenous counterparts[66].

In Zones 3 and 4, Floodplain resident (black) are predicted to fare slightly better under 2040 than under 2020 scenario (Table 4.10), because the 2040 Scenarios have higher dry season flows, which increase the availability of dry season habitat and food.

The changes predicted in Table 4.10 and Figure 4.10 are averages for the last 20 years of the reference period, but in reality abundances will fluctuate from year to year in response to wet and dry years (Figure 4.11). In effect, average predicted change may mask prolonged periods when fish abundances, and thus fish catches, are much lower or much higher.

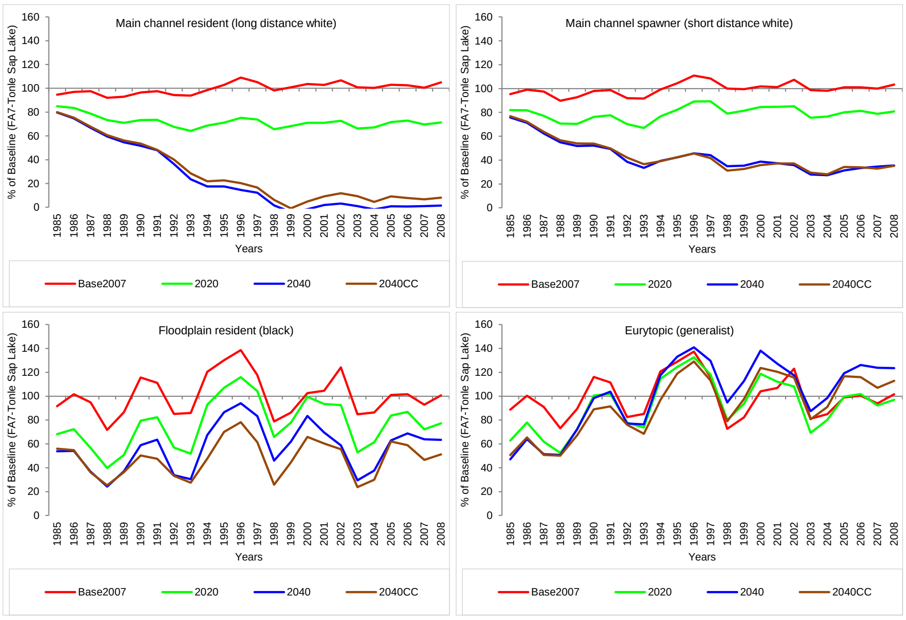


Figure 4.11 Examples of time-series of predictions of change in abundance of selected fish indicators (in Zone 7) under the main development scenarios

---

[65] Source: MRC Fisheries Database
[66] See BioRA Technical Report Series: Volume 1: Specialists' Report

4.3.5 Indicators dealing with herpetofauna

The predicted change in herpetofauna relative to Baseline in the non-inundated parts of the mainstream Mekong River for the main development scenarios are shown in Table 4.12. These animals are both invaluable members of the LMB aquatic ecosystems and major contributors to the OAAs that underpin the diets of the people of the area (see Section 6.1.4).

Table 4.12 Herpetofauna: Mean predicted change for Scenarios 2020, 2040 and 2040CC as a percentage of 2007 Baseline in the river sections

Zone	Indicator	Zone							
		1	2	3	4	5	6	7	8
Scenario 2020	Ranid	0	-15	-10	-5	-10	-10	-10	-20
	Aquatic serpents	-10	-20	-15	-15	-30	-15	-10	-15
	Aquatic turtles		-30	-20	-30	-65	-30	-20	-35
	Semi-aquatic turtles			-20	-25	-35	-25	-10	-40
	Amphibians-human use			-5	-5	-5	-5	-10	-15
	Aquatic/semi-aquatic reptiles-human use			-25	-30	-35	-20	-10	-15
	Species richness of riparian/FP amphibians	-25	-25	-5	-10	-20	-20	-15	-30
	Species richness of riparian/FP reptiles	-40	-50	-15	-35	-55	-45	-15	-40
Scenario 2040	Ranid	0	-10	-15	-10	-10	-15	-10	-25
	Aquatic serpents	5	-5	0	0	-25	-30	-15	-25
	Aquatic turtles		-30	0	-20	-75	-65	-20	-55
	Semi-aquatic turtles			-25	-30	-50	-40	-10	-40
	Amphibians-human use			-10	-10	-10	-10	-15	-25
	Aquatic/semi-aquatic reptiles-human use			-10	-10	-35	-35	-15	-30
	Species richness of riparian/FP amphibians	-25	-30	-10	-10	-30	-40	-20	-50
	Species richness of riparian/FP reptiles	-15	-25	5	-10	-65	-70	-20	-55
Scenario 2040CC	Ranid	0	-15	-15	-15	-5	-10	-10	-10
	Aquatic serpents	5	-5	0	0	-30	-25	-25	0
	Aquatic turtles		-30	0	-20	-75	-65	-30	0
	Semi-aquatic turtles			-20	-30	-55	-55	-5	-40
	Amphibians-human use			-10	-10	-10	-10	-10	-10
	Aquatic/semi-aquatic reptiles-human use			-10	0	-40	-30	-25	-10
	Species richness of riparian/FP amphibians	-30	-35	-10	-20	-20	-35	-15	0
	Species richness of riparian/FP reptiles	-15	-40	0	-15	-55	-70	-20	-10

Less than 2007				More than 2007		
<-70%	-40 to -70%	-20 to -39%	-19 to+19	+20 to +39%	+40 to +70%	>70

The reptiles are more closely linked to the river for their food and habitat requirements, while the amphibians tend to tolerate a broader array of habitats and food. Thus, serpents and turtles are expected to be most affected by the scenarios, with aquatic turtles in remaining river reaches Zone 5 declining by ~65% under Scenario 2020, ~75% under Scenario 2040 and ~75% under Scenario 2040CC; and semi-aquatic turtles declining by ~50%, ~80% and ~55% over the respective scenarios. These animals would respond to the loss of riparian habitat as a result of reduced flooding, reduced sediment delivery and land transformation, and to the predicted decline in fish, which form a major part of their diet. Although the turtles also feed on snails, crustacean and aquatic plants, fish are their main food[67]. Similarly, water snakes are among the top predators, feeding predominantly on fishes and amphibians, reptiles and Crustacea[68]. There is also predicted reduction in floodplain- and riparian-dependant reptiles in the lower river under the development scenarios, which is associated with a loss of vegetated habitat.

4.3.6 Indicators dealing with birds and mammals

The relationship between birds and the Mekong River tends to be less direct than it is for fish, but in common with other riverine biota, birds will be affected by water-resource developments in two main ways: change in river-related habitats and change in availability of food from the river.

Many river-related birds such as waders and terns are dependent on riverine sandbars where they make their nests and lay their eggs[69], which are expected to decline in area and nature with falling sediment supplies. The natural flow seasons also play a role, as nesting takes place on the sand during the drier summer months when the banks are exposed[70]; this is a time when eggs are incubated and chicks hatch but are not yet ready to fly and so are vulnerable to unexpected and unseasonal flows. Other bird species depend on flooded forests (eagles), flooded grasslands (sarus crane, Bengal florican) or the interface between water and land (masked finfoot). Fish and OAAs are major food items of many river-related birds such as fish eagles, fish owls and river terns, and their numbers are expected to decline if fish numbers fall.

The predicted changes in birds relative to 2007 in the non-inundated parts of the mainstream Mekong River under the main development scenarios are shown in Table 4.13. Essentially, the birds are minimally affected by Scenario 2020 and more severely affected by Scenario 2040. Two groups of birds would potentially be most affected under the scenarios. Tree-nesting large waterbirds rely

---

67 Das, I. 2008. Pelochelys cantorii Gray 1864 – Asian giant soft-shell turtle. In: Rhodin, A.G.J., Pritchard, P.C.H., van Dijk, P.P., Saumure, R.A., Buhlmann, K.A., and Iverson, J.B. (Eds). Conservation biology of freshwater Turtles and Tortoises: A Compilation project of the IUCN/SSC Tortoise and Freshwater Turtle Specialist Group. Chelonian Research Monograph, 5: 011.1-011.6; Auliya, M., van Dijk, P.P., Moll, E.O., and Meylan, P.A. 2016. Amyda cartilaginea (Boddaert 1770) – Asiatic soft-shell turtle. In: Rhodin, A.G.J., Pritchard, P.C.H., van Dijk, P.P., Saumure, R.A., Buhlmann, K.A., Iverson, J.B. and Mittermeier, R.A (Eds). Conservation biology of freshwater Turtles and Tortoises: A Compilation project of the IUCN/SSC Tortoise and Freshwater Turtle Specialist Group. Chelonian Research Monograph, 5(9): 092.1-092.17.

68 Voris, H.K. and Murphy, J.C. 2002. The prey and predators of Homalopsine snakes. J. Natural History, 36:1621-1632.

69 Goes, F. 2013. The Birds of Cambodia: An Annotated Checklist. Centre for Biodiversity Conservation, Fauna and Flora International Cambodia Programme and Royal University of Phnom Penh.

70 Casey, D., Wood, M. and Mundinger, J. 1985. Effects of Water Levels on Productivity of Canada Geese in the Northern Flathead Valley: Annual Report 1984. Montana Department of Fish, Wildlife and Parks; McDonald, P.M. and Sidle, J.G. 1992. Habitat changes above and below water projects on the North Platte and South Platte Rivers in Nebraska. Prairie Naturalist, 24: 149-158; Schwalbach, M.J., Higgins, K.F., Dinan, J.J., Dirks, B.J. and Kruse, C. D. 1993. Effects of water levels on interior Least Tern and Piping Plover nesting along the Missouri River in South Dakota. Pp. 75-81. In: Higgins K. F. and M. R. Brashier (eds.) Proceedings of the Missouri River and its tributaries: Piping Plover and Least Tern symposium. South Dakota State University. Brookings, South Dakota; Tibbs, J.E. and D.L. Galat. 1998. The influence of river stage on endangered Least Terns and their fish prey in the Mississippi River (USA). Regulated Rivers: Research and Management, 14: 257-266; Sidle, J.G., Carlson, D.E., Kirsch, E.M. and Dinan, J.J. 1992. Flooding: Mortality and habitat renewal for Least Terns and Piping Plovers. Colonial Waterbirds, 15(1): 132-136; Leslie, D.M. Jr., Wood, G.K. and Carter, T.S. 2000. Productivity of endangered Least Terns (*Sterna antillarum athalassos*) below a hydropower and flood-control facility on the Arkansas River. The Southwestern Naturalist, 45 (4): 483-489.

on riparian trees and certain fish species; their numbers are expected to decline by ~30% in Zone 4 under Scenario 2020, and by ~85% in Scenario 2040. Bank/hole nesting species would also be substantially affected by the expected increase in bank erosion. Other groups, such as medium/large ground-nesting channel species, may also be affected by loss of habitat such as exposed sandy banks, but as their baseline numbers in the LMB are already low as a result of other impacts, such as harvesting, the loss of sandy banks for nesting is not thought to be a limiting factor and a reduction in this key habitat is unlikely to have a marked impact on their numbers.

Table 4.13 Birds: Mean predicted change for Scenarios 2020, 2040 and 2040CC as a percentage of 2007 Baseline in the river sections

Zone	Indicator	Zone							
		1	2	3	4	5	6	7	8
Scenario 2020	Medium/large ground-nesting channel species	-10	5	-5	-15				
	Tree-nesting large waterbirds.				-40			-40	
	Bank / hole nesting species	0	0	0	-15	-20	-25	-20	-20
	Flocking non-aerial passerines of graminoid beds				0	-5	-15	-5	-5
	Large ground-nesting species on wetland floodplains							-10	-5
	Channel-using large species in bankside forest				-5			-10	
	Natural rocky crevice nester in channels		10	5	5				
	Dense woody vegetation / water interface				-20			-15	
	Small non-flocking birds of seasonally flooded vegetation	5	0		-15	5	0	-5	
Scenario 2040	Medium/large ground-nesting channel species	-10	5	0	-15				
	Tree-nesting large waterbirds.				-90			-65	
	Bank / hole nesting species	0	0	0	-25	-30	-45	-35	-50
	Flocking non-aerial passerines of graminoid beds				0	-5	-20	-5	-10
	Large ground-nesting species on wetland floodplains							-15	-5
	Channel-using large species in bankside forest				-5			-10	
	Natural rocky crevice nester in channels		15	5	5				
	Dense woody vegetation / water interface				-20			-15	
	Small non-flocking birds of seasonally flooded vegetation	5	5		-10	0	-5	-10	
Scenario 2040CC	Medium/large ground-nesting channel species	-10	10	-5	-15				
	Tree-nesting large waterbirds.				-90			-75	
	Bank / hole nesting species	0	0	0	-25	-30	-40	-45	-20
	Flocking non-aerial passerines of graminoid beds				-5	-5	-20	-5	-5
	Large ground-nesting species on wetland floodplains							-15	-10
	Channel-using large species in bankside forest				-10			-10	
	Natural rocky crevice nester in channels		15	0	5				
	Dense woody vegetation / water interface				-20			-15	
	Small non-flocking birds of seasonally flooded vegetation	5	0		-15	0	0	-10	

Less than 2007				More than 2007		
<-70%	-40 to -70%	-20 to -39%	-19 to+19	+20 to +39%	+40 to +70%	>70

The predicted changes in mammals relative to Baseline in the non-inundated parts of the mainstream Mekong River under the main development scenarios are shown in Table 4.14. The dolphins in Zone 4 are predicted to decline by ~45% under Scenario 2020, and by ~95-100% under Scenario 2040 and 2040CC. This is mainly in response to the decline in fish, which are a major part of their diet. Otters are also predicted to decline in numbers, but to a lesser extent: ~-30-35% under Scenario 2040 and 2040CC for the same reason. They will be less affected than dolphins as they can move away from the river, and have a more varied diet.

Table 4.14 Mammals: Mean predicted change for Scenarios 2020, 2040 and 2040CC as a percentage of 2007 Baseline in the river sections

Zone	Indicator	Zone							
		1	2	3	4	5	6	7	8
Scenario 2020	Irrawaddy dolphin				-45				
	Otters		-45		-20			-40	-40
	Wetland ungulates				-15				
Scenario 2040	Irrawaddy dolphin				-100				
	Otters		-60		-35			-65	-70
	Wetland ungulates				-20				
Scenario 2040CC	Irrawaddy dolphin				-95				
	Otters		-70		-40			-75	-20
	Wetland ungulates				-25				

Less than 2007				More than 2007		
<-70%	-40 to -70%	-20 to -39%	-19 to+19	+20 to +39%	+40 to +70%	>70

More important threats to the mammals are hunting for household consumption and/or trade[71]; accidental entrapment in fishing gear; and degradation/conversion of their terrestrial and wetland habitats[72]. As a result their numbers are already extremely low in the LMB, and dolphins and ungulates are on the brink of local extinction[73].

[71] Beasley, I. 2007. Conservation of the Irawaddy dolphin, *Orcaella brevirostris* (Owen in Gray, 1866) in the Mekong River: biological and social considerations influencing management. PhD Thesis. James Cook University, Australia. http://eprints.jcu.edu.au/2038; Duckworth, J.W. and Hills, D.M. 2008. A specimen of Hairy-Nosed Otter *Lutra sumatrana* from Far Northern Myanmar. IUCN *Otter Spec. Group Bull.*, 25(1): 60- 67; Shepherd, C.R. and Nijman, V. 2014. Otters in the Mong La Wildlife Market, with a First Record of Hairy-Nosed Otter, *Lutra sumatrana*, in Trade in Myanmar. IUCN *Otter Spec. Group Bull.,* 31 (1): 31 – 34; Smith, B. D. and Jefferson, T. A. 2002. Status and conservation of facultative freshwater cetaceans in Asia. Raffles Bulletin of Zoology 173–187.

[72] Dong, T., Tep, M., Lim, S., Soun, S. and Chrin, T. 2010. Distribution of Otters in the Tropeang Roung, Koh Kong Province, Cambodia. IUCN *Otter Spec. Group Bull.*, 27(2); Timmins, R., Duckworth, J.W., Samba Kumar, N., Anwarul Islam, M., Sagar Baral, H., Long, B. and Maxwell, A. 2012. *Axis porcinus*. In: IUCN 2013. The IUCN Red List of Threatened Species. Version 2015.2. <www.iucnredlist.org>. [Accessed on 13 June 2015]; Wilson, D.E. and Mittermeier, R.A. (eds.) 2011. Handbook of the mammals of the world. Vol. 2. Hoofed mammals. *Lynx edicions*. Barcelona WISDOM Mekong. 2010. The 8th Annual Mekong Flood Forum, 26.-27. May 2010, Vientiane, Laos. www.wisdom.caf.dlr.de.

[73] IUCN. 2013. Ecological Survey of the Mekong River between Louangphabang and Vientiane Cities, Lao PDR, 2011-2012. Vientiane, Lao PDR: IUCN. 241pp.

5 Predictions of change for impounded reaches under the main development scenarios

The reservoirs associated with the mainstream dams will change much of the channel habitat that is present at FA2, FA4 and FA5 in Scenarios 2007 and 2020 into deeper, lake-like habitat under the conditions modelled for Scenarios 2040 and 2040CC (see Section 3; Table 5.1). For instance, ~19% of the river in BioRA Zone 2 would be converted to lake-like habitat by Scenario 2020, but this would increase to ~88% in Scenario 2040 (thus, only ~12% of the river in Zone 2 would remain); and those river lengths would be subjected to substantially altered water and sediment flows because of the dams represented within the scenario. The following sections outline the expected implications for the river ecosystem.

Table 5.1 River length in each BioRA zone that would be inundated by mainstream reservoirs in each scenario

BioRA Zone	Length of river represented by zone	2007		2020		2040	
		Length inundated by reservoirs					
	m	m	%	m	%	m	%
Zone 1	167 903	0	0	0	0	68 000	41%
Zone 2	555 800	0	0	104 000	19%	384 000	88%
Zone 3	762 500	0	0	0	0	0[74]	0
Zone 4	521 000	0	0	0	0[75]	230 000	32%
Zone 5	476 000	0	0	0	0	238 000	50%
Zones 6-8	n/a	0	0	0	0	0	0
Total	2 483 203	0	0	104 000	4%	920 000	37%

5.1 Erosion and the availability of habitats

Once a river is impounded, rocky and sandy habitats along its channel are flooded by the reservoir and the bottom of the reservoirs are likely to be covered with fine sediments. The riparian zone of vegetation will be largely drowned, eliminating any refuge that that provides to wildlife. It is unlikely that similar vegetation and habitats will establish around the reservoir because of the unnatural fluctuations of water levels and the greatly reduced deposition of sediments and nutrients; instead there could be a barren zone around the high water mark of the reservoirs, vegetated by whatever

[74] Ban Kum and Latsu are situated in Zone 4, close to the upstream boundary with Zone 3. The models effectively indicate little or no flooding in FA3.Should the designs of Ban Kum and Latsu HPPs be such that some parts of Zone 3 are flooded, they are not accounted for here.
75 Don Sahong reservoir is excluded because it does not flood across the whole channel.

plants can cope with the fluctuations of water levels. Natural riverine habitats would be mostly lost in both the aquatic area and the riparian zone, and some new habitat would become available in the still waters of the reservoir, which could be exploited by some fish and other aquatic species. The reservoirs could become major barriers to the movement of people and terrestrial wildlife, especially if they fill valleys floors and have steep terrain at their edges.

Sediment deltas will develop at the upstream ends of the reservoirs, with the composition and extent dependant on the sediment content of the inflowing water. Reservoirs such as Pak Beng, which is scheduled to be the first mainstream dam in the LMB under Scenario 2040, will likely have higher rates of sediment accretion that reservoirs lower in the cascade. The lower, larger impoundments, such that associated with Sambor HPP, will trap sediments that are transported through the smaller, upstream impoundments.

5.2 Riverine and wetland vegetation

Much of the natural riparian vegetation will be destroyed because it is under water or in newly water-logged soils, which become anoxic and kill the roots[76]. Inundation also prevents the dispersal of seeds or accumulation of organic matter, and so recruitment in the riparian communities is halted. Thus, the herbaceous marsh and upper and lower bank riparian vegetation are expected to be reduced by 90-100% (Table 5.2).

Table 5.2 Vegetation: Expected responses of indicators to change from river to reservoir

Indicator	% change relative to river				
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Channel_Riparian trees	0	0	Not inundated in Development scenarios	-70	-70
Channel_Extent of upper bank vegetation	-100	-100		-100	-100
Channel_Extent of lower bank vegetation	-100	-100		-100	-90
Channel_Extent of herbaceous marsh vegetation	-100	-100		-100	-60
Channel_Weeds and grasses on sandbanks and sandbars	-90	-90		-90	-40
Channel_Biomass of algae	15	15		15	15
Floodplain_Extent of flooded forest					-50
Floodplain_Extent of herbaceous marsh vegetation					-100
Floodplain_Extent of grassland vegetation					-60
Floodplain_Biomass of algae					15
Indigenous vegetation biomass	-90	-90		-90	-70
Overall vegetation biomass	-60	-60		-50	-40
Mangroves					
Marine algae					

76 Nilsson, C. and Berggren, K. 2000. Alterations of riparian ecosystems resulting from river regulation. BioScience, 50 (9): 783-792.

The exception is likely to be Zones 1 and 2, where the river is relatively steep-sided, and so the riparian trees will be outside of the inundation levels (Table 5.2). New vegetation may establish along the shoreline depending on the duration, timing, and frequency of changes in water level[77] and some rooted aquatics, such as *Potamogeton crispus* L., may establish in the shallow areas, but overall the structure of the vegetation, the type of habitats it offers to animals, and its uses for people, will differ markedly from that of the river. While the biomass of indigenous vegetation is expected to be as much as 90% lower in the reservoirs than in the river, the overall vegetation biomass is likely to be about half. This is because non-native vegetation (such as *Mimosa pigra* and *Eichhornia crassipes*) is expected to increase (see Table 4.8).

Predicting how algal biomass would change within a reservoir constructed on the river is difficult, and may not be uniform over the length of the water body. The river turbulence is undoubtedly important in ensuring that water adjacent to algal cells does not become depleted of nutrients, thus stimulating algal growth, but it also ensures that cells spend some of their time deep in the water below the photic zone thus inhibiting growth. Concentrations of chlorophyll in the Mekong are high (although data are limited) indicating that primary production in upstream impoundments is unlikely to be dramatically higher than production in the river.

In the shallow Tonle Sap Lake, algal biomass is lowest in the flood season (3.4 µg/L in 2005) when the lake is filled with turbid Mekong water and highest in the dry season (54 µg/L in 2005) when water levels are low, temperatures relatively high and the water relatively clear. In general, algal measurements in the Lake exceed the highest river measurements[78], which suggests that algal biomass in a shallow reservoir in Zone 5 or 6 is likely to be higher than in the river, but possibly not by very much. However, in localized protected areas of impoundments where sediment deposition rates are high and light penetration is high, algal blooms may persist for the dry season. Algal blooms, should they occur, can be harmful to animals and people, however, as the can lead to foul odours and tastes, deoxygenation of bottom waters, toxicity and fish kills[79].

5.3 Aquatic macroinvertebrates

Groups of macroinvertebrates are expected to respond differently to impoundment depending on the morphology of the impoundment, which is partially dictated by its location within the basin. Impoundments in Zone 1 will be narrow and deep, relative to those in Zones 4 and 5, which will be broad and shallow. For instance, the insects that are mostly important as food for fish and birds live on stones or sand and most will not survive in the reservoir because the bottom will be covered in

[77] Baxter, R.M. 1977. Environmental effects of dams and impoundments. Annual Review of Ecology and Systematics, 8: 255-283.
[78] Say Samal. 2008. Trophic linkage: the importance of microalgae to the fisheries of Boeng Tonle Sap, Cambodia. Ph.D Thesis. School of Biological Sciences, Monash University, Australia.
[79] Paerl, H.W., Fulton, R.S., Moisander, P.H. and Dyble. J. 2001. Harmful Freshwater Algal Blooms, With an Emphasis on Cyanobacteria. The Scientific World Journal, Vol. 1, pp. 76-113, 2001. doi:10.1100/tsw.2001.16.

fine silt[80] (Table 5.3). On the other hand, some of the groups that contribute directly towards the OAA harvest, such as snails, bivalves[81], shrimps[82] and crabs are expected to be more abundant in the reservoirs than in the river. The standing waters of reservoirs also provide excellent habitat for zooplankton[83], which is a critical food item for some fish and thus an important link in the food chain from algae to people[84]. Based on chlorophyll data from Tonle Sap Lake, algal biomass in shallow impoundments in Zones 4 and 5 will be appreciably higher those that in the river during the dry season. Overall, benthic invertebrate biomass will probably be increased in Zones 4 and 5, although the composition will be quite different. Similarly, the amount of insect emergence from the reservoir may be similar to that from the river, but is expected to be comprised of different species, which may affect its value as a food source, and to occur at different times of the year to that in the river, depending on how the impoundment is managed.

Table 5.3 Macroinvertebrates: Expected responses of indicators to change from river to reservoir

Indicator	% change relative to river				
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Insects on stones	-95	-95	Not inundated in development scenarios	-95	-95
Insects on sand	-100	-100		-100	-100
Burrowing mayflies	-100	-100		-100	-100
Aquatic snails	-50	-50		-50	-50
Aquatic snail diversity	-80	-80		-80	-80
Neotricula aperta abundance	-100	-100		-100	-100
Bivalve abundance	-50	-25		50	50
Shrimps and crabs	-25	0		50	50
Littoral invertebrate diversity	-50	-50		-50	-50
Benthic invertebrate diversity	-25	-25		-25	-25
Zooplankton abundance	10	30		100	100
Zooplankton diversity	25	25		25	25
Benthic invertebrate abundance	0	10		20	50

[80] Kondolf, G. M., Gao, Y., Annandale, G.W., Morris, G.L., Jiang, E., Hotchkiss, R., et al. 2014. Sustainable sediment management in reservoirs and regulated rivers: Experiences from five continents. Earth's Future, 2. doi:10.1002/2013EF000184.
[81] Linares, M.S., Calisto, M. and Marques, J.C. 2017. Invasive bivalves increase benthic communities complexity in neotropical reservoirs. Ecological Indicators, 75: 279–285.
[82] Mannini, P., Katonda, I., Kissaka, B. and Verburg, P. 1999. Feeding ecology of *Lates stappersii* in Lake Tanganyika. Hydrobiologia, 407: 131-139.
[83] *Marzolf*, *G. R.* 1990. Reservoirs as environments for zooplankton. In: *Thornton*, *K.W.*, *Kimmel*, *B.L.* and *Payne, F.E.* (*Eds*) *Reservoir Limnology*: *Ecological Perspectives*. *John Wiley* & *Sons*, New York: 195–208.
[84] Carpenter, S.R. and Kitchell, J.F. (Eds) 1993. The Trophic Cascade in Lakes. Cambridge University Prress, Cambridge, UK.

Neotricula aperta, the snail host for Schistosomiasis[85], requires stony substrates and flowing water, and so will not survive in a reservoir[86] (Table 5.3). Invertebrates such as mosquitoes will be unaffected by impoundments. They are rare in the river, or impoundments, or any large water bodies that contain fish. Mosquito-transmitted disease in the lower Mekong occurs primarily in forested and urban areas where there are temporary aquatic habitats such as phytotelmata, and puddles of water in roof gutterings, old tyres and the like which are fish free and where mosquito larvae grow rapidly. Blackfly larvae (Simuliidae) may be abundant downstream of impoundments if there is suitable substrate, such as stones or concrete, for attachment and a current for feeding. They benefit from the algae and seston in the water, which may be at higher concentrations in the outflow from an impoundment than in the free flowing river. However, blackflies do not appear to be a substantial pest to humans or stock in the LMB as they are in Africa (where they transmit Onchocerciasis) or northern North America (where they savagely attack humans and large animals). In the Mekong, as in Australia, the blackflies seem to largely ignore humans, and do not seem to be associated with transmission of any important diseases. They are, however, eaten by people in some parts of the basin[87].

5.4 Fish

Impoundment fisheries in the LMB

Hortle[88] estimated capture-fishery yields from impoundments in the LMB at ~200 kg/hectare/year, but these data have been contested. de Silva and Funge-Smith[89] found strong negative correlation between productivity and lake area, with a yield of ~200 kg/ha only applying for very small reservoirs, and a mean yield for all reservoirs of ~21.9 kg/ha. Lower production figures are consistent with 'run of the river' HPP reservoirs, where the reservoirs are largely confined to the natural river channel, and do not create the lentic or still water environments that favour fish production. The species composition of fisheries in reservoirs is likely to be dominated by lower-value species, and fishers will need to adapt their gears and operation.

One of the main mitigation strategies against reduced fisheries as a result of water-resource development in the LMB is cage culture and culture-based fisheries in the impoundments. While these measures may provide some mitigation, they are unlikely to substitute lost production. Furthermore, former wild-capture fishermen may be unable to exploit the new fish source because of the high capital cost for setup, high recurrent costs of feeding the fish, and the skills needed to manage aquaculture businesses.

---

[85] A disease caused by infection with freshwater parasitic worms.
[86] Attwood, S.W., Campbell, I., Upatham, E.S. and Rollinson, D. 2004. Schistosomes in the Xe Kong river of Cambodia: the detection of *Schistosoma mekongi* in a natural population of snails and observations on the intermediate host's distribution. Annals of Tropical Medicine and Parasitology, 8: 221-231.
[87] Leksawasdi, P. 2010. Compendium of research on selected edible insects in northern Thailand. Pp 183-188 in Durst, P.B., Johnson, D.V., Leslie, R.N. and Shono, K. (eds). Forest Insects as food: humans bite back. FAO Bangkok, Thailand.
[88] Hortle, K.G. 2007. Consumption and the yield of fish and other aquatic animals from the Lower Mekong Basin: Mekong River Commission, Vientiane, Lao PDR.
[89] de Silva, S.S. and Funge-Smith, S.J. 2005. A review of stock enhancement practices in the inland water fisheries of Asia. Asia-Pacific Fishery Commission, Bangkok, Thailand. RAP Publication No. 2005/12: 93 p.

The expected response of the fish indicators to a change from river to reservoir are summarised in Table 5.4. None of the white species will be able to survive in the reservoirs associated with Scenarios 2020 and 2040, and so rhithron resident species, main channel resident (long distant white) species and main channel spawner (short distance white) species are expected to be essentially eliminated from impounded areas (Table 5.4).

On the other hand, it is expected that the generalist and non-native fish species will benefit from the impounded conditions and thus will increase in abundance, and dominate catches in the reservoirs (Table 5.4). However, since these species tend to be smaller than the migratory white species, the overall fish biomass will probably be lower in the impoundments than in the river in 2007 Baseline. The exception to this is possibly the reservoir associated with the Sambor HPP (Table 5.4 and Figure 3.2)[90] in Zone 5. Sambor is likely to result in a massive shallow reservoir that would increase habitat for, and hence the production of, eurytopic (generalist) species, which are the dominant guild in Zone 5. This large increase in a dominant fish group should result in an increase in fish biomass in the reservoir.

Table 5.4 Fish: Expected responses of indicators to change from river to reservoir

Indicator	% change relative to river				
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Rhithron resident species	-100	-100	Not inundated in development scenarios	-100	-100
Main channel resident (long distant white) species	-100	-100		-100	-100
Main channel spawner (short distance white) species	-100	-100		-100	-100
Floodplain spawner (grey) species	-80	-80		-80	-80
Eurytopic (generalist) species	80	80		80	100
Floodplain resident (black)				20	-50
Estuarine resident species					
Anadromous species	-100	-100		-100	-100
Catadromous species				-50	-80
Non-native species	50	50		100	100

5.5 Herpetofauna

When a section of a river changes to reservoir each group of amphibians and reptiles may respond differently. In general, only the semi-aquatic snakes and turtles, which will be prejudiced by the absence of seasonal flooding[91][92], are expected to decline in impounded areas. Other groups are

[90] And possibly Stung Treng HPP.
91 Hampton, P.M. and Ford, N.B. 2007. Effects of flood suppression on natricine snake diet and prey overlap. Canadian Journal of Zoology, 85: 809–814.
[92] Swan, K.D., Hawkes, V.C. and Gregory, P.T. 2015. Breeding phenology and habitat use of amphibians in the drawdown zone of a hydroelectric reservoir. Herpetological Conservation and Biology, 10(3):864–873.

predicted to increase by between 5 and 20% (Table 5.5)[93]. This is because the shallow waters around the margin of the impoundment, particularly in the lower, flatter reaches of the LMB, should be suitable for many of them[94].

The formation of Hugo Lake and its impact on amphibians[95]

The study of the formation of Hugo Lake in Oklahoma, USA and its impact on amphibians found that the shoreline habitat supported more frogs than had the river. Reptiles were also more abundant and species richness greater. About 28% of the recorded reptile species increased in number as a direct effect of impounding the river.[96]

The evidence is not conclusive, however, and other studies have suggested that the complex habitat structure of rivers and floodplains, and the greater amount of leaf litter present in unaltered systems, supports greater species richness than does the habitat made available in reservoirs[97]. The prediction also assumes that there will be no major drawdowns in the water level of the reservoirs. Apart from their negative effects on vegetation, drawdowns may also expose and harm hibernating reptiles and amphibians that are buried in lake sediments.

Table 5.5 Herpetofauna: Expected responses of indicators to change from river to reservoir

Indicator	% change relative to river				
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Ranid amphibians	5	5	Not inundated in development scenarios	10	10
Aquatic serpents	15	15		20	20
Aquatic turtles		10		15	15
Semi-aquatic turtles				-10	-10
Amphibians for human use				0	0
Aquatic/semi-aquatic reptiles for human use				-10	-10
Species richness of riparian/floodplain amphibians	0	0		5	5
Species richness of riparian/floodplain reptiles	0	0		-5	-5

93 Note, these populations may take some time to establish as initially the physio-chemical properties of lake (water temperature, pH, concentration of chloride and ammonium magnesium ions, the presence of submerged vegetation) are in flux, which could negatively affect the herpetofauna93.

94 Bayley, P. 1995. Understanding Large River: Floodplain Ecosystems. BioScience, Vol. 45, No. 3, Ecology of Large Rivers (Mar., 1995), pp. 153-158.

95 Corps of Engineers. 1973. Hugo Lake, Kiamichi River Oklahoma. Project Economic Data.

96 Hunt, S.D., Guzy, J.C., Price, S.J., Halstead, B.J., Eskew, E.A. and Dorcas, M. E. 2013. Responses of riparian reptile communities to damming and urbanization. Biological Conservation, 157:277–284.

97 Dreslik, M.J. and Phillips, C.A. 2005. Turtle communities in the upper midwest USA. Journal of Freshwater Ecology, 20: 148–164; Jones, K.B. 1988. Comparison of herpetofaunas of a natural and altered riparian ecosystem. Management of amphibians, reptiles, and small mammals in North America: Proceedings of the Symposium. Flagstaff, Arizona. U.S. Department of Agriculture Forest Service. General Technical Report RM: 166N, 222-227.

5.6 Birds and mammals

The expected responses of the birds to a change from river to reservoir are provided in Table 5.6. None of the groups of birds that are dependent on riverine habitats are expected to fare well at reservoirs, mainly because the combination of inundation and lack of seasonal flooding will eliminate habitats such as sandy banks, reeds and grasses, large riverside trees, rocky crevices and vertical river banks that can be used for nesting, but also because of the change in food available in reservoirs.

Table 5.6 Birds: Expected responses of indicators to change from river to reservoir [98]

Indicator	% change relative to river				
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Medium/large ground-nesting channel species	-80	-80	Not inundated in development scenarios	-80	-80
Tree-nesting large waterbirds				-40	-40
Bank-/hole-nesting species	-100	-100		-100	-100
Flocking non-aerial passerine of tall graminoid beds				-60	-60
Large ground-nesting species of floodplain wetlands					
Large channel-using species that require bank-side forest				-40	-40
Rocky-crevice nester in channels		-100		-100	-100
Dense woody vegetation / water interface				-100	-100
Small non-flocking land bird of seasonally-flooded vegetation	-80	-80		-80	-80

The expected responses of the mammals to the change from river to reservoir are provided in Table 5.7. Neither hog deer nor dolphins are expected to survive in or around impounded areas. The hog deer depend on riparian and floodplain vegetation, which would be severely reduced in the absence of flooding. The habitat usage and feeding patterns of dolphins are thought to be strongly influenced by the long-distance movement of small cyprinid fish, and thus their predicted decline is attributed to the predicted decline in migratory white fish. Finally, although otters can and will inhabit reservoir edge habitats, their numbers are expected to be lower than in the river because of increased susceptibility to predation along reservoir edges as a result of, for instance, fewer holting[99] areas.

Table 5.7 Mammals: Expected responses of indicators to change from river to reservoir

Indicator	% change relative to river				
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Mekong dolphin			Not inundated in development scenarios	-80	
Otter spp.		-50		-50	
Hog deer				-100	

[98] Assumed total loss of natural river banks, rock crevices and seasonally flooded vegetation.
[99] An area where otters breed (like a den), referred to as a holt.

6 Overview of impacts to the aquatic ecosystems: main water-resource development scenarios

Section 4 and 5 presented the predicted outcome for each BioRA indicator under the main development scenarios for the river and impounded sections of the mainstream Mekong, respectively. This section summarises the nett changes in response to the main scenarios (i.e., for river and impounded reaches combined, where applicable) in the form of:

- changes in key composite indicators, and;
- changes in overall condition (health) of the river ecosystem.

6.1 Changes in key composite indicators

The key composite indicators are:

- **Erosion and sedimentation**, which indicate channel and bank erosion in Zones 1, 2, 3, 4 and 5, and floodplain sedimentation in tonnes per day in Zones 6, 7 and 8.
- **Extent of indigenous wetland vegetation**, which is the weighted sum of the predicted changes in riparian and floodplain vegetation indicators including non-native species but excluding algae.
- **Fish biomass**, which is a weighted sum of the predicted changes in each of the fish indicators, including non-native species.
- **OAA biomass**, which is a weighted sum of the predicted changes for shrimps, crabs, molluscs, insects, amphibians, snakes and turtles[100].
- **Aquatic biodiversity**, which captures the risk of local extinction of species, based on the most severe of the predicted percentage changes for individual indicators in each discipline.

The composite indicators were selected because they encompass all the BioRA disciplines, summarise the major concerns with respect to ecosystem functioing and provision, and are similar to indicators used in previous MRC assessments, such as the BDP[101] and SEA[102].

Changes in the physical environment (flow, sediments, nutrients, connectivity, salinity) driven by the developments in Scenario 2020 and 2040 are expected to affect the nature and availability of

[100] Hortle, K.G. 2007. Consumption and the yield of fish and other aquatic animals from the Lower Mekong Basin: Mekong River Commission, Vientiane, Lao PDR.
[101] MRC. 2011. Assessment of Basin-wide Development Scenarios and the BDS 2011-2015. Vientiane, Lao PDR.
[102] International Centre for Environmental Management. 2010. MRC Strategic Environmental Assessment (SEA) of hydropower on the Mekong mainstream: Summary of the Final Report. Hanoi, Viet Nam.

riverine habitats and the ability of species to complete their life cycles. The nett effect of these changes expressed using the key ecosystem indicators is provided in Table 6.1 and Figure 6.1.

Table 6.1 Key ecosystem indicators: Expected nett responses to the main development scenarios relative to 2007 Baseline

Zone	Indicator		2020	2040	2040CC
Zone 1	Erosion	river channel	+115	+115	+115
		impoundment	n/a	-100	-100
	Extent of indigenous riparian and wetland vegetation		-0	-35	-40
	Fish biomass		-35	-55	-55
	OAA biomass		-25	0	0
	Biodiversity		-35	-55	-60
Zone 2	Erosion	river channel	+45	+70	+65
		impoundment	-100	-100	-100
	Extent of indigenous riparian and wetland vegetation		-25	-80	-80
	Fish biomass		-40	-70	-75
	OAA biomass		+5	+35	+35
	Biodiversity		-50	-85	-85
Zone 3	Erosion	river	+25	+30	+20
		impoundment	n/a	n/a	n/a
	Vegetation biomass		-10	-10	-10
	Fish biomass		-40	-60	-65
	OAA biomass		-15	-15	-15
	Biodiversity		-30	-35	-35
Zone 4	Erosion	river channel	+35	+35	+40
		impoundment	n/a	-100	-100
	Extent of indigenous wetland vegetation		0	-30	-35
	Fish biomass		-15	-40	-40
	OAA biomass		-15	0	0
	Biodiversity		-40	-80	-80
Zone 5	Erosion	river channel	+60	+80	+80
		impoundment	n/a	-100	-100
	Extent of indigenous riparian and wetland vegetation		-10	-45	-45
	Fish biomass		-20	+5	+5
	OAA biomass		-15	+5	+10
	Biodiversity		-35	-75	-75
Zone 6	Floodplain sedimentation		-65	-95	-95
	Extent of indigenous riparian and wetland vegetation		-15	-30	-25
	Fish biomass		-20	-40	-35
	OAA biomass		-5	-10	-10
	Biodiversity		-25	-45	-45
Zone 7	Floodplain sedimentation		-25	-55	-55
	Extent of indigenous riparian and wetland vegetation		-10	-15	-10
	Fish biomass		-15	-25	-35
	OAA biomass		-10	-10	-15
	Biodiversity		-25	-50	-50
Zone 8	Floodplain sedimentation		-70	-95	-95
	Extent of indigenous riparian and wetland vegetation		-30	-40	-5
	Fish biomass		-15	-30	-10
	OAA biomass		-10	-15	0
	Biodiversity		-35	-50	-35

CHANGE considered negative for ecosystem **HEALTH**		
<70%	40 to 70%	20 to 39%

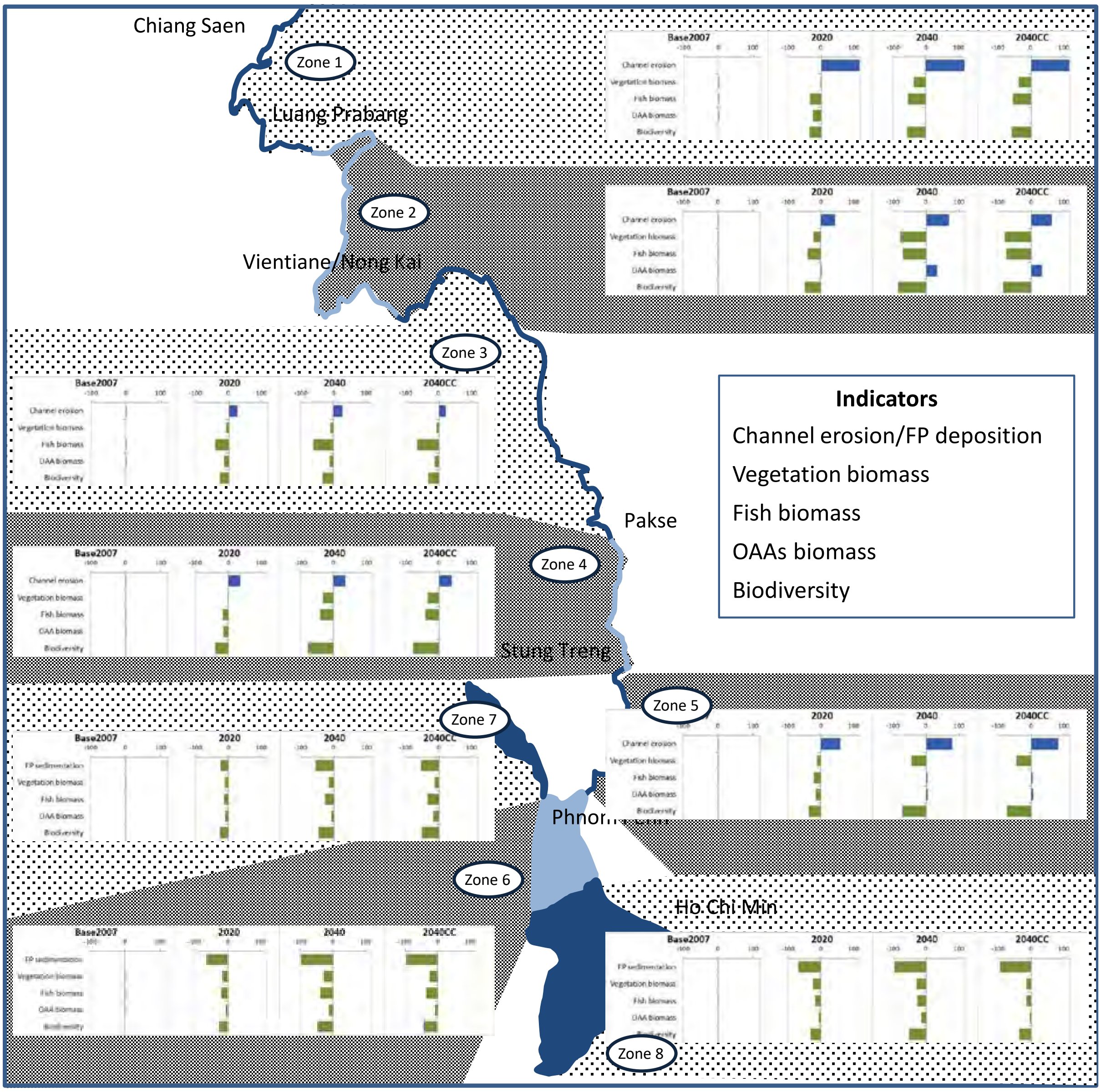


Figure 6.1 Nett predicted changes from Baseline in key ecosystem indicators for the BioRA Zones on the mainstream LMB for the 2020 (left), 2040 (middle) and 2040CC (right) scenarios relative to 2007. FP = Floodplain; OAA = Other Aquatic Animals.

With the exception of erosion, the outcomes in Table 6.1 and Figure 6.1 are averages for the BioRA zones as a whole (see Section 2), i.e., they integrate the predictions for flowing and impounded reaches. In the case of erosion, localised change is obscured when the impounded and non-impounded parts of the river are considered together and so these are reported separately in Table 6.1, and the effect for channel erosion (river reach only) in each zone is presented in Figure 6.1.

6.1.1 Channel erosion and floodplain sedimentation

The substantial loss of sediments transported down through the LMB is deemed to be one of the principal causes of ecosystem impact associated with the main development scenarios. All but the finest sediments are expected to settle out in reservoirs associated with the many proposed dams, and, in the reservoirs, all riverine habitats would be lost and replaced with lake habitats.

Under Scenarios 2020, 2040 and 2040CC (Table 6.1) the reduced supply of sediment to the downstream river as a result of trapping of sediments in the impoundments is expected to dramatically increase present levels of bed and bank erosion (channel erosion). This will result in greater instability of banks, increased loss of land and a reduction in ecologically-important sandy and gravel riverine habitats that are important for species; such as fish that use them as spawning beds, or birds and reptiles that build their nests on them.

The increase in channel erosion (and thus loss of key riverine habitats) in the remaining non-impounded section of the river is expected to be greatest in Zone 1 (more than double present levels; Table 6.1) because of the steepness of the river slope and consequent relatively high shear stress. It will also increase in Zones 2, 4 and 5 under Scenarios 2020, 2040 and 2040CC.

In Zones (3, 5)[103], 6, 7 and 8, the reduced sediment supply in the scenarios is predicted to reduce the amount deposited on floodplains. In Zone 7 deposition is expected to be ~25% lower than Baseline under Scenario 2020, and ~60% lower under Scenario 2040. Upstream sediments that deposit on the Cambodian floodplains, the Tonle Sap Great Lake and the Delta are widely acknowledged to be the key factor driving their primary and secondary[104]. Thus it is expected that the predicted decline in sediment inputs will lead to a marked drop in biotic productivity.

6.1.2 Extent of indigenous riparian and wetland vegetation

The main channel impoundments included in the development scenarios would drown out much of the riparian and wetland vegetation and change the character of what remains. Zone 2, which would be almost entirely inundated in Scenario 2040 and 2040CC, would experience the greatest loss in indigenous riparian and wetland vegetation, of up to ~80%.

Downstream of the impoundments in the river sections, indigenous riparian and floodplain vegetation would decline by 5-40%[105], due to increased dry season flows, reduced inter-seasonal variability, increased channel erosion, decreased deposition on floodplains and a reduction in the supply of nutrients essential for growth (in Figure 6.1).

---

103 Channel erosion is reported for these sites, but sedimentation d predictions are available in Table 4.6.
104 Junk, W.J., Bayley, P.B. and Sparks, R.E. 1989. The flood pulse concept in river floodplain-systems. Can. Spec. Publ. Fish. Aquatic Sci. 106:110-127; Bayley, P. 1995. Understanding Large River: Floodplain Ecosystems. BioScience, Vol. 45, No. 3, Ecology of Large Rivers (Mar., 1995), pp. 153-158; Baran, E. and Guerin, E. 2012. Influence of sediment load on Mekong floodplain and coastal fisheries - state of knowledge and research options. Report for the Project 'A Climate Resilient Mekong: Maintaining the Flows that Nourish Life' led by the Natural Heritage Institute. WorldFish Center, Phnom Penh, Cambodia. 40 pp;
105 Depending on the morphology of the zone.

With the decline in indigenous vegetation, non-native species are likely to increase noticeably. If non-native species such as *Mimosa pigra* and *Imperata cylindrical,* or *Eichhornia crassipes* and *Brachiaria mutica* are included in the predictions, overall vegetation biomass is expected to be unchanged or increase[106], but the plant communities would be very different. Evidence from other parts of the World suggests that proliferation of these non-native species will produce a suite of knock-on economic and ecological impacts that are not addressed here. For instance, the documented negative economic impacts of water hyacinth invasion worldwide include clogging of irrigation channels, choking off of navigational routes, smothering of rice paddies, loss of fishing areas and mosquito infestations[107]. The knock-on effects of *Mimosa pigra, a* prickly shrub reaching a height of 3 - 6 m, are also mostly undesirable, and result from its tendency to develop into dense monospecific stands on floodplains and in swamp forests. *Mimosa* infestations also grow over shallow nursery areas for fish, interfere with stock watering and grazing, irrigation projects, electric power lines, tourism, recreational use of waterways and the traditional lifestyles of indigenous peoples[108].

6.1.3 Fish biomass

At present, white fish are the biggest contributor to fish biomass in Zones 1, 2, 3 and 4 (Figure 6.2); and in Zones 5, 6 and 7 their contribution to overall biomass is less but still noteworthy. They are expected to decline as their habitat changes due to the predicted reduction in sediment supply, increase in erosion and extensive barriers to migration posed by the scenario HPP dams both in the tributaries and in the mainstream[109,110]. They will decline in the upper part of the study area under Scenario 2020, followed by a near basin-wide loss under the 2040 scenarios.

As discussed earlier, it is expected that their decline will be offset to a degree by an increase in eurytopic and non-native species. These thrive in a wide range of environments, including reservoirs, and would also benefit from reduced competition from white fish. The switch from white species to non-native species is already occurring in response to existing developments in the LMB. For instance, in 2014/15, in Zone 1, although white fish as a whole still dominated the catch, the most prevalent species was the non-native *Cyprinus carpio* (~21% of the catch); and in the Delta, the non-native *Oreochromis niloticus* comprised ~7% of the catch[111].

---

[106] Triet, T., Le Cong Kiet, Nguyen Thi Lan Thi and Pham Quoc Dan. 2004. The invasion of *Mimosa pigra* in the wetlands of the Mekong Delta, Vietnam. In: Julien, M., Flanagan, G., Heard, T., Hennecke, B., Paynter, Q and Wilson, C. (Eds). Research and management of *Mimosa pigra*. CSIRO Entomology, Canberra. 45-51.

[107]Masterson, J. 2007. Smithsonian Marine Station. Indian River Lagoon Species Inventory. www.sms.si.edu/irlspec/eichhornia_crassipes.htm. Accessed by C. Brown: 23/08/2017.

[108] Thamasara S 1985. Mimosa pigra L. Proceedings of the Tenth Conference of the AsianPacific Weeds Science Society, 1985, Chaingmai, Thailand. pp. 7-12. Asian-Pacific Weeds Science Society, Department of Agriculture, Bangkok, Thailand; Robert GL 1982. Economic returns to investment in control of Mimosa pigra in Thailand. Document No. 42-A-82, International Plant Protection Centre, Corvallis.

[109] Dugan, P., Barlow, C., Agostinho, A.A. and Winemiller, K.O. 2010. Fish Migration, Dams and Loss of Ecosystem Services in the Mekong Basin. AMBIO A Journal of the Human Environment 39(4):344-8.

[110] Note: The barriers include tributary dams, which are expected to have a major negative impact on fish connectivity[110].

[111] Source: MRC Fisheries Database.

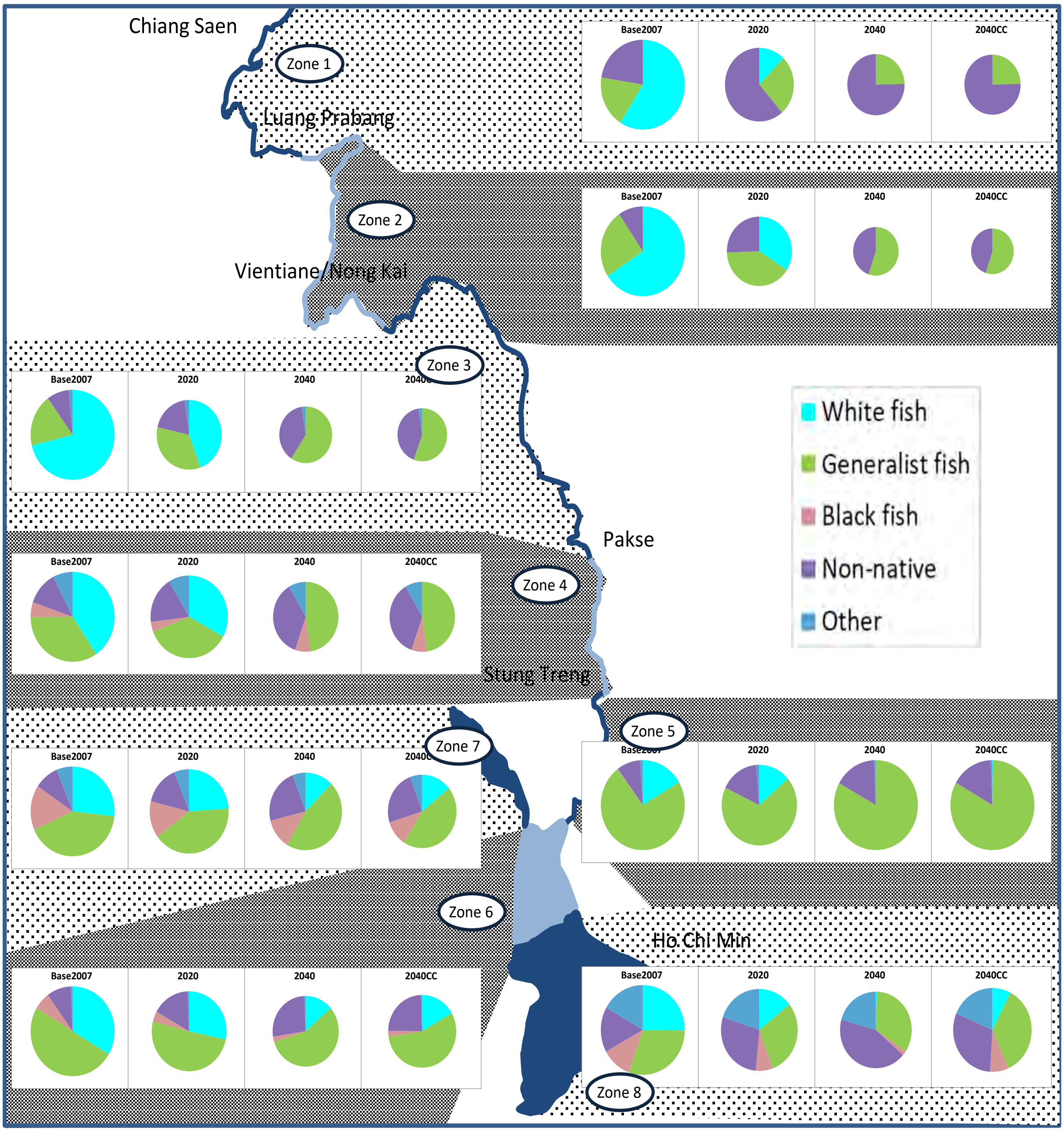


Figure 6.2 Nett (river and reservoirs combined) predicted change in fish biomass and contribution from different groups for the main development scenarios relative to the 2007 Baseline. Size of circle = biomass.

With the exception of Zone 5, it is unlikely that the increase in the generalist and non-native fish species will completely offset the loss of white fish. Thus, overall reductions in fish biomass and yields are anticipated under the scenarios, particularly in Zones 1 to 4 (Table 6.2 and Figure 6.2).

Table 6.2 Predicted changes in fish biomass, in river and reservoir for all site/scenario combinations[112]

Zone	2020	2040	2040CC
1	-35	-55	-55
2	-40	-70	-75
3	-40	-60	-65
4	-15	-40	-40
5	-20	+5	+5
6	-20	-40	-35
7	-15	-25	-35
8	-15	-30	-10

Under Scenario 2040 and 2040CC, the Sambor Dam and reservoir would dominate Zone 5 and likely result in the creation of extensive shallow habitats ideally suited to the generalist fish that presently make up the bulk of the species there. The nett result would be a predicted INCREASE in fish biomass in Zone 5 under Scenarios 2040 and 2040CC (Table 6.2 and Figure 6.2).

6.1.4 Biomass of OAAs

The change from a flowing river habitat to a high proportion of still-water reservoir habitat will probably benefit many of the species that comprise the OAAs. Bivalves, shrimps and crabs are all expected to be more abundant in the reservoirs. Snails (excluding *Neotricula aperta)* are also expected to do fairly well in shallow vegetated areas if reservoir operation allows these to exist. Similarly, frogs, aquatic serpents and aquatic turtles will probably benefit from the lake-like conditions, although semi-aquatic turtles may decline in numbers[114]. In general, and depending on the operation of the reservoir, the overall biomass of OAAs is expected to be higher in impoundments than in the river sections. For this reason, OAA biomass is predicted to increase by ~44% in Zone 2 under Scenario 2040 and 2040CC because much of this zones would be impounded (88%; Table 6.1), and assuming the water quality does not deteriorate.

The harvest and value of OAAs in the LMB

OAAs play a critical role in food security[113]. They are an important food source, particularly for poorer people in rural areas who often have ready access to habitats in which aquatic invertebrates are abundant; and are an important cash crop. OAAs are often most abundant during the dry season when fish may be more difficult to catch and family rice supplies exhausted.

Commonly-targeted OAAs include molluscs (both snails and mussels), Crustacea (shrimps and crabs), insects, snakes, frogs and turtles.

---

112 Except in Zone 5, where increases in eurytopics could offset the loss in biomass through the decline in the other guilds, because they (eurytopics) comprise a large percentage of the population (~64%).

113 Hortle, K.G. 2007. Consumption and the yield of fish and other aquatic animals from the Lower Mekong Basin. MRC Technical Paper No. 16. Mekong River Commission, Vientiane. 88 pp; FAO and IUCN. 2003. The role and nutritional value of aquatic resources in the livelihoods of rural people. A participatory assessment in Attapeu Province, Lao PDR. FAO, Bangkok.

114 Hunt, S.D., Guzy, J.C., Price, S.J., Halstead, B.J., Eskew, E.A. and Dorcas, M. E. 2013. Responses of riparian reptile communities to damming and urbanization. Biological Conservation 157:277–284.

Figure 6.3 Woman harvesting snails and bivalves in a canal in the Mekong Delta.

The situation will probably be somewhat different in the non-impounded sections of the river, where OAA biomass is expected to decline. The reasons for this may vary but are mainly as a result of the change in flows, habitat, food and shelter, such as loss of sandy habitats and a reduction in fish. Some may increase in abundance, because of an increase in algal growth where there is better light penetration[115].

6.1.5 Biodiversity

For most riverine plants and animals, the risk of extirpation/loss of biodiversity increases through Scenario 2020 to Scenario 2040 (Figure 6.1). The reasons for this are evident from the predictions for individual indicators, and include the expected impacts on hundreds of kilometres river channel and riparian forests, on white and other groups of fish, and the knock-on effects on herpetofauna, birds and mammals. The risk of local extinction of species as a result of the planned water-resource developments is particularly high for the two large species that are iconic in the LMB: the Irrawaddy dolphins and the migratory giant Mekong catfish. Both face certain extinction, and possibly global extinction, under Scenario 2040. It is worth noting, however, that the bigger threat to herpetofauna, birds and mammals is harvesting pressures for household consumption and trade and, as a result, the risk of extinction is high across all scenarios for these groups because the harvesting threat is the same whether or not the scenarios are enacted.

6.2 Country-level summaries of key indicators

The changes in the key indicators are summarised per LMB country in Figure 6.4. Note: channel erosion was not predicted for the Viet Nam Delta. The country-level summaries indicate that Laos, Thailand and Cambodia are all expected to experience increased levels of channel erosion, >100% increase, even under the 2020 scenario (Figure 6.4). This is in response to the predicted reduction in sediment supply combined with only minor changes in the volume and power of the water. The channel erosion for Lao PDR and Thailand is slightly higher than that for Cambodia because the rivers are generally steeper in Lao PDR and Thailand than in Cambodia, and thus more susceptible to erosion as a result of reduced sediment supply. The predictions for floodplain sedimentation are the reverse of those for channel erosion as the reduced sediment supply will translate into reduced sedimentation on the floodplains (Figure 6.4). In the case of floodplain sedimentation, Cambodia

[115] Hill, W.R. 1996. Effects of light. Pages 121-148. In: R.H. Stevenson, M.L. Bothwell and R.L. Lowe, editors. Algal Ecology: Freshwater benthic ecosystems. Academic Press, San Diego.

and Viet Nam are expected to be most affected because this is where the large floodplains are located.

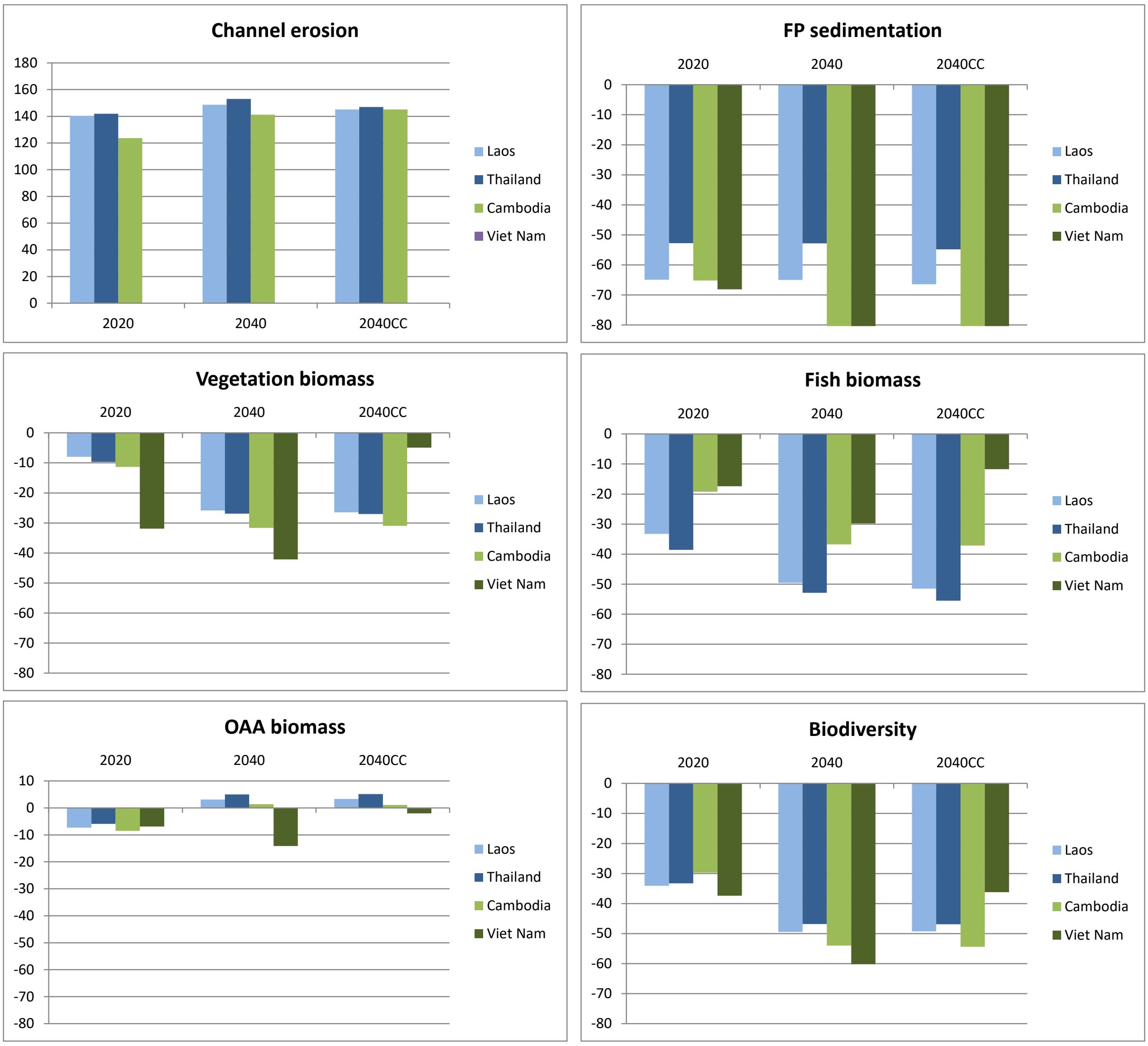


Figure 6.4 Predicted changes in the key indicators in response to the main development scenarios per LMB country. Note: Channel erosion was not predicted for Zone 8: Viet Nam Delta.

The biomass of indigenous riparian and floodplain vegetation is expected to be lower under all the development scenarios relative to 2007 Baseline, but the reduction is greatest under the 2040 Scenario. The main reason for this is the reduced supply of sediment and nutrients associated with these scenarios. The biggest loss is expected in Vietnam and Cambodia because of the relatively greater amount of floodplain vegetation in these countries. As mentioned in Section 6.1.2, the vegetation biomass predictions here **exclude** non-native species, which are likely to increase in response to the indigenous vegetation being stressed.

The relative reduction in fish biomass associated with the main development scenarios is most marked in Lao PDR and Thailand, and could be as high as 50% at a country level under Scenario 2040 and 2040CC (Figure 6.4). As discussed in Section 5.4, the predicted reductions are because the river reaches in Lao PDR and Thailand are generally steeper than in other parts of the LMB and thus highly susceptible to erosion as a result of reduced sediment supply; the white fish in these reaches will decline because the depend successful migration to the more downstream parts of the LMB, and; it is unlikely that the increase in the generalist and non-native fish species will completely offset the loss of white fish (Figure 6.5). Furthermore, under the 2040 level of development, large reaches of the mainstream Mekong will be transformed into lake habitat where overall fish biomass will be dominated by generalist and non-native fish species and biomass will probably be lower than in the river under 2007 Baseline.

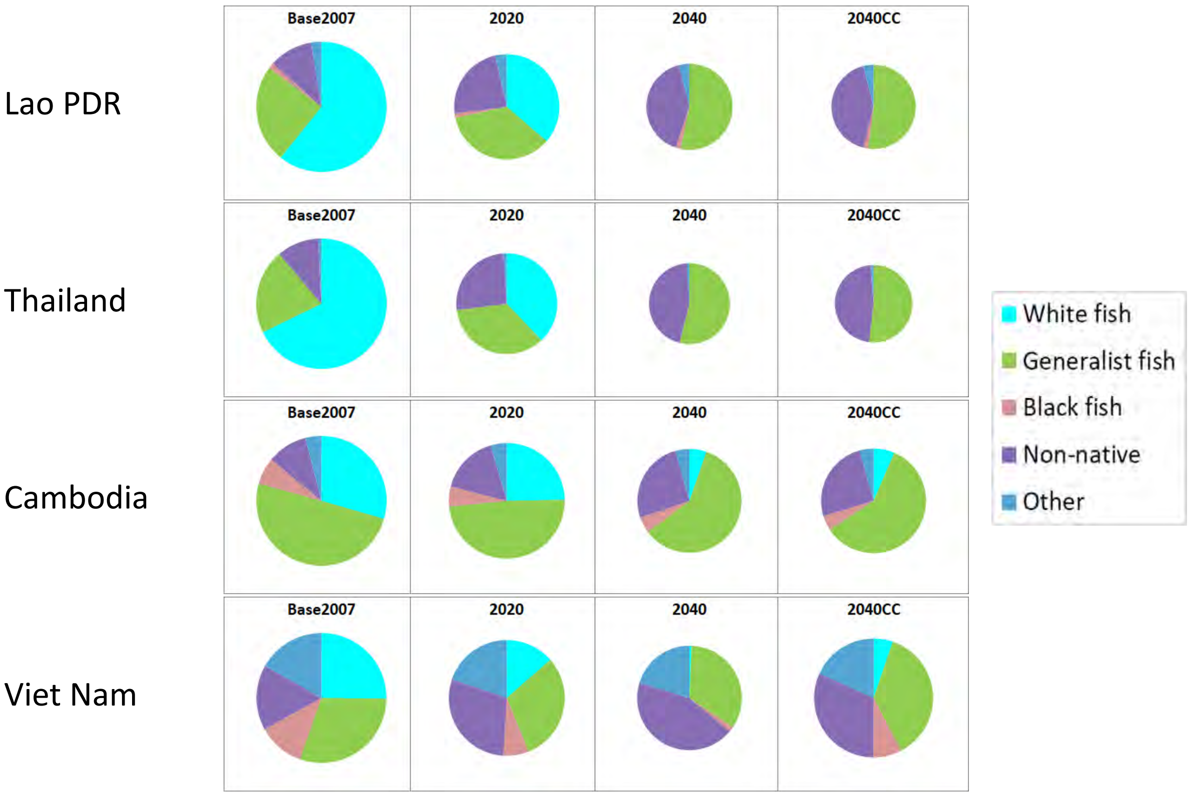


Figure 6.5 Nett (river and reservoirs combined) predicted country-level change in fish biomass and contribution from different groups for the main development scenarios relative to the 2007 Baseline. Size of circle = biomass.

The predicted changes in the biomass of OAAs are relatively small and fairly evenly distributed between the countries (Figure 6.4). This is because some groups are expected to be negatively affected by the proposed developments and/or climate change in the main scenarios and others are expected to be affected positively. In general, the presence of impoundments is expected to benefit OAA biomass.

The risks to biodiversity in the LMB countries reflect the expected changes in the composition of the communities of macroinvertebrates, reptiles, amphibians, fish, mammals and birds that are outlined in Section 4. The risk of biodiversity loss as a result of the proposed developments is expected to be greatest in Vietnam (but only slightly), which is a reflection of both the predicted impacts on flooding and nutrient supply to the vast floodplains in the Delta, and the precarious state of many species in the Delta as a result of past developments and management aimed at maximising agriculture and aquaculture.

6.3 Changes in overall condition (health) of the river ecosystem

The changes described above, and those discussed in Section 4, can be summarised in terms of the overall health of the riverine ecosystems[116] in the LMB. As a general guide, rivers in conservation areas usually aim for an A or high B condition; so-called 'working rivers' drop to a C or D condition, and E category rivers describe a poor ecological condition not conducive to sustainable development[117].

The basin-wide overview of changing river condition associated with each development level shows that river condition is predicted to decline through the development sequence, from 2007 Baseline when most parts of the river are in a Category B condition, to mostly Category C condition for Scenario 2020, and mostly Category D condition for Scenario 2040 and 2040CC (Figure 6.6 and Figure 6.7)[118].

It is worth noting that even under Scenario 2040, the Tonle Sap Great Lake is somewhat buffered from the changes in the mainstream Mekong River related to the development scenarios. This is because, according to the modelling, the flow reversal of the Tonle Sap River is preserved even under the Scenario 2040, but also because it receives nearly 50% of its inflow from a combination of tributaries other than the Tonle Sap River and direct rainfall[119]. Thus, any additional developments targeting these other tributaries would be expected to have a negative impact on the overall condition of the lake ecosystem. The importance of the contributions from these non-Mekong sources is highlighted through the evaluation of the Climate Change sub-scenarios in Section 7.2.1.

The warmer, wetter conditions that lie behind the 2040CC scenario do not result in a major improvement in river condition relative to the 2040 scenario because the major impacts are related to the decline in sediment supply, nutrients, river connectivity and fish migrations associated with

[116] The condition of a river system indicates its ability to support and maintain a balanced, integrated composition of habitats and biota on a temporal and spatial scale that is comparable to the natural characteristics of the region (Kleynhans 1996). To aid interpretation, ecosystem condition is often scored on a scale from A to E, with A being natural and E = critically modified. The baseline condition of the LMR is described in BioRA Technical Report Series: Volume 1: Specialists' Report.

[117] Kleynhans, C.J. 1996. A qualitative procedure for the assessment of the habitat integrity status of the Luvuvhu River. Journal of Aquatic Ecosystem Health 5: 41 – 54.

[118] It does not make sense to allocate a river condition to an impoundment and so this has not been done.

[119] Kummu, M., Tes, S., Yin, S., Adamson, P., Jozsa, J., Koponen, J., Richey, J., Sarkkula, J. 2014. Hydrological Processes. 28: 1722-1733.

both the 2040 scenarios. Indeed, in some zones, the elevated flows, combined with the reduced sediments will exacerbate channel erosion and reduce the availability of some aquatic habitats. The ecological rating of the Delta, which is predicted to decline to the lowest rating of E category under Scenario 2040, would likely be slightly better under Scenario 2040CC (Figure 6.6) as a result of the flooding effects associated with sea-level rise.

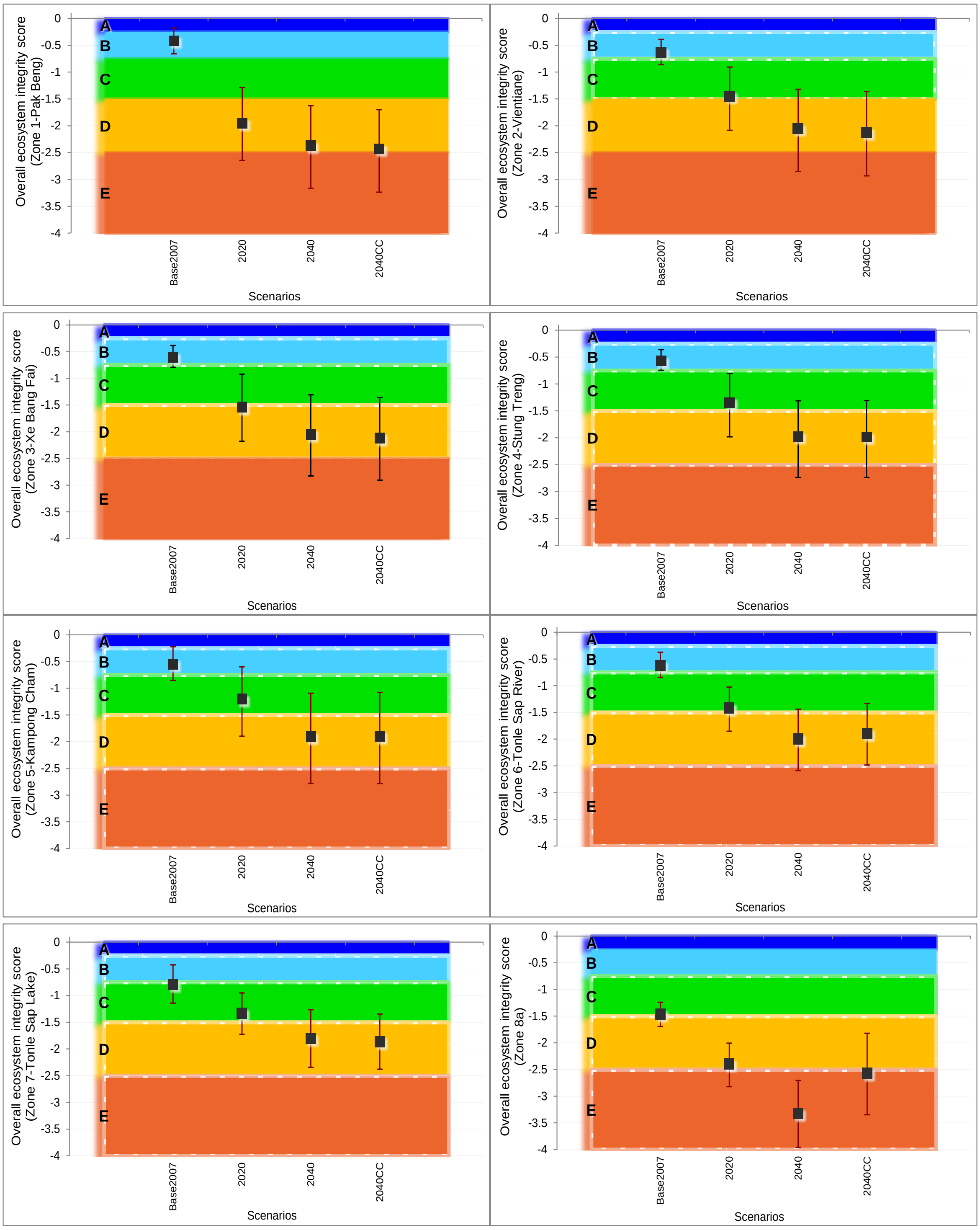


Figure 6.6 Predicted ecosystem condition for each zone (including confidence limits) under the main development scenarios. A = natural condition; B = largely natural; C = moderately modified; D = largely modified; E = critically modified.

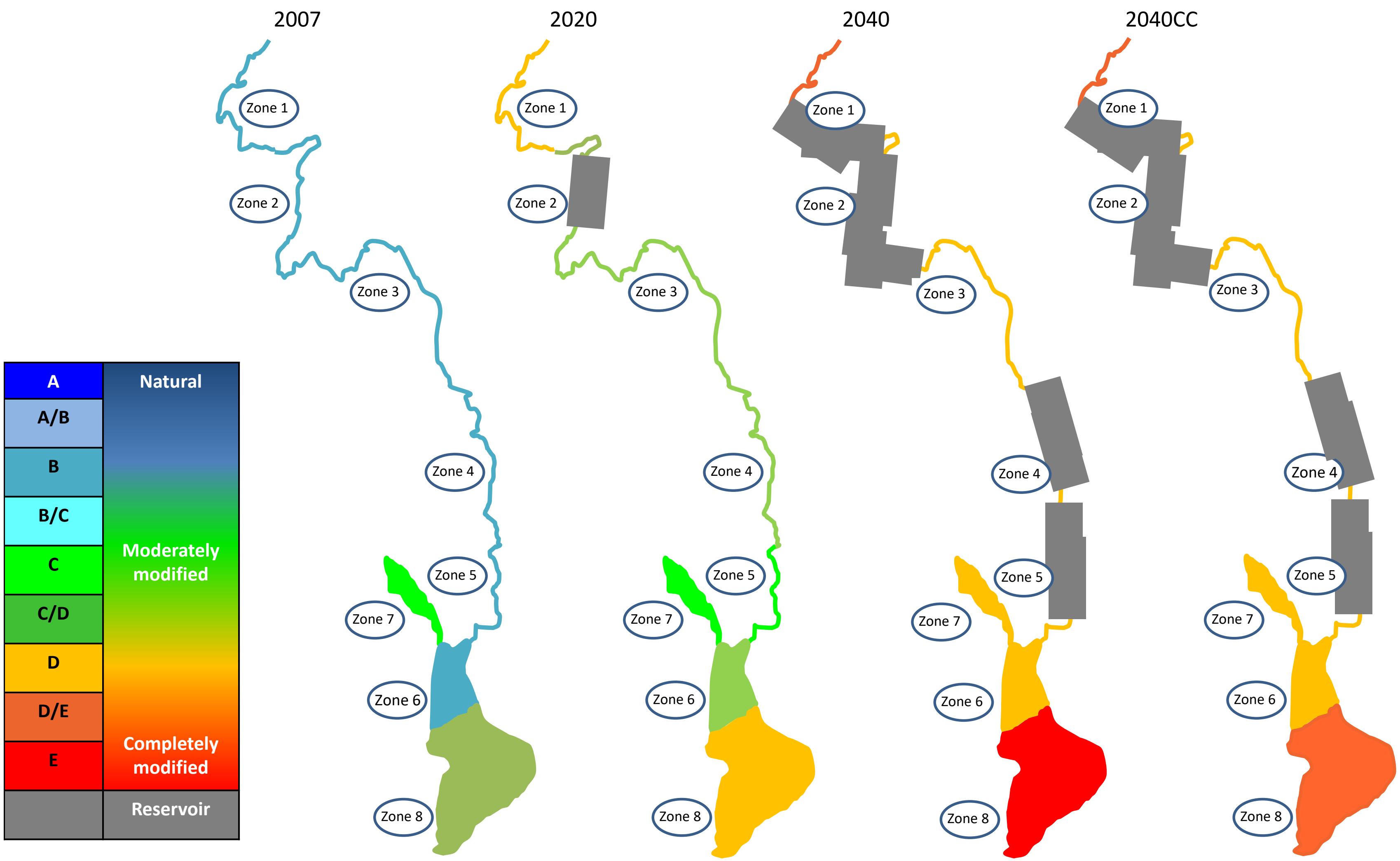


Figure 6.7 Mekong River condition predicted for the main development scenarios (*impoundments show the approximate river length inundated but are not necessarily to scale*)

The predicted average overall condition for the whole LMB for each scenario (Figure 6.8) shows that the 2040 scenarios would likely place the average health of the mainstream in a D-category, with the reaches/areas in Cambodia being in a slightly better overall condition than those in Lao PRD, Thailand and Viet Nam. However, the biggest changes are expected in Lao PDR and Thailand, where the river is expected to drop from a 2007 Baseline average B category to a D-D/E category under Scenario 2040. The parts of the mainstream in Cambodia are expected to drop from a B/C category to a C/D category, and those in Viet Nam from a C/D to a D/E category. Changes in Viet Nam relative to the 2007 Baseline are somewhat moderated because the ecosystem are already considerably modified from natural and, equally importantly, water flow in the Delta is actively managed through sluices and dikes; but the ecosystem condition will still be negatively affected by the predicted changes in sediment delivery and the predicted changes to the composition of the freshwater fish community. The vertical lines around each point in Figure 6.6 indicate the uncertainty associated with the predictions.

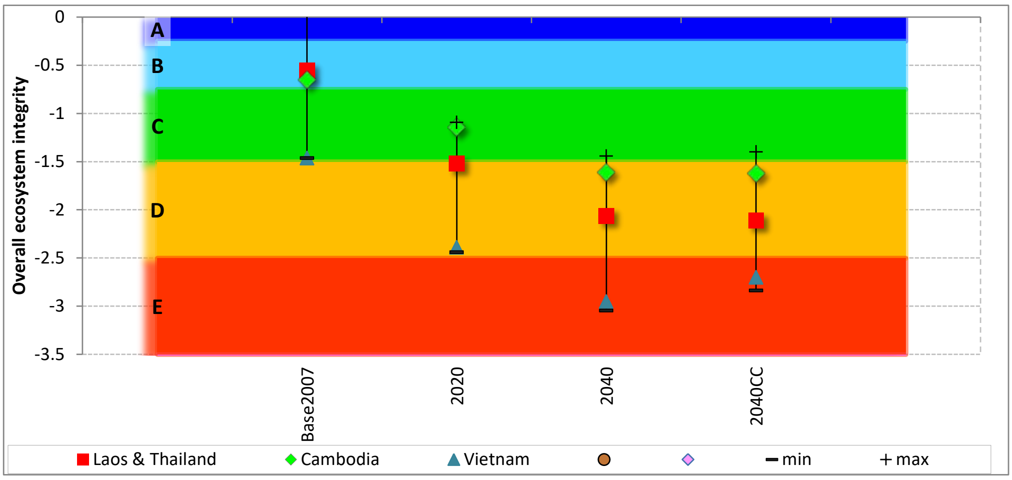


Figure 6.8 **Expected overall condition of the LMB mainstream (including confidence limits) under the main development scenarios.**

The evaluation of the main development scenarios yielded the following important insights:

- The modelled data for the scenarios show that changes in the timing and volume of water flows will be minor (accordingly, BioRA predicts no major impact on the river ecosystem as a result of changes in flow), but this is not borne out by recorded data measuring the influence of the development in the UMB on the flows entering the LMB at Chiang Saen.
- Trapping of bed and suspended sediments in tributary and mainstream dams will increase bed and bank erosion in the downstream river, and reduce the deposition of nutrient rich sediment on the floodplains, even in Scenario 2020.

- The reservoirs associated with the mainstream dams in Scenarios 2040 and 2040CC will convert much of the mainstream Mekong River from Chiang Saen to Kratie[120] into deeper, lake-like habitat that is unsuitable for many of the species that inhabit the river but that will benefit others, such as bivalves, frogs and snails.
- The tributary and, particularly mainstream, dams will disrupt migration routes essential for the continued occurrence of 30-40% of the species that comprise the Mekong fish community and 30-40% of the total caught fish biomass.
- The planned 2040 developments as modelled in the main development scenarios are expected to:
    - seriously reduce indigenous riparian and wetland vegetation, mostly through inundation associated with the 2040 planned level of development;
    - change the composition of algal and invertebrate communities that form the base of the aquatic food-chain, thereby affecting the viability of a wide range of animals and plants;
    - change the composition and reduce the biomass of fish in the LMB
    - eliminate white fish and promote invasion by non-native species.

These changes will likely extend across the whole basin, but are expected to be felt first and most in the upper reaches of the LMB, in Zones 1 and 2. To some extent, the Tonle Great Sap Lake is buffered from development along the Mekong River by direct inflows and rainfall, provided reversal of the Tonle Sap River is preserved. The nature and functioning of the lake will be affected, however, by the reduction in sediments supplied by the Mekong River and the blocking of the migration paths of white fish. Similarly, the Viet Nam Delta would be cushioned from future changes by the fact that it is already highly modified and controlled, and the fact that higher flows in the dry season could aid fish recruitment. Nonetheless, it will be affected by, *inter alia*, the change in sediment supply and alterations in the make-up and dynamics controlling fish communities.

For the basin as a whole, and based on the modelled data for the mains development scenarios generated in the Council Study, the factors that will most impact the aquatic ecosystems associated with the Mekong River are:

- barriers to the upstream/downstream migration of biota;
- loss of sediments;
- change from flowing to still water habitats;
- reduction of floodplain flooding associated with floodplain protection infrastructure.

[120] There is a large area from Vientiane to Pakse that is not impounded.

7 Overview of impacts to the aquatic ecosystems: thematic sub-scenarios

The thematic sub-scenarios are variations of the 2040CC scenario with different levels of thematic development superimposed (Table 3.6). The exception is the climate change sub-scenarios, which incorporate wetter or drier climatic conditions than those modelled for Scenario 2040. Adding variations to Scenario 2040CC of any one kind of impact is a useful way of assessing the influences of that sector. This is especially so where a sector could be ameliorating or exacerbating effects already described under Scenario 2040CC (Sections 4 to 6).

Thematic sub-scenarios were analysed for variations in:

- Climate change
- Agricultural landuse
- Irrigation
- Flood-protection infrastructure
- Hydropower.

7.1 Inputs from the Modelling Team

In accordance with the design of the Council Study (Section 1.2.3), the BioRA outcomes are based on the modelled time-series data received from the Modelling Team. Ecologically-relevant summaries of these data for the sub-scenarios are provided and discussed in this section as they provide the context for the BioRA predictions. The reasons behind the modelling outputs are the subject of the Modelling Report, and are not addressed here.

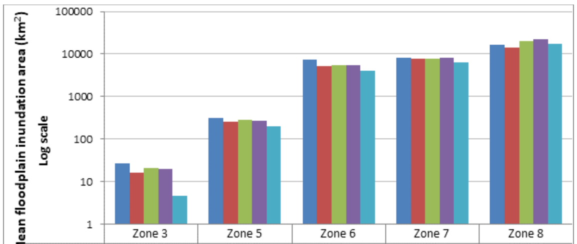
On the whole, relative to 2040CC, the modelling for the sub-scenarios yielded:

- relatively small changes in the seasonality of river flows for all sub-scenarios;
- some changes in floodplain hydraulics linked to floodplain protection infrastructure;
- changes in sediment and nutrient supply, linked to the presence of mainstream and tributary dams and/or operation of mainstream dams.

7.1.1 Hydrology and hydraulics

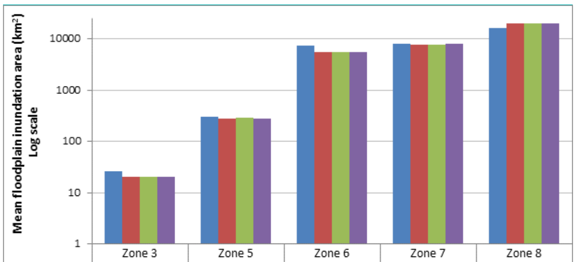
With the exception of the climate change scenarios, the channel hydrology and hydraulics time-series received as input for the sub-scenarios were very similar to those for 2040CC, suggesting that the non-hydropower sub-scenarios did not have a major effect on the flow regimes.

In general, the floodplain inundation time-series followed expected trends (as illustrated in Figure 7.1 to Figure 7.5). For instance, in Zone 8, C2_2040Wet had a slightly higher inundated areas than 2040CC (Figure 7.1) and C3_2040Dry slightly lower. Changes in flooding were however muted by floodplain protection infrastructure, which was at 2040 levels for all the non-floodplain protection scenarios sub-scenarios.



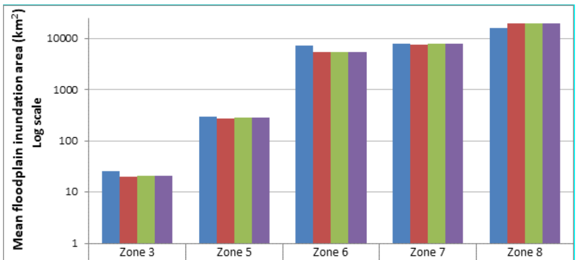
	Zone 3	Zone 5	Zone 6	Zone 7	Zone 8
Base2007	26	305	7481	8137	16 496
2040	16	254	5082	7864	14 165
2040CC	20	275	5500	7709	19 737
C2_2040Wet	20	273	5514	8103	22 668
C3_2040Dry	5	203	4103	6371	17 685

Figure 7.1 Mean modelled floodplain inundation areas under 2007, 2040, 2040CC, C2_2040Wet and C3_2040Dry



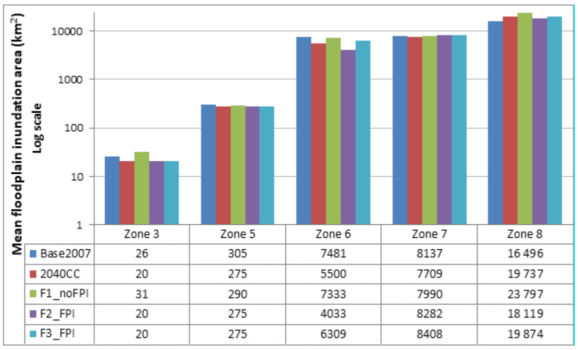
	Zone 3	Zone 5	Zone 6	Zone 7	Zone 8
Base2007	26	305	7481	8137	16 496
2040CC	20	275	5500	7709	19 737
A1_noALU	21	287	5624	7630	19 958
A2_ALU	21	283	5505	7901	19 761

Figure 7.2 Mean modelled floodplain inundation under 2007, 2040CC, A1_noALU and A2_ALU



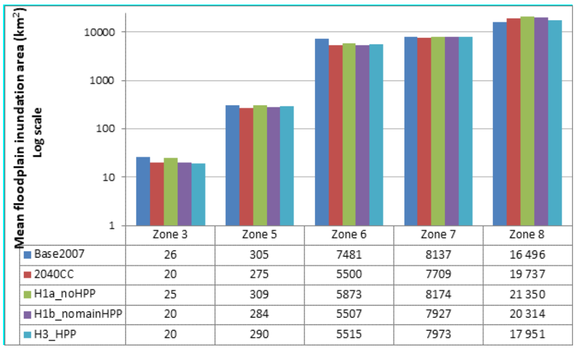
	Zone 3	Zone 5	Zone 6	Zone 7	Zone 8
Base2007	26	305	7481	8137	16 496
2040CC	20	275	5500	7709	19 737
I1_noIrr	21	288	5608	7988	19 952
I2_Irr	21	283	5505	7934	20 322

Figure 7.3 Mean modelled floodplain inundation areas under 2007, 2040CC, I1_noIRR, I2_IRR and 2040CC



	Zone 3	Zone 5	Zone 6	Zone 7	Zone 8
Base2007	26	305	7481	8137	16 496
2040CC	20	275	5500	7709	19 737
F1_noFPI	31	290	7333	7990	23 797
F2_FPI	20	275	4033	8282	18 119
F3_FPI	20	275	6309	8408	19 874

Figure 7.4 Mean modelled floodplain inundation areas under 2007, 2040CC, F1_noFPI, F2_FPI, F3_FPI.



	Zone 3	Zone 5	Zone 6	Zone 7	Zone 8
Base2007	26	305	7481	8137	16 496
2040CC	20	275	5500	7709	19 737
H1a_noHPP	25	309	5873	8174	21 350
H1b_nomainHPP	20	284	5507	7927	20 314
H3_HPP	20	290	5515	7973	17 951

Figure 7.5 Mean modelled floodplain inundation areas under 2040CC, H1a_noHPP, H1b_nomainHPP and H3_HPP

7.1.2 Sediments and nutrients

The annual sediment loads calculated from the modelled sediment time-series for the main development scenarios and all of the sub-scenarios are illustrated in Figure 7.6. The sediment loads for each of these followed expected trends, i.e., relative to 2007, more dams resulted in lower sediment loads and more runoff (associated with wetter climates) resulted in higher sediment loads. The modelled sediment loads in the river were also in line with other similar estimates[121].

[121] E.g., Kondolf, G.M., Rubin, Z.K., Minear, J.T. 2014. Dams on the Mekong: Cumulative sediment starvation. Water Resources Research 50, 5158–5169. doi:10.1002/2013WR014651.

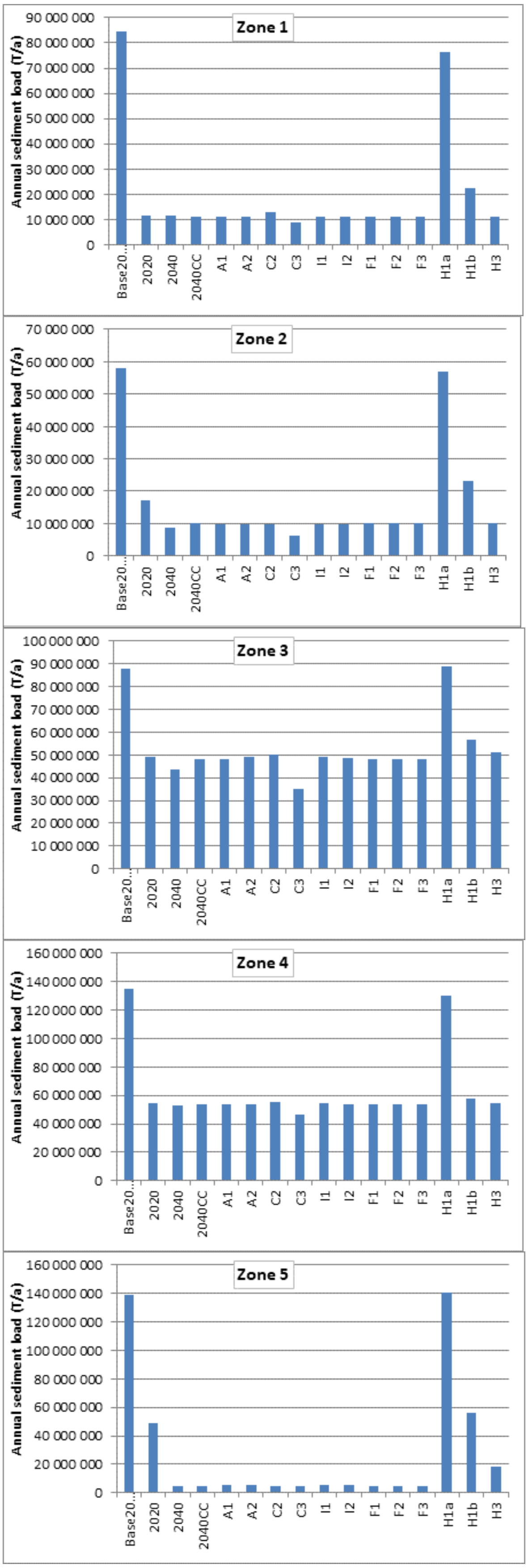


Figure 7.6 **Modelled input data for average annual sediment loads for the main development scenarios and the sub-scenarios (Table 3.6).**

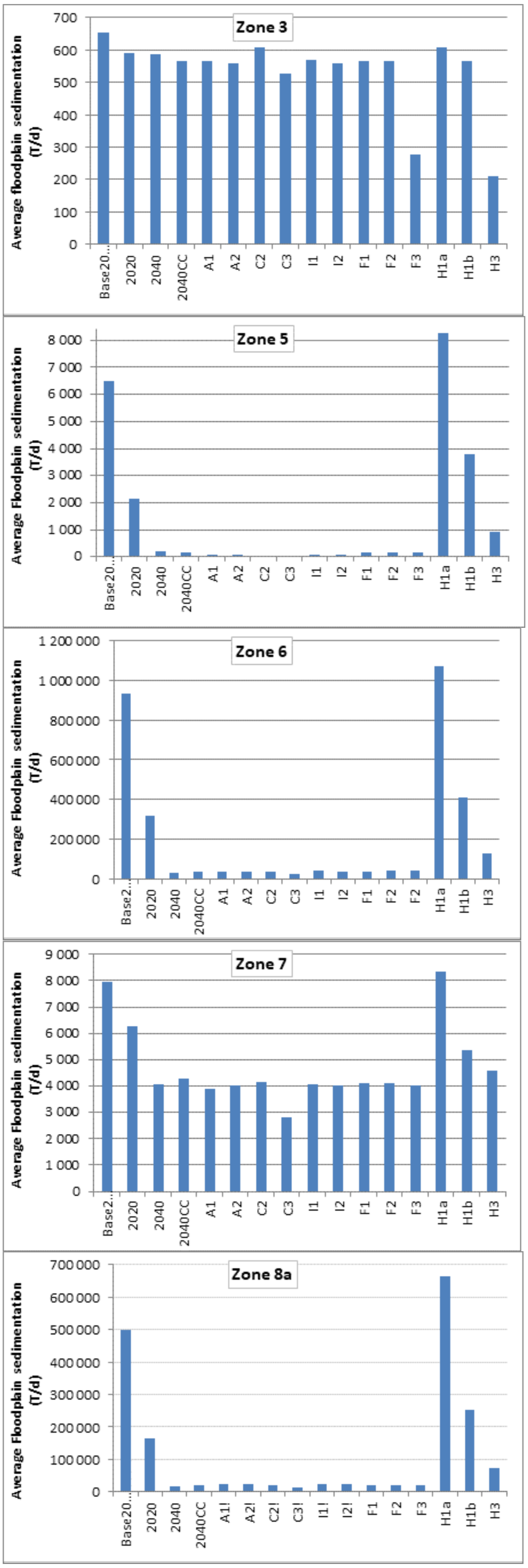


Figure 7.7 Modelled input data for average floodplain sedimentation for Zones 3, 5, 6, 7 and 8a for the main development scenarios and the sub-scenarios (Table 3.6).

As was the case for the main development scenarios, the nutrient concentrations in the river followed similar trends to those reported for sediments.

7.2 BioRA results

7.2.1 Ecosystem response to climate change sub-scenarios

To assess the effect of different assumptions about climate change on the environment, three different climatic futures were paired with Scenario 2040, and evaluated in terms of their relative impact on the Mekong River ecosystem (Table 7.1):

2040CC	2040 but with a warmer and wetter climate than 1985-2008 (already described above in Sections 4 to 6)
C2_2040Wet	2040 but with a wetter climate than 204CC and sea level rise;
C3_2040Dry	2040 with a drier climate than 1985-2008 and sea level rise.

Each sub-scenario represents different climatic conditions (rainfall and temperature, which drives potential evaporation) used in the rainfall-runoff modelling to produce the hydrological sequences. For instance Scenario 2040 is based on the hydrological period 1985-2008, and thus the climatic conditions (rainfall and evaporation levels) that underlie it are those recorded from 1985 to 2008. For 2040CC, however, the climatic conditions driving the model were warmer (more evaporation) and wetter (more rain) than for the 2040 scenario; and were combined with sea level rise, which affects flooding in Zones 6, 7 and 8. The driving conditions for the C2_2040Wet and C3_2040Dry have similar temperatures to 1985-2008, but both include sea level rise; and more and less rainfall, respectively.

Table 7.1 Sub-scenarios to test the effects of climate change

Scenario		Level of Development for water-related sectors						Climate
		ALU	DIW	FPI	HPP	IRR	NAV	
2040	Planned Development Scenario 2040	2040	2040	2040	2040	2040	2040	1985-2008
2040CC	Planned Development 2040 + Warmer and Wetter Climate	2040	2040	2040	2040	2040	2040	Warmer and wetter
C2_2040Wet	Planned Development 2040 + Wetter Climate	2040	2040	2040	2040	2040	2040	Wetter
C3_2040Dry	Planned Development 2040 + Drier Climate	2040	2040	2040	2040	2040	2040	Drier

The outputs for key BioRA summary indicators for the 2040CC and additional three climate change sub-scenarios relative to the 2007 Baseline scenario are shown in Figure 7.8 and Table 7.2. These indicate that in general, the predicted ecosystem impacts are greatest for C3_2040Dry, slightly less for 2040CC and least for C2_2040Wet, but that the differences are mostly small. Note that in Figure

7.8, channel erosion is reported for Zones 1-5, and floodplain sedimentation is reported for Zone 6-8.

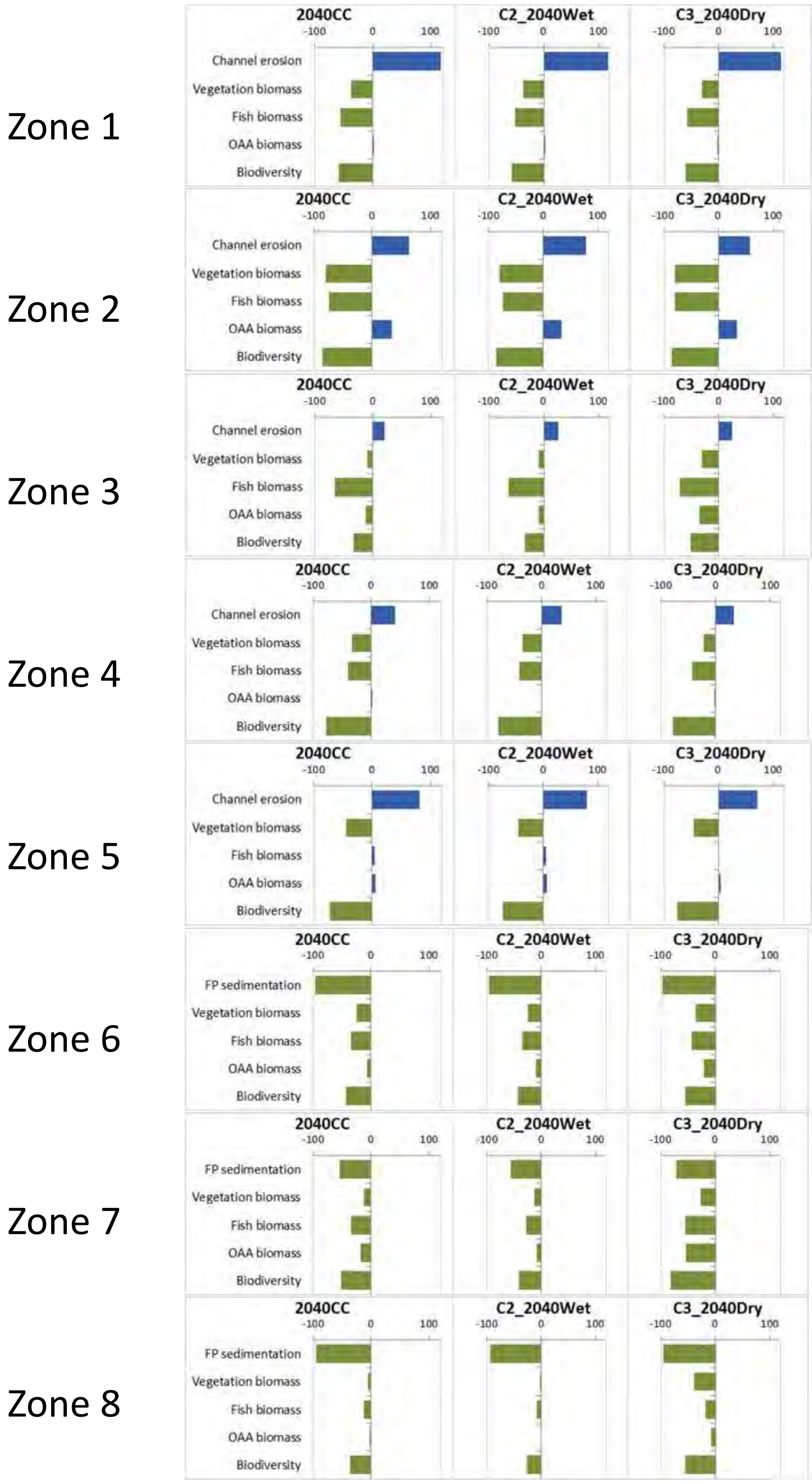


Figure 7.8 Predicted changes from 2007 Baseline in key ecosystem indicators for the BioRA zones for the climate change sub-scenarios (left to right): 2040CC, C2_2040Wet and C3_2040Dry. FP = floodplain; OAA = Other Aquatic Animals.

Table 7.2 Key ecosystem indicators: Expected nett responses to the climate change sub-scenarios relative to 2007 Baseline

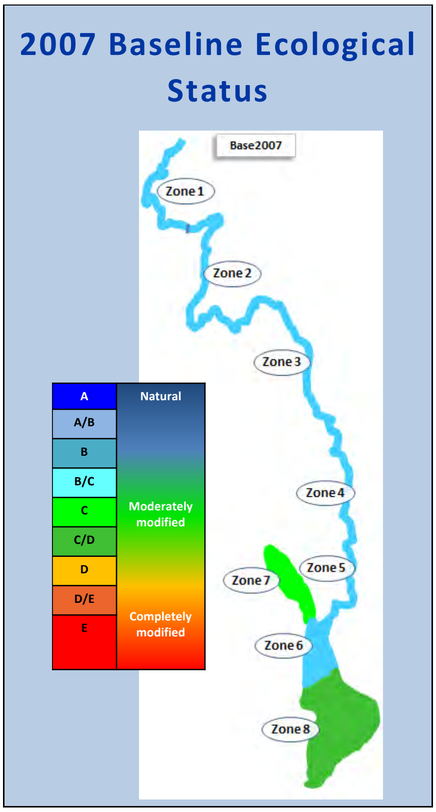
Zone	Indicator		2040CC	2040CC_Wet	2040CC_Dry
Zone 1	Erosion	river channel	+115	+115	+115
		impoundment	-100	-100	-100
	Extent of indigenous riparian and wetland vegetation		-40	-40	-30
	Fish biomass		-55	-55	-55
	OAA biomass		0	0	0
	Biodiversity		-60	-60	-60
Zone 2	Erosion	river channel	+65	+75	+60
		impoundment	-100	-100	-100
	Extent of indigenous riparian and wetland vegetation		-80	-80	-80
	Fish biomass		-75	-75	-80
	OAA biomass		+35	+35	+35
	Biodiversity		-85	-85	-85
Zone 3	Erosion	river	+20	+25	+25
		impoundment	n/a	n/a	n/a
	Vegetation biomass		-10	-10	-30
	Fish biomass		-65	-65	-70
	OAA biomass		-10	-10	-35
	Biodiversity		-30	-35	-50
Zone 4	Erosion	river channel	+40	+35	+35
		impoundment	-100	-100	-100
	Extent of indigenous wetland vegetation		-35	-35	-20
	Fish biomass		-40	-40	-40
	OAA biomass		0	0	0
	Biodiversity		-80	-80	-75
Zone 5	Erosion	river channel	+80	+80	+70
		impoundment	-100	-100	-100
	Extent of indigenous riparian and wetland vegetation		-45	-45	-45
	Fish biomass		+5	+5	0
	OAA biomass		+10	+5	+5
	Biodiversity		-75	-75	-75
Zone 6	Floodplain sedimentation		-95	-95	-95
	Extent of indigenous riparian and wetland vegetation		-25	-25	-40
	Fish biomass		-35	-35	-45
	OAA biomass		-10	-10	-25
	Biodiversity		-55	-45	-55
Zone 7	Floodplain sedimentation		-55	-55	-70
	Extent of indigenous riparian and wetland vegetation		-10	-10	-25
	Fish biomass		-35	-25	-55
	OAA biomass		-15	-10	-55
	Biodiversity		-50	-40	-85
Zone 8	Floodplain sedimentation		-95	-90	-95
	Extent of indigenous riparian and wetland vegetation		-5	-10	-45
	Fish biomass		-10	-10	-20
	OAA biomass		0	0	-5
	Biodiversity		-35	-25	-55

CHANGE considered negative for ecosystem **HEALTH**		
<70%	40 to 70%	20 to 39%

The possible exception to these predictions is Zone 4, where the drier climate (C3_2040Dry) is expected to lessen the negative impacts of elevated dry season flows on the riparian vegetation, herpetofauna and birds of the area, resulting in a slightly higher river condition. This is a small change relative to Scenario 2040, however, and in no way approaches the condition of Baseline 2007 (Figure 7.9).

The differences in geomorphological conditions and habitat quality; vegetation; macroinvertebrates; fish; herpetofauna; birds, and; mammals in the unimpounded section of the river between 2040CC and the climate-change sub-scenarios are illustrated in Figure 7.10, where blue bars denote a positive impact on ecosystem condition and red bars a negative impact on ecosystem condition.

Figure 7.9 Estimated Baseline 2007 ecological conditions of the mainstream ecosystems the LMB



For Zone 7, the Tonle Sap Great Lake, the incremental effects of a drier climate (C3_2040Dry) are more marked than for the other zones (Figure 7.8 and especially Figure 7.10). About 48% of the wet season volume of the Lake is derived from inflows other than the Mekong River (tributaries of the lake and rainfall), and it was noted earlier that because of this the Tonle Sap system is somewhat buffered against developments in the mainstream Mekong River. This does not buffer it against climate change, however, as shown by the severe impact of Scenario C3_2040Dry.

The Cambodian Floodplains (Zone 6) and the Vietnamese Delta (Zone 8) are most affected by the rise in sea level included in 2040CC, which would hold back floodwaters and increase flooding for comparable discharges. However, anti-flooding floodplain protection infrastructure (FPI) is at 2040 levels and will prevent much of the flooding that would be expected without it, and thus differences in flooding are muted, which carries forward into the differences in predicted ecosystem change.

The wetter climate futures are expected to mitigate some of the ecological impacts associated with the 2040 scenario but only slightly, and the drier climate future are expected to exacerbate these. All scenarios carry the important message that the effects of climate change, whether positive or negative, will become most apparent in the lower parts of the LMB, *viz*. Zones 6, 7 and 8. This is clear from the predictions for overall ecosystem health for each of the zones (Figure 7.11), which show minimal or no change in overall health for Zones 1-5 across the climate change sub-scenarios, but noticeable positive (blue) changes for Scenario C3_2040Wet and negative (red) changes for Scenario C3_2040Dry in Zones 6, 7 and 8, relative to 2040CC.

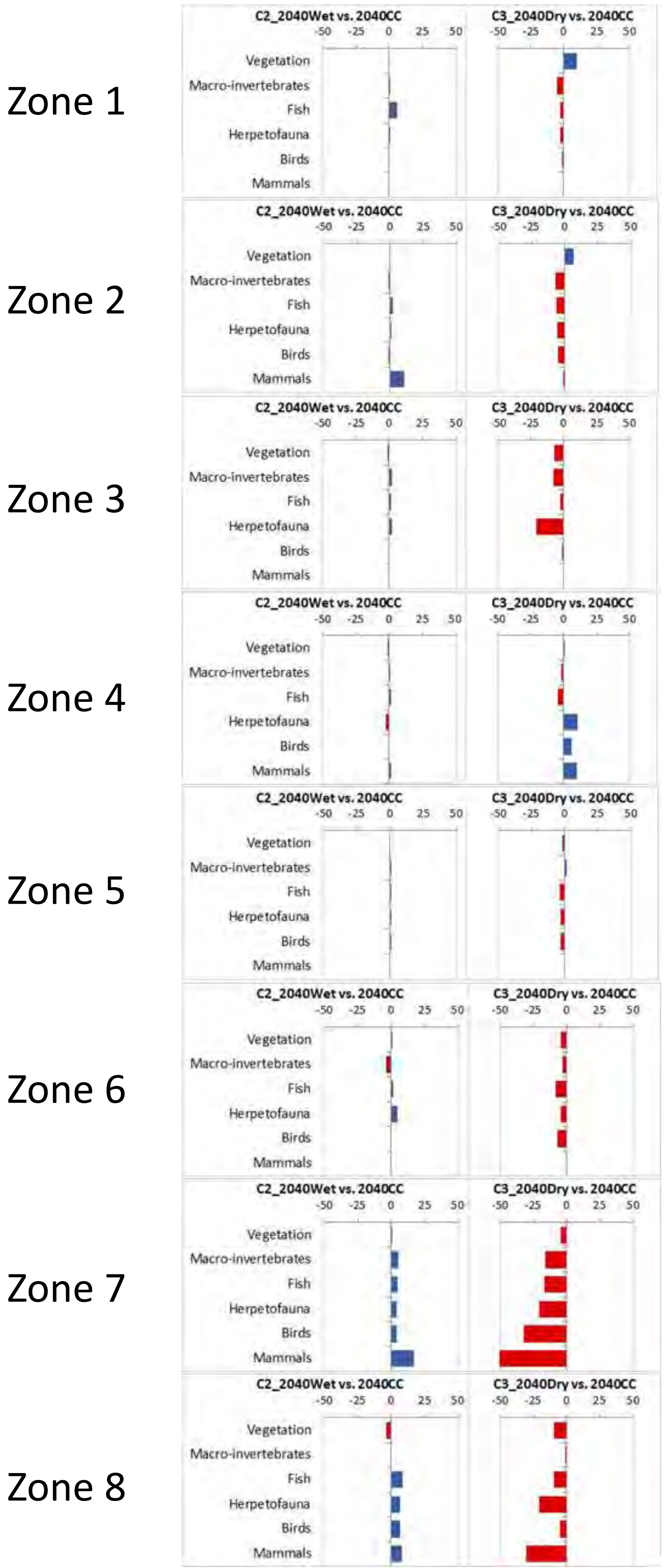


Figure 7.10 Difference in health for vegetation, macroinvertebrates, fish, herpetofauna, birds and mammals between 2040CC and the climate-change sub-scenarios.

The sensitivity of the Tonle Sap Great Lake to climate is evident in its predicted overall ecosystem health (Figure 7.11), which shows no change in category in Zone 7 from Scenario 2040CC to Scenario C2_2040Wet, but drops one whole health category (C/D to E) under the C3_2040Dry scenario. Similarly, Zone 8 (Viet Nam Delta) is expected to drop one half a category from Scenario 2040CC to Scenario C2_2040Dry.

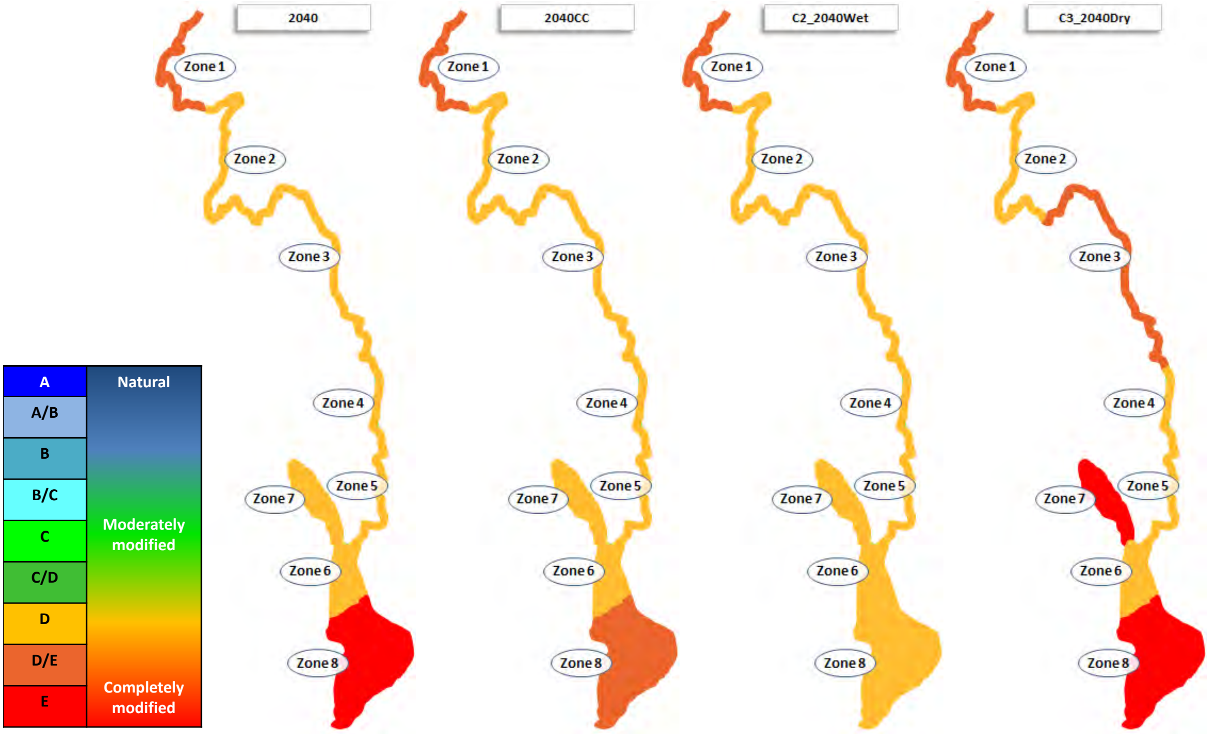


Figure 7.11 Mekong River condition predicted for the climate change sub-scenarios

The key messages from the climate change sub-scenarios are:

- A wetter climate future will mitigate some of the ecological impacts associated with Scenario 2040, but only slightly because flood protection measures are expected to limit the increase in flooding.
- A drier climate future will exacerbate the ecological impacts associated with Scenario 2040, especially in the lower parts of the LMB.
- For Tonle Sap Great Lake, the Cambodian floodplains and the Viet Nam Delta, the effects of a drier climate on ecosystem condition are greater than the positive effects of a wetter climate (see Figure 7.10 and Figure 7.11). This is partly due to the inflows from the Lake's tributaries and direct rainfall into the Lake that provide a buffer against changes in the mainstream Mekong River are reduced in the drier climate, but also because these systems are so dependent on flooding extent and duration, both of which are expected to be reduced under a drier climate.
- It is possible that the developments in Scenario 2040, would provide the downstream ecosystem with some level of protection against extreme flood events, but this could not be evaluated using the selected array of scenarios.

- The resilience of the LMB aquatic ecosystems, particularly Tonle Sap Great Lake, to a drier climate will be compromised by the developments in Scenario 2040.

7.2.2 Ecosystem response to agricultural landuse sub-scenarios

To assess the impacts of agricultural landuse on the river ecosystem, different levels of agricultural landuse were evaluated in terms of their relative impact on the Mekong River ecosystem. Comparisons were made between 2040CC and two sub-scenarios with different levels of landuse, *viz*. (Table 7.3):

A1_noALU: 2040CC but with agricultural landuse at 2007 levels;

A2_ALU: 2040CC but with a higher level of agricultural landuse than that modelled in the 2040CC scenario.

Table 7.3 Sub-scenarios to test the effects different levels of agricultural landuse

Scenario		Level of Development for water-related sectors						Climate
		ALU	DIW	FPI	HPP	IRR	NAV	
2040CC	Planned Development Scenario 2040CC	2040	2040	2040	2040	2040	2040	Mean warmer & wetter
A1_noALU	Planned Development 2040 without ALU	2007	2040	2040	2040	2040	2040	
A2_ALU	Planned Development 2040 with HIGH ALU	HIGH	2040	2040	2040	2040	2040	

The outputs for key BioRA summary indicators for the 2040CC and two agricultural landuse sub-scenarios relative to the 2007 Baseline scenario are shown in Figure 7.12. The differences in geomorphological conditions and habitat quality; vegetation; macroinvertebrates; fish; herpetofauna; birds, and; mammals in the unimpounded section of the river between 2040CC and the agricultural landuse sub-scenarios are illustrated in Figure 7.13. <u>Importantly, these all incorporate the estimated 2040 floodplain protection infrastructure</u>. The impacts on the ecosystem resulting from agricultural landuse change and floodplain protection are often similar, interconnected, and extremely difficult to separate. This means that the effects of agricultural landuse distinguishable using the agricultural landuse sub-scenarios are almost certainly underestimated as the assessment assumes that the differences in agricultural landuse between the sub-scenarios do not affect flooding.

The key BioRA summary indicators show that the predicted changes under the three scenarios are very similar (Figure 7.12), although not identical, which suggest that developments other than agricultural landuse are the drivers of ecosystem change predicted in the scenarios. This is possibly because much of the riparian zone had already been converted to agriculture by 2007, and/or because the effects of herbicide and pesticide use are not considered and/or because these do not distinguish the impacts of flood protection.

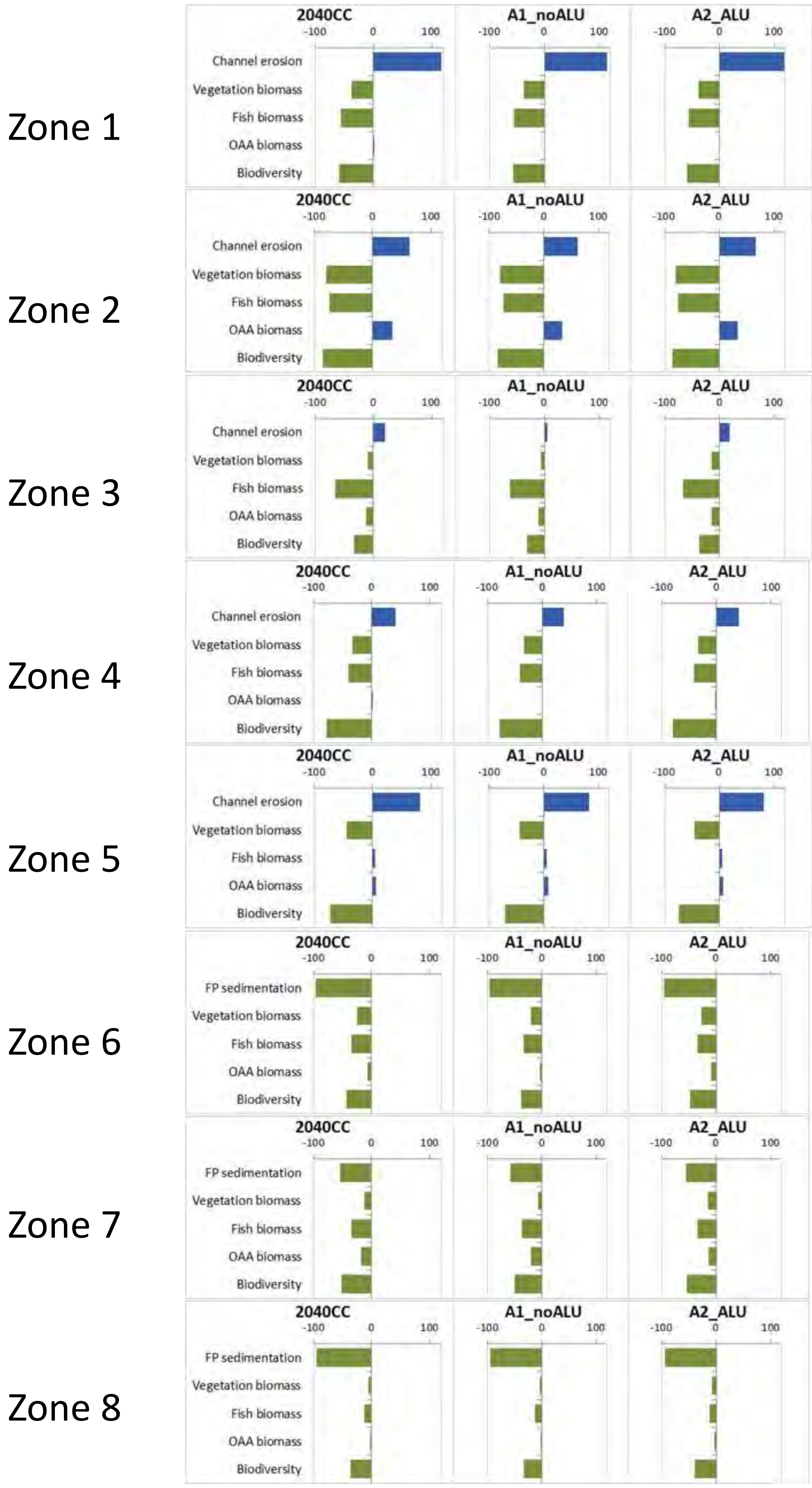


Figure 7.12 Predicted changes from 2007 Baseline in key ecosystem indicators for the BioRA zones for the agricultural landuse sub-scenarios (left to right): 2040CC, A1-noALU and A2_ALU. FP = floodplain; OAA = Other Aquatic Animals.

The incremental effects of the differences in the geomorphological conditions and habitat quality; vegetation; macroinvertebrates; fish; herpetofauna; birds, and; mammals in the unimpounded section of the river between 2040CC and the agricultural landuse sub-scenarios are shown in Figure 7.13, where blue bars denote a positive impact on ecosystem condition and red bars a negative impact on ecosystem condition.

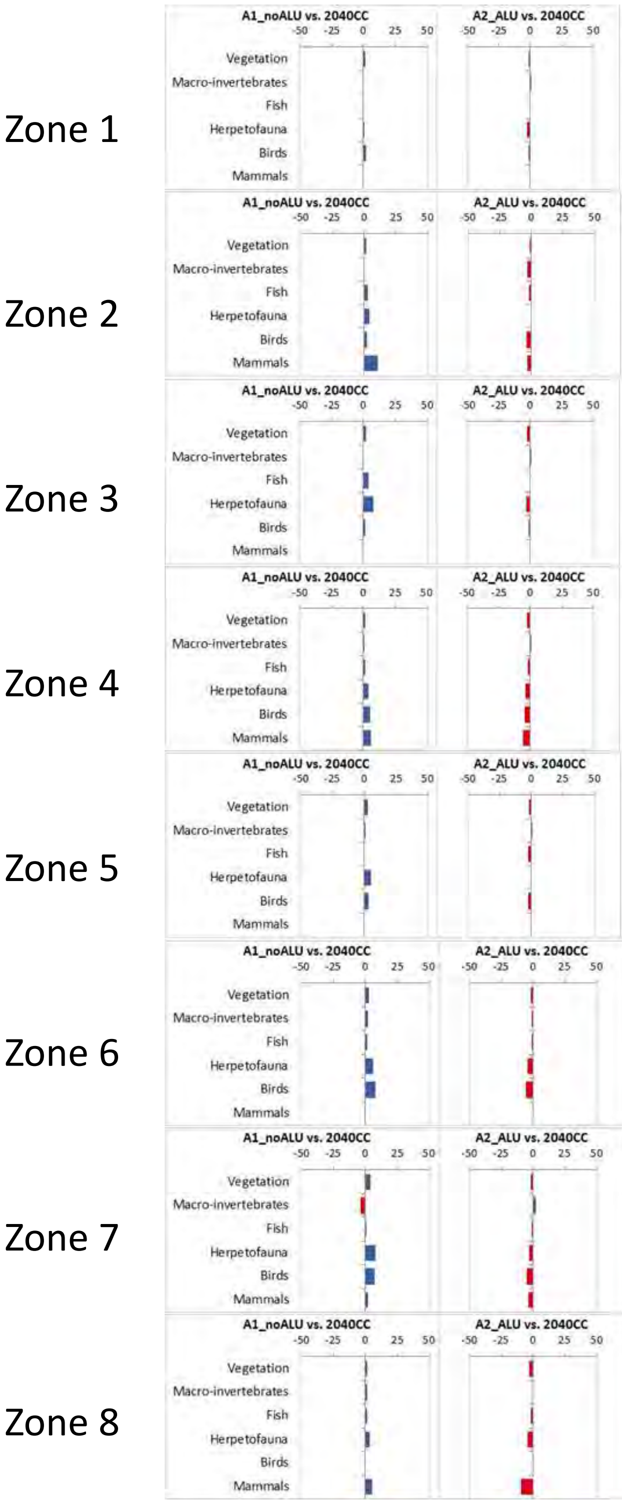


Figure 7.13 Difference in health for vegetation, macroinvertebrates, fish, herpetofauna, birds and mammals between 2040CC and the agricultural landuse sub-scenarios.

For the most part, reducing agricultural landuse to 2007 levels is predicted to result in slightly better ecosystem conditions relative to 2040CC (blue bars in Figure 7.13), even with all other developments at 2040 levels. Conversely, increasing the level of agricultural landuse above those in the Scenario 2040CC is expected to lead to slightly poorer ecosystem conditions relative to 2040CC (red bars in Figure 7.13). Under A2_ALU in Zone 6, the modelled duration of floodplain inundation is longer than for 2040CC, which favours some components of the ecosystem, e.g., the flooded forest and herbaceous march, and results in slightly better predicted conditions for A2_ALU.

While agricultural landuse developments undoubtedly do have an effect on aquatic ecosystems, both sets of results (Figure 7.12 and Figure 7.13) suggest that, in the context of the Council Study, impacts that may have been associated with changes agricultural landuse are largely masked by the impacts of the other sector developments comprising Scenario 2040CC, particularly when the effects of herbicide and pesticide use are not considered.

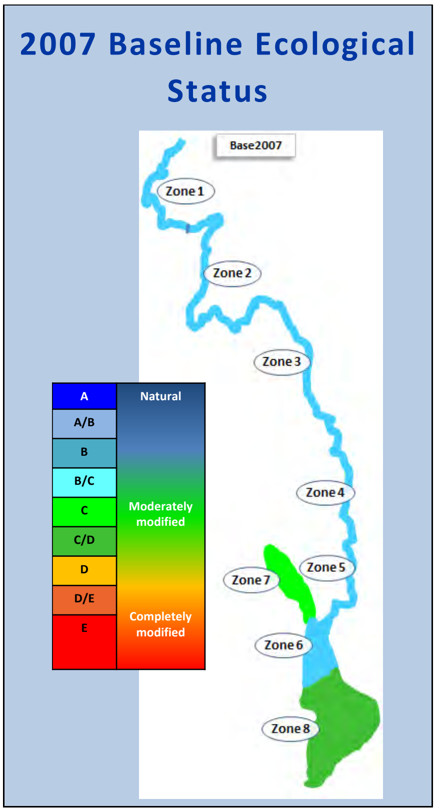


Figure 7.14 Estimated Baseline 2007 ecological conditions of the mainstream ecosystems the LMB

The differences between Scenario 2040CC and the agricultural landuse sub-scenarios are insufficient to affect the predictions for overall ecosystem health except in Zone 8, where they translate into an increase in overall ecosystem health in the Delta (Zone 8) under A1-noALU (Figure 7.15). This is a small change relative to Scenario 2040, however, and in no way approaches the condition of Baseline 2007 (Figure 7.14).

The ecosystem condition categories that result from increased agricultural landuse (A2_ALU) to levels higher than those included in Scenario 2040CC are similar to Scenario 2040CC (Figure 7.15).

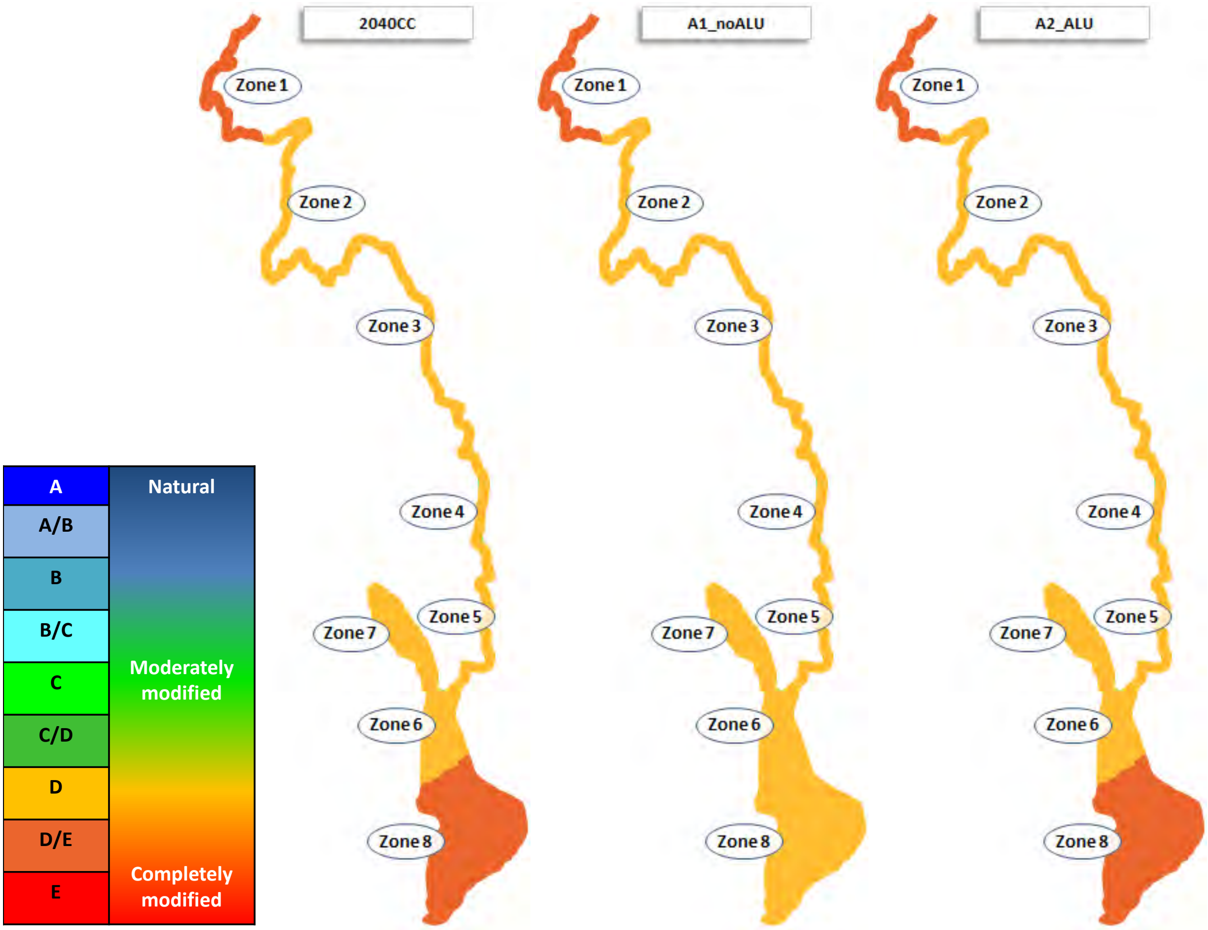


Figure 7.15 Mekong River condition predicted for the agricultural landuse sub-scenarios

The key messages from the agricultural landuse sub-scenarios are:

- In the context of the Council Study, incremental hydrological-, hydraulic- and sediment-related impacts associated with agricultural landuse development are masked by the much greater impacts associated with the other sector developments comprising Scenario 2040CC.
- However, it was not possible to capture the full extent of some of impacts associated with agricultural landuse. For instance:
    - herbicide and pesticide use could have a devastating impact on the plants and animals at the base of the food chain in the LMB, but was not included in the assessment;
    - detailed and localised impacts associated with loss of habitat as a result of conversion to agricultural fields are not captured.

7.2.3 *Ecosystem response to irrigation sub-scenarios*

To assess the impacts of irrigation on the ecosystem, comparisons were made between 2040CC and two sub-scenarios with different levels of irrigation development, *viz*. (Table 7.4):

I2_IRR: 2040CC but with irrigation development at 2007 levels;

2040CCI2: 2040CC but with a higher level of irrigation development than that modelled in the 2040CC scenario.

Table 7.4 Sub-scenarios to test the effects of development in the irrigation sector

Scenario		Level of Development for water-related sectors						Climate
		ALU	DIW	FPI	HPP	IRR	NAV	
2040CC	Planned Development Scenario 2040CC	2040	2040	2040	2040	2040	2040	Mean warmer & wetter
I1_noIRR	Planned Development 2040 without IRR	2040	2040	2040	2040	2007	2040	
I2_IRR	Planned Development 2040 with IRR HIGH	2040	2040	2040	2040	HIGH	2040	

Values for the key BioRA summary indicators and ecosystem indicators indicate that the sub-scenarios are almost identical to Scenario 2040CC (Figure 7.17). This suggests that developments other than abstraction for irrigation are the drivers of ecosystem change in the Council Study development scenarios.

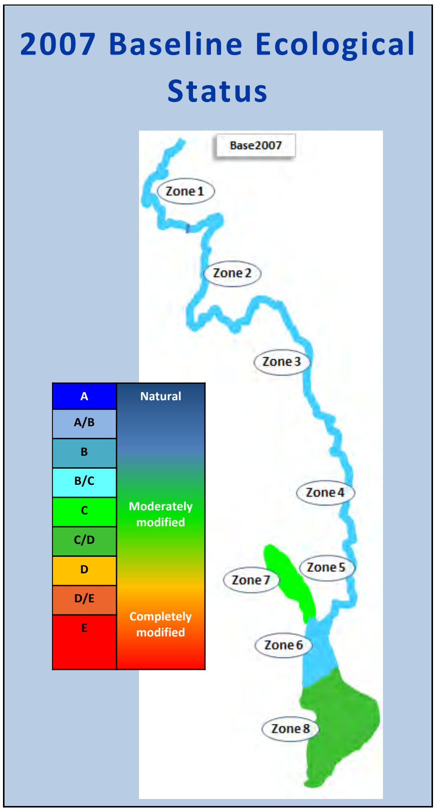


Figure 7.16 Estimated Baseline 2007 ecological conditions of the mainstream ecosystems the LMB

In Zone 5, 6 and 7, predicted discipline condition is higher for the I1_noIRR scenario, although this is only very slightly so (Figure 7.18). In Zone 6 and 8, slight improvements in condition relative to Scenario 2040CC are predicted for I2_IRR (Figure 7.18), but this is more likely a reflection of slight inconsistencies in the modelling than a true reflection of the impact of the level of irrigation development.

The small predicted differences between Scenario 2040CC and the irrigation sub-scenarios do not affect overall ecosystem health in the mainstream ecosystems of the LMB (Figure 7.19).

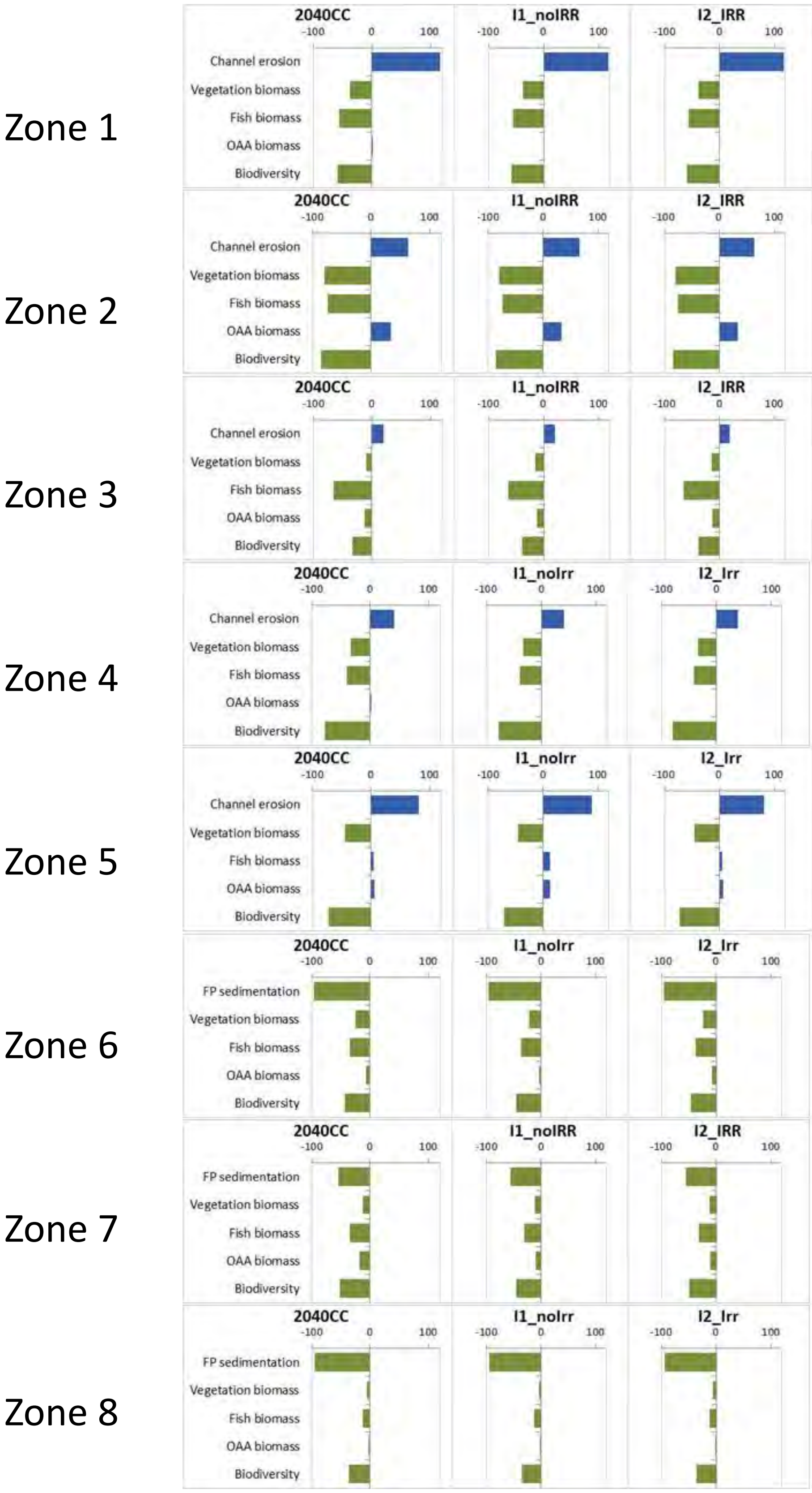


Figure 7.17 Predicted changes from Baseline in key ecosystem indicators for the BioRA zones for the irrigation sub-scenarios (left to right): 2040CC; I1_noIRR and I2_IRR. FP = floodplain; OAA = Other Aquatic Animals.

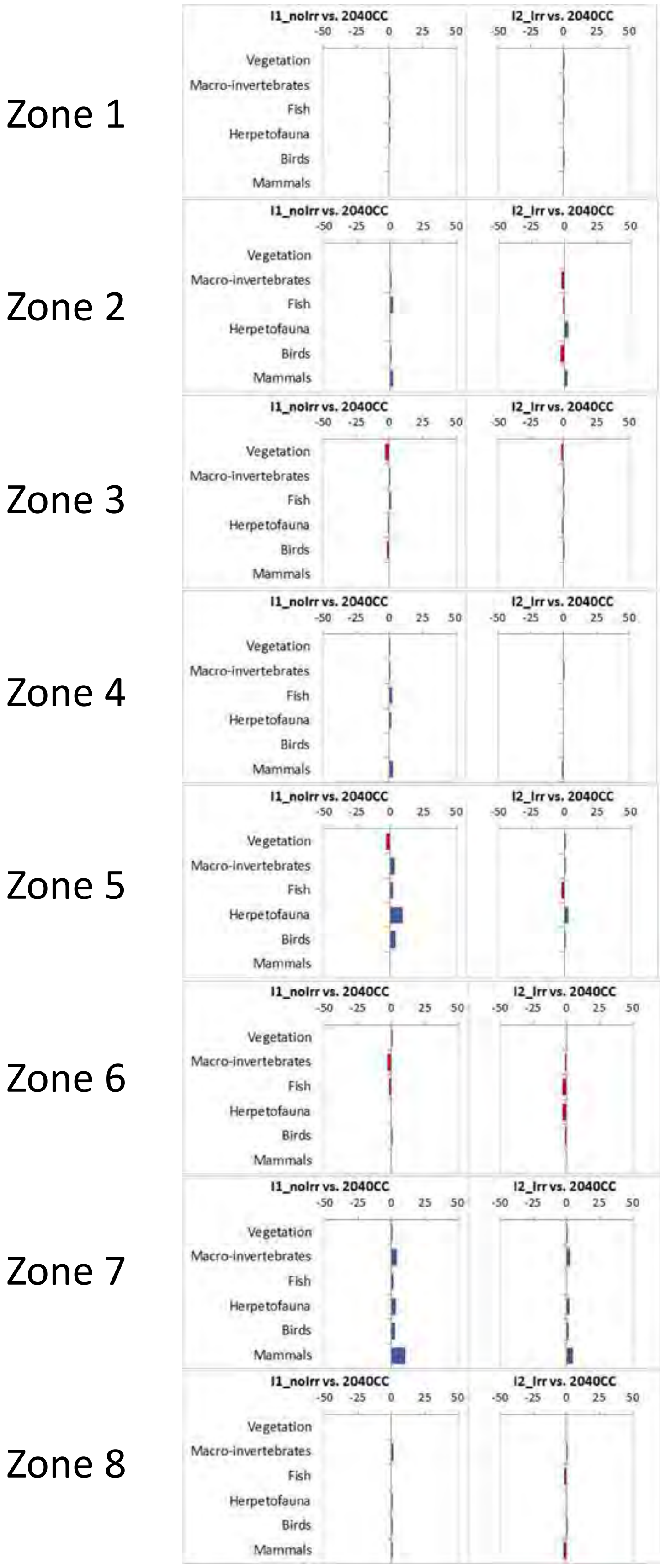


Figure 7.18 Difference in health for vegetation, macroinvertebrates, fish, herpetofauna, birds and mammals between 2040CC and the irrigation development sub-scenarios.

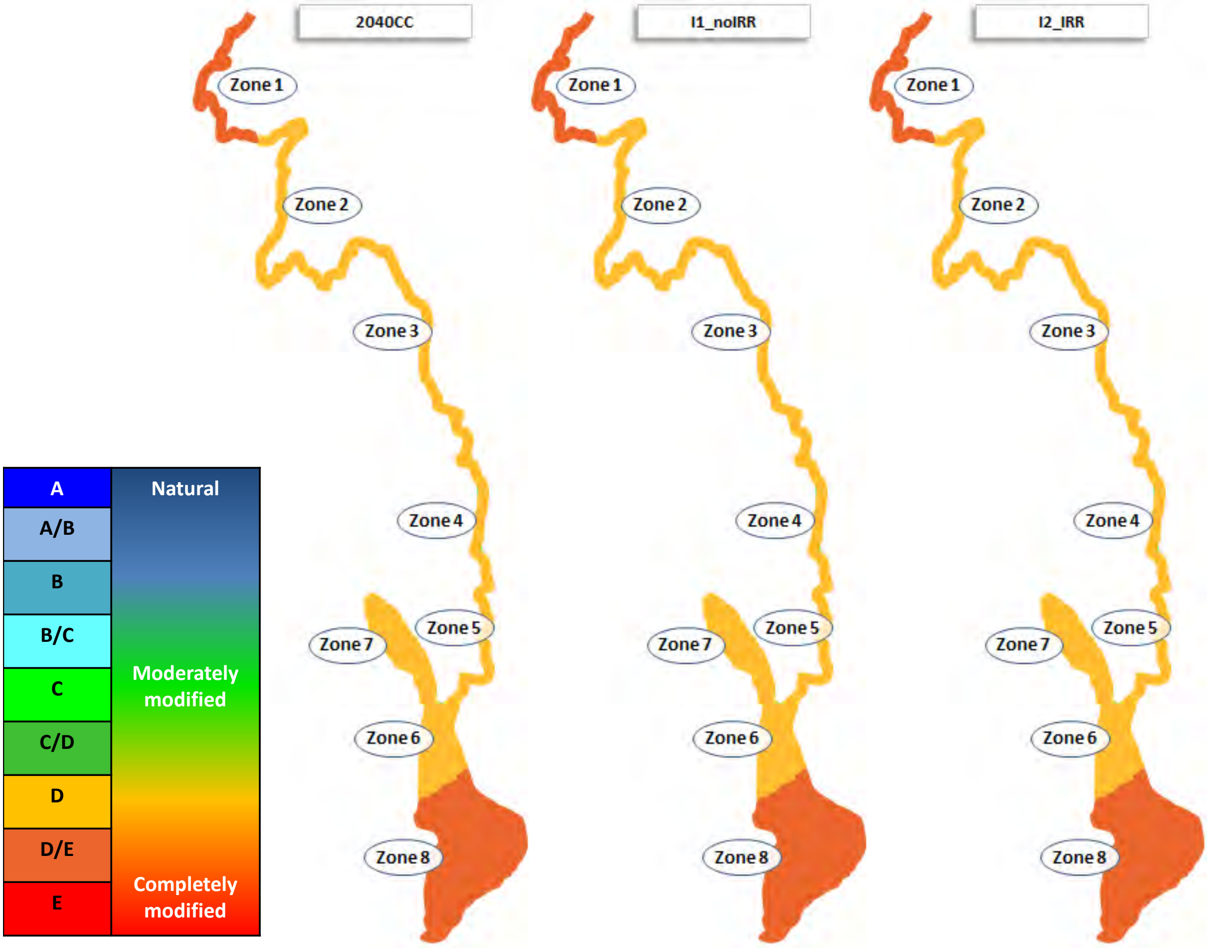


Figure 7.19 Mekong River condition predicted for the irrigation sub-scenarios

The key messages from the irrigation sub-scenarios are:

- The small differences in predicted change between Scenario 2040CC and the irrigation sub-scenarios do not affect overall ecosystem health in the LMB.
- In the context of the Council Study, incremental impacts associated with irrigation are masked by the much greater impacts associated with the other sector developments comprising Scenario 2040CC.
- It is possible that the modelled data do not capture the full extent of impacts associated with irrigated crops. For instance, herbicide and pesticide use was not modelled but could have a devastating impact on the plants and animals at the base of the food chain in the LMB.

7.2.4 Ecosystem response to flood-protection infrastructure sub-scenarios

To assess the effect of flood-protection infrastructure on the environment, three different sets of assumptions about flood protection were paired with Scenario 2040CC, and evaluated in terms of their relative impact on the Mekong River ecosystem, *viz*. (Figure 7.11):

F1_noFPI: 2040CC but with flood-protection infrastructure at 2007 levels;

F2_FPI: 2040CC but with a higher level of flood-protection infrastructure than that modelled in the 2040CC scenario (see Table 3.4).

F3_FPI: 2040CC with flood protection infrastructure at 2020 and with joint operation of mainstream dams and selected tributary dams to reduce flooding.

Table 7.5 Sub-scenarios to test the effects of flood-protection infrastructure

Scenario		Level of Development for water-related sectors						Climate	Floodplain development
		ALU	DIW	FPI	HPP	IRR	NAV		
2040CC C	Planned Development Scenario 2040CC	2040	2040	2040	2040	2040	2040	Mean warmer & wetter	2040
F1_noFPI	Planned Development 2040 without FPI	2040	2040	2007	2040	2040	2040		
F2_FPI	Planned Development 2040 with FPI HIGH	2040	2040	HIGH	2040	2040	2040		
F3_FPI	2040CC with flood protection infrastructure at 'Level 3'	2040	2040	2020, plus dams	2040	2040	2040		

The outputs for key BioRA summary indicators for the 2040CC and the three additional flood-protection sub-scenarios relative to the 2007 Baseline scenario are shown in Figure 7.20.

The differences in the health of geomorphology (habitat quality); vegetation, macroinvertebrates, fish, herpetofauna, birds and mammals in the unimpounded section of the river between 2040CC and the flood-protection infrastructure sub-scenarios are illustrated in Figure 7.21. As expected, the outcomes closely reflect the relative proportions of expected change in floodplain inundation as a result of floodplain protection infrastructure applied for Scenario 2040 and the sub-scenarios, and should be evaluated in the context of these.

Based on the modelled outcomes, beyond a very slight predicted increase in impacts in one or two zones, the changes in the floodplain protection have little or no additional effect on the key BioRA indicators *for the channel* in Zones 1-5. The results for Zones 1, 2, 4 and 5 suggest that, in the context of the Council Study, any impacts on the channel that may have been associated with floodplain infrastructure are masked by the impacts of the other sector developments comprising Scenario 2040CC.

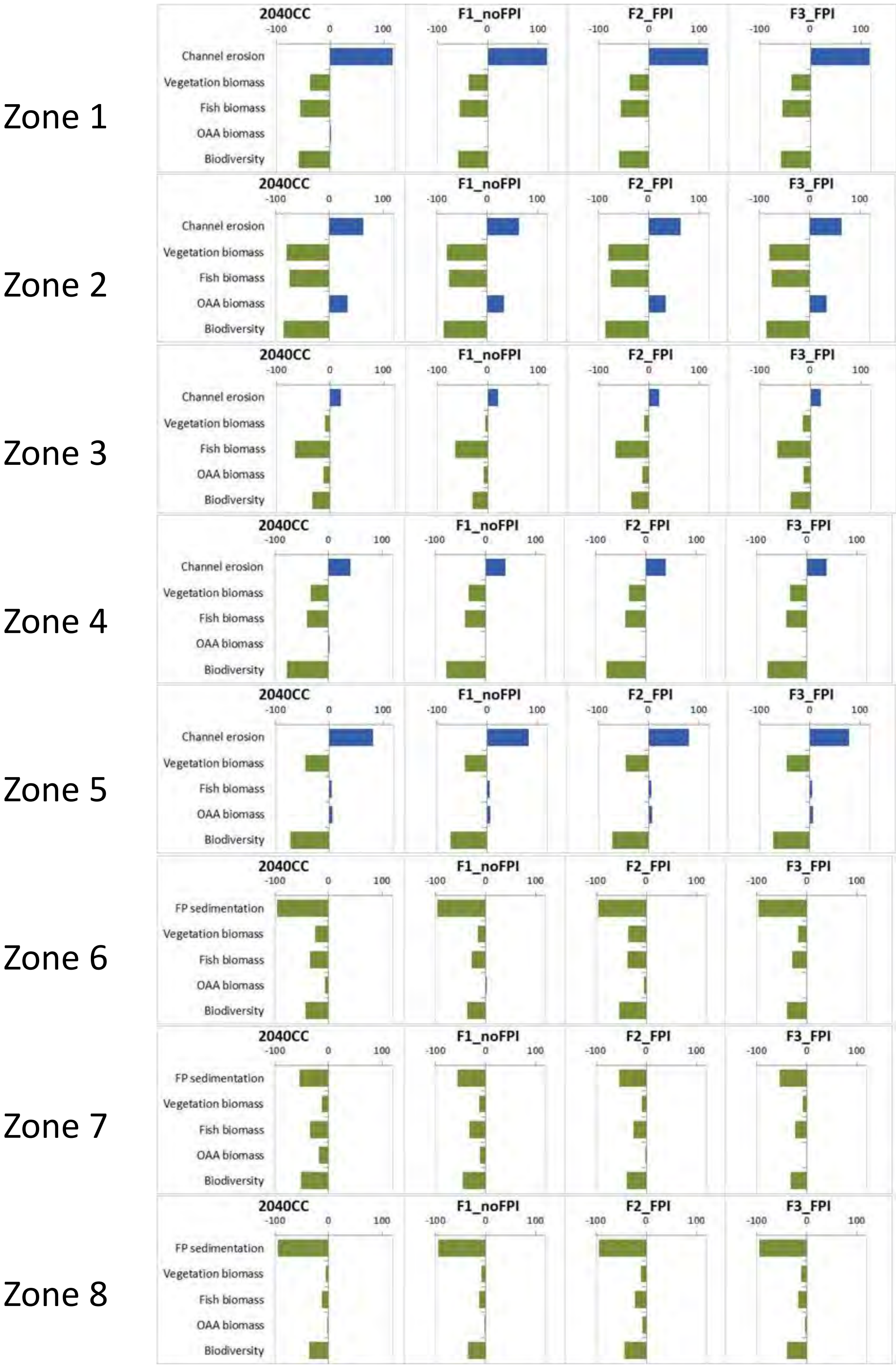


Figure 7.20 Predicted changes from Baseline in key ecosystem indicators for the BioRA zones for the flood-protection sub-scenarios (left to right): 2040CC; F1_noFPI, F2_FPI and F3_FPI. FP = floodplain; OAA = Other Aquatic Animals.

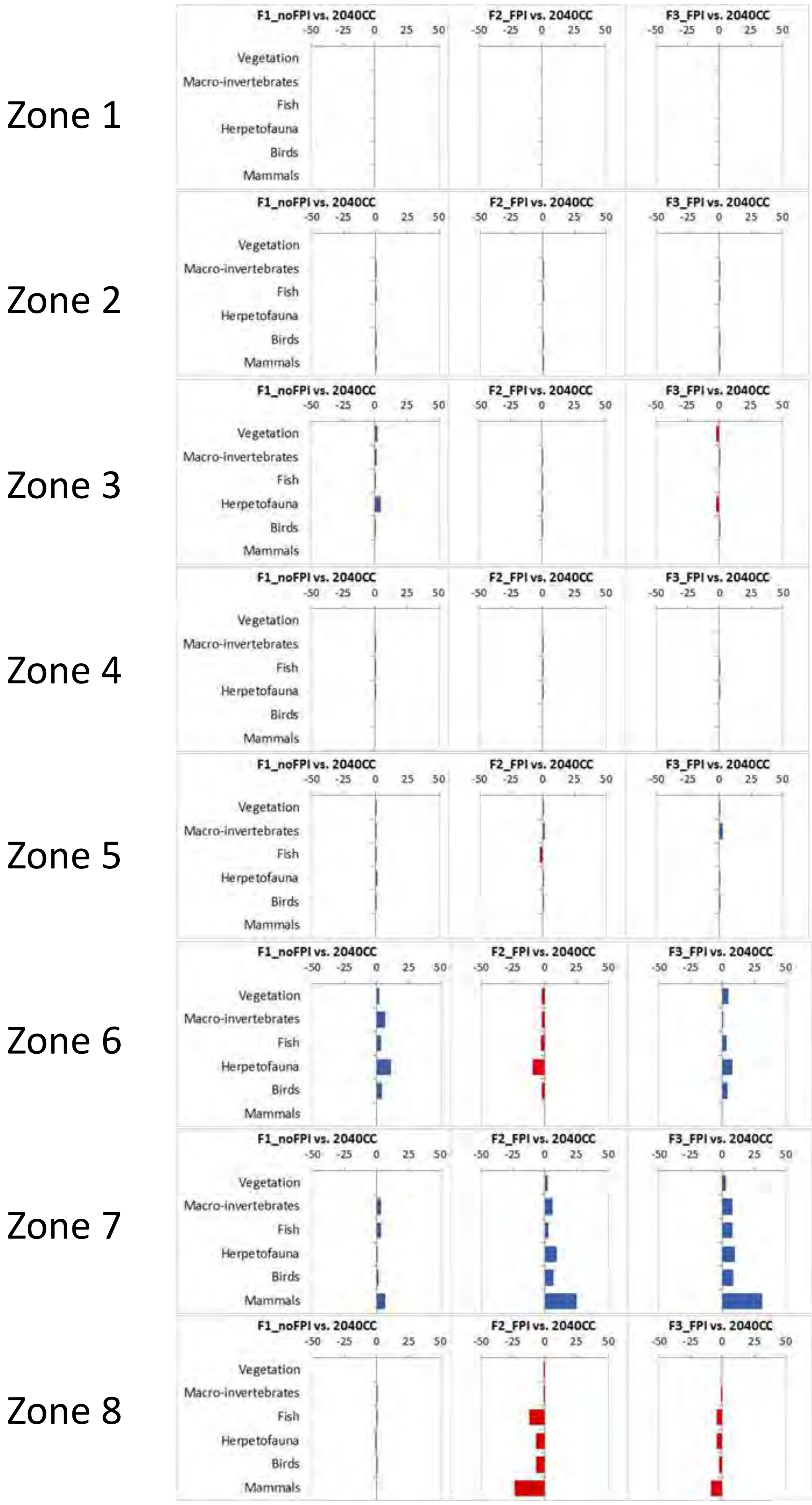


Figure 7.21 Difference in health for vegetation, macroinvertebrates, fish, herpetofauna, birds and mammals between 2040CC and the flood-protection infrastructure sub-scenarios

For the floodplains of Zone 3, 6 and 7, reducing the influence of floodplain infrastructure (F1_noFPI) to *c*. 2007 is predicted to lead to increased flooded areas and a slight concomitant increase in ecosystem condition. This is most marked in Zone 6 where, for example, urban and peri-urban development in the Chaktomuk has had a considerable influence on flooding frequency, extent and duration (Figure 7.22[122]); although much of this pre-dates 2007.

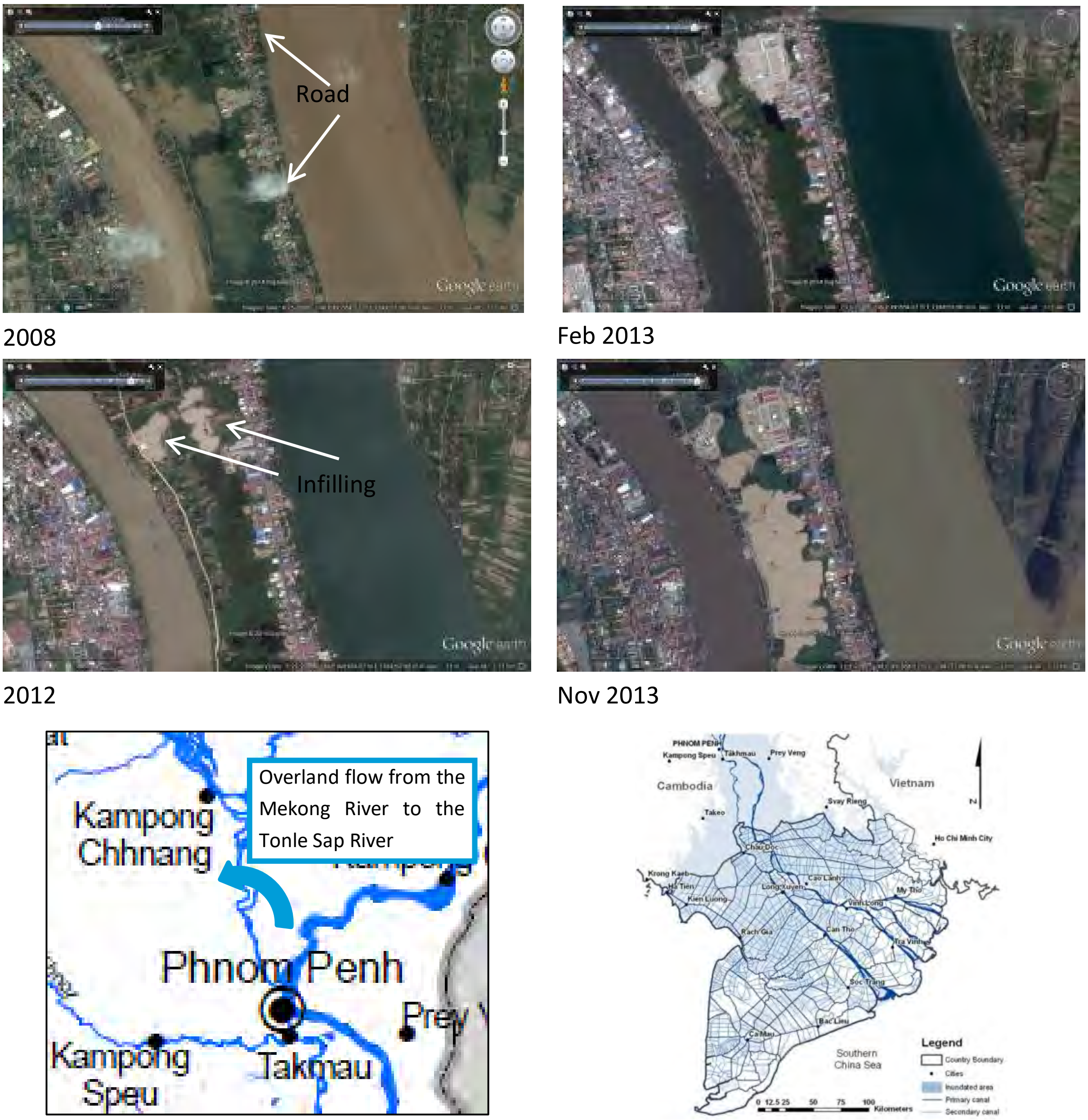


Figure 7.22 Top 4 photographs: Time-series of progressive infilling of the floodplain between the Mekong and Tonle Sap Rivers (adapted from WorldFish Center 2007). Bottom left: Map showing route of historic overland flow from Mekong mainstream to Tonle Sap. Exchange has been limited by road construction and floodplain infilling. Bottom right: Canal network in the Mekong Delta (MRC 2005).

[122] Geomorphology section. BioRA Technical Report Series: Volume 1: Specialists' Report

Canalisation of the Delta, and the development of roads and other raised infrastructure that limit the flow of water onto or within the floodplain, also predates Baseline 2007 (Figure 7.22), and the any influence on ecosystem condition of the relatively small changes in flooding applied for F1_noFPI are masked by the impact of other sector developments (Figure 7.21), which are predicted to considerably reduce the condition relative to Baseline 2007 (Figure 7.23).

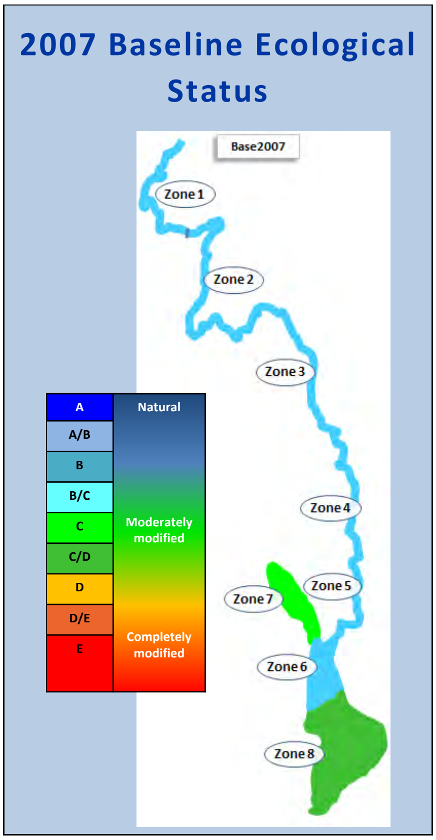


Figure 7.23 Estimated Baseline 2007 ecological conditions of the mainstream ecosystems the LMB

The floodplain protection infrastructure modelled in F2_FPI is designed to reduce flooding relative to 2040CC and as such is predicted to also reduce habitat for riverine species (Figure 7.11) leading to a decline in overall ecosystem condition relative to Scenario 2040CC. In Zones 1-6, this influence is minor relative to the other sectors (small red bars in Figure 7.11), but is more marked in the Delta (Zone 8). In Zone 7, the Tonle Sap Great Lake, there are no physical flooding limitations or defenses applied, and so the F2_FPI leads to greater flooding, presumably as a result of less flood storage in the upstream zones, are thus improved ecological conditions relative to Scenario 2040. Further encroachment into the Tonle Sap Authority outer zones may affect flooding, but this was not accounted for in the modelled scenarios.

F3_FPI has the floodplain infrastructure at 2020 levels but includes synchronised dam operations to reduce large floods. This is expected to lead to more regular homogenous flooding relative to the varied flooding predicted as a result of climate change in Scenario 2040CC. The more homogenous flooding is expected to benefit the large floodplain ecosystems in Zones 6 and 7. In the result for the Delta is more difficult to explain, and is possibly related to the fact that the larger floods overtop the flooding defences, whereas a large proportion of the more regular homogenous floods in F3_FPI are prevented from reaching the floodplain. Thus, floodplain inundation is predicted to be less under F3_FPI than under 2040CC, resulting in the negative consequences of the ecosystem shown in Figure 7.21.

The small predicted differences between Scenario 2040CC and the irrigation sub-scenarios with respect to overall ecosystem health in the mainstream ecosystems of the LMB are illustrated in Figure 7.24, which underscores the message that the effects on the ecosystem of floodplain protection as modelled in the Council Study are likely to be most distinguishable from the effects of other sectoral developments in the lower parts of the LMB. Both F1_noFPI and F3_FPI are predicted to result in improved conditions in the Cambodian portions of the LMB relative to Scenario 2040CC, with F3_FPI resulting in one half a category improvement for both Zone 6 and Zone 7. F2-FPI is generally slightly prejudicial for ecosystem health, particularly in the Delta, where it is predicted to lead to a one half category decline in ecosystem condition.

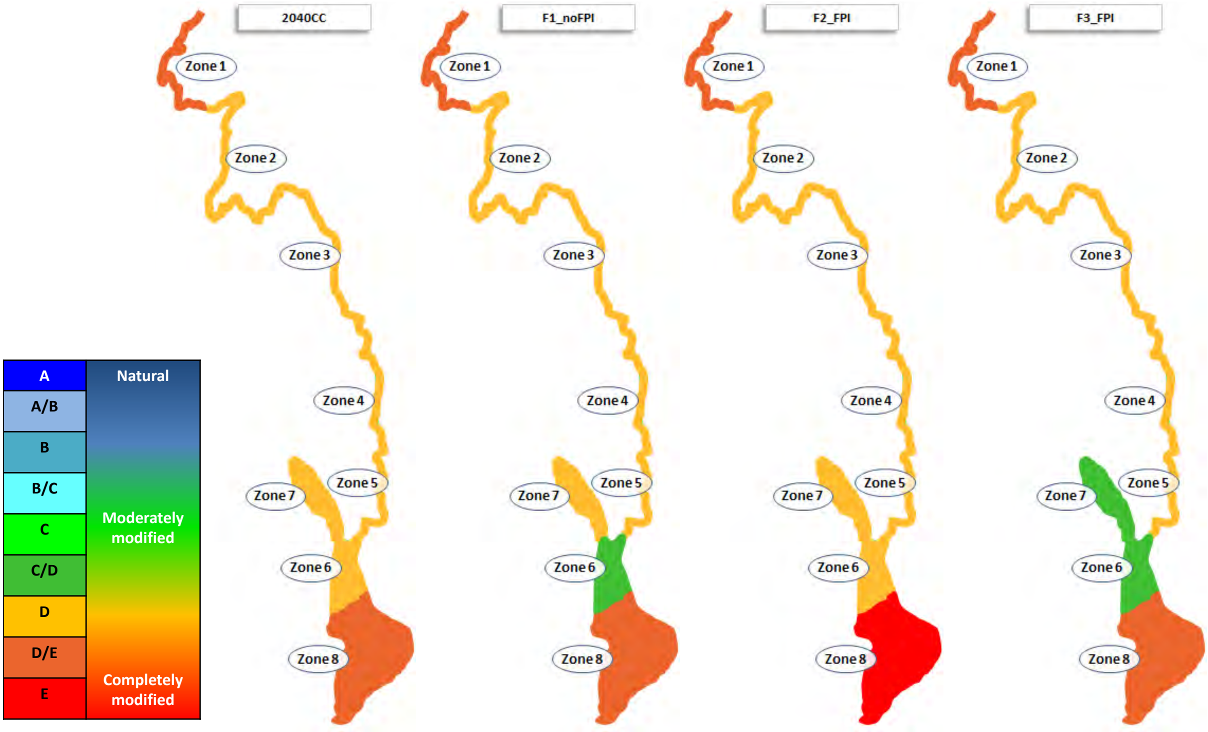


Figure 7.24 Mekong River condition predicted for the flood protection sub-scenarios

The key messages from the floodplain infrastructure sub-scenarios are:

- The BioRA outcomes for the floodplain protection sub-scenarios closely reflect the relative proportions of expected change in floodplain inundation applied for Scenario 2040 and the sub-scenarios, and these can be adjusted in later runs of the DSS to see the effect of difference assumptions.
- The small differences in predicted change between Scenario 2040CC and the floodplain infrastructure sub-scenarios do not affect overall ecosystem health in the upper portions of the LMB as the incremental impacts associated with floodplain infrastructure developments are masked by the much greater impacts associated with the other sector developments comprising Scenario 2040CC.
- The combination of floodplain infrastructure at 2020 levels and synchronised dam operations to reduce large floods delivered the largest mitigation of floodplain infrastructure impacts imbedded in the 2040CC scenario.

7.2.5 *Ecosystem response to hydropower sub-scenarios*

To assess the effect of hydropower on the environment, three[123] different levels of hydropower development and/or operation were paired with Scenario 2040CC, and evaluated in terms of their relative impact on the Mekong River ecosystem (Table 7.6), *viz*.:

H1a_noHPP: 2040CC but with hydropower at 2007 levels;

H1b_nomainHPP: 2040CC with the Lancang HPPs and 2040 tributary HPPs, but with no main channel dams in the LMB;

H2_HPP: Identical to Scenario 2040CC, and so excluded from further analyses;

H3_HPP: 2040CC but with consideration of mitigation measures and operations at the HPPs, which are outlined in the Hydropower Thematic Report.

Table 7.6 Sub-scenarios to test the effects different levels of hydropower development

Scenario		Level of Development for water-related sectors						Climate
		ALU	DIW	FPI	HPP	IRR	NAV	
2040CC	Main Development Scenario 2040CC	2040	2040	2040	2040	2040	2040	Mean warmer & wetter
H1a_noHPP	2040CC with both the Lancang HPPs and LMB hydropower development at 2007 levels	2040	2040	2040	2007	2040	2040	
H1b_nomainHPP	2040CC with the Lancang HPPs and tributary dams at 2040 levels	2040	2040	2040	2040, excl. LMB mainstream dams	2040	2040	
H2_HPP	Same as 2040CC	2040	2040	2040	2040	2040	2040	
H3_HPP	2040CC but with consideration of mitigation measures and operations at the HPPs	2040	2040	2040	2040 with mitigation measures	2040	2040	

The modelled *flow changes* associated with mainstream and tributary hydropower plants are negligible[124], and thus most of the predicted differences in impacts between the hydropower sub-scenarios relate to differences in their modelled effects on sediment movement and fish migration.

The outputs for key BioRA summary indicators for the 2040CC and the three hydropower sub-scenarios relative to the 2007 Baseline are shown in Figure 7.25, which shows that the predicted

[123] H2_HPP is the same as Scenario 2040CC, so excluded from the analysis.
[124] Although measured data suggest changes in seasonality of flows may be a factor.

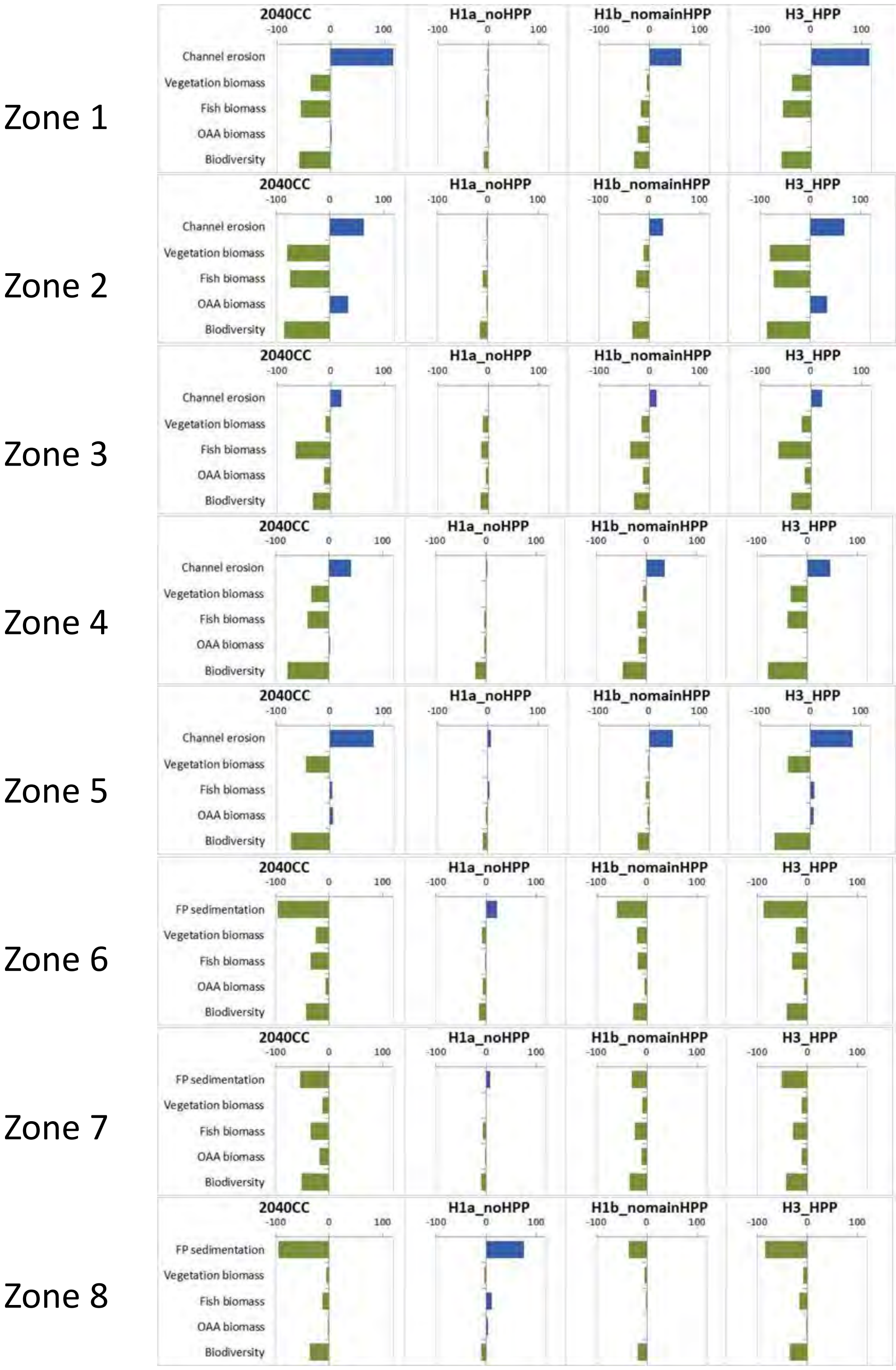


Figure 7.25 Predicted changes from Baseline in key ecosystem indicators for the BioRA zones for the hydropower sub-scenarios (left to right): 2040CC, H1a_noHPP, H1b_nomainHPP and H3_HPP. FP = floodplain; OAA = Other Aquatic Animals.[125]

---

[125] H2_HPP is the same as 2040CC – and so is not shown.

outcomes for H1a-HPP are similar to those for Baseline 2007, except that H1a_HPP has greater floodplain sedimentation in Zone 8. This is because it is underlain by 2040CC climate change, which has higher flows than 2007 Baseline. H1b-HPP outcomes are considerably better than those for 2040CC, reflecting the removal of the connectivity impacts associated with the main channel dams. The results for 2040CC and H3_HPP, relative to 2007 Baseline, are very similar.

The differences in the health of geomorphology (habitat quality); vegetation, macroinvertebrates, fish, herpetofauna, birds and mammals in the unimpounded section of the river between 2040CC and the hydropower sub-scenarios are illustrated in Figure 7.26, and Figure 7.27 provides additional detail on the expected impacts on basin-wide fish biomass and community structure.

Possibly somewhat unexpectedly, in Zones 1-4, macroinvertebrates, herpetofauna and, to a certain extent, birds are expected to fare slightly better under 2040CC than under H1a_noHPP or H1b_HPP (red bars in Figure 7.26). This is because the elevated dry season flows[126], reduced sediment loads and enhanced algal growth under 2040CC relative to H1a_noHPP will favour some groups. For instance, insects on rocks are predicted to benefit from the higher lowflows and increase availability of rocky substrate under 2040CC, and are a major component of the diet of birds such as rocky crevice nesters. For the most part though, the BioRA predictions linked with H1a_noHPP, including those for biomass and structure of fish communities, approximate those for Baseline 2007. Indeed in some instances, the outcome for H1a_noHPP is slightly better than baseline. This is partly because of influence of the warmer wetter climate that underlies the hydrological and hydraulic aspects of H1a_noHPP, but also a product of the greater inundation and sediment/nutrient supply to the Delta in the modelled input data. Nonetheless, given that H1a-NoHPP includes all planned 2040 water-resource developments for the other sectors, the similarities in the outcomes between H1a_noHPP and Baseline 2007 underscore the overriding influence of hydropower in the Council Study water-resource scenarios.

The predicted impacts for H1b_nomainHPP are also considerably lower than those for 2040CC because:

- the assumptions about sediment management in the tributary dams used in modelling H1b_nomain HPP limit the sediment loss in Zones 2-5[127] to ~60% of 2007 Baseline (whereas for 2040CC it is ~90%). Thus, erosion and the impacts on habitats is similarly lower, and deposition of sediments onto the floodplains in the lower parts of the LMB are higher;
- there are no barriers to the movement of sediments, fish or other biota in the mainstream; although the tributary HPPs still represent barriers for migrating fish and other biota.

[126] Modelled dry season flows for 2040CC and H1b-nomainHPP at Zones 1-5 are ~40% higher than 2007 Baseline; whereas modelled dry season flows for H1a_noHPP are ~10% lower than 2007 Baseline.
[127] In Zone 1, predicted channel erosion for H1b-nomainHPP is very similar to 2040CC because they are subjected to similar sediment loses and flows from the Langcang cascade.

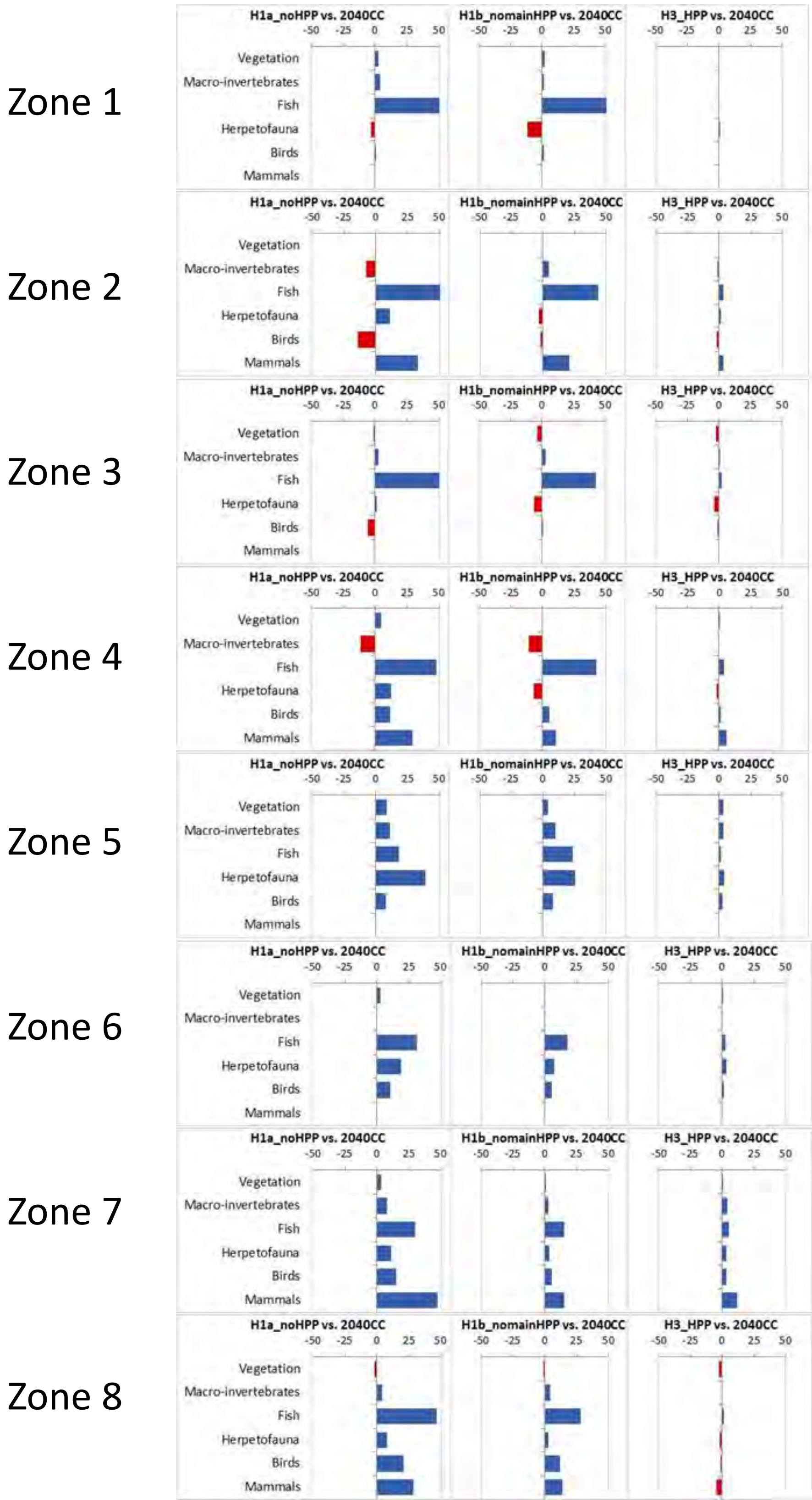


Figure 7.26 **Difference in health for geomorphology (habitat quality); vegetation, macroinvertebrates, fish, herpetofauna, birds and mammals between 2040CC and the hydropower sub-scenarios**

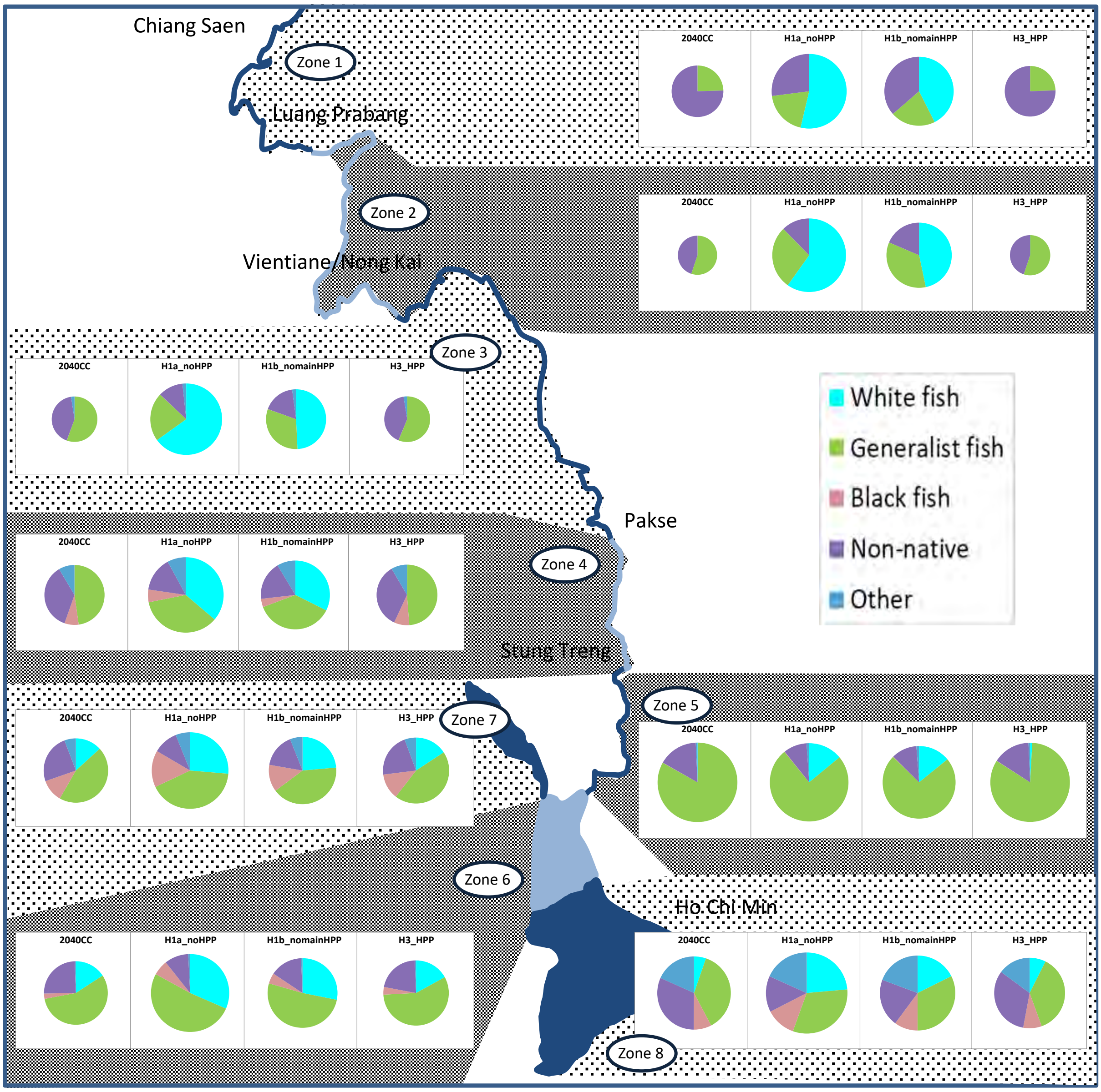


Figure 7.27 Nett (river and reservoirs combined) proportional predicted change in fish biomass and composition for the mainstream Mekong in the LMB for the hydropower sub-scenarios relative to 2040CC. Size of circle = biomass.

H3_HPP deals with mitigation measures incorporated into the hydropower projects in 2040CC. These included fish passes, a minimum flow and flushing in the main channel dams[128]. Of these, only sediment flushing was not already included in 2040CC (the efficacy of fish passage measures in facilitating upstream *and* downstream migration past the main channel dams was set at 50% for Scenario 2040CC). The amelioration of impacts as a result of the sediment flushing is illustrated by the blue bars in Figure 7.26. These indicate that H3_HPP would have very slightly lower impacts that 2040CC in Zones 2, 3, 4 and 5, and more marked improvements in Zones 6, 7 and 8. The reduction in

[128] Hydropower Thematic Report

impacts is directly related to greater sediment (and thus nutrient) supply into these areas, especially the availability of phosphorous, which is considered limiting to the primary production that underpins the food chain[129].

The predicted change in fish biomass and composition for the mainstream Mekong in the LMB for the hydropower sub-scenarios relative to 2040CC (Figure 7.27) underscore the expected influence of the main channel dams. In Figure 7.27, although fish biomass is noticeably lower for H2_nomainHPP, than for H1a_HPP it is clear that without the main channel dams, the overall impact of hydropower on fish production in the LMB is expected to be considerably lower than with the dams in place, even with some mitigation measures, such as sediment flushing and fish passage measures in place. Importantly, H1b-nomainHPP is expected to allow for the continued presence of migratory white fish throughout the LMB, which will aid in restraining the spread of non-native species.

2007 Baseline ecological status is shown in Figure 7.28, and the influence of the hydropower sub-scenarios on overall ecosystem condition is illustrated in Figure 7.29. Under H1a_noHPP, the steeper zones in the river are most affected by higher erosion and associated habitat loss as a result of reduced sediments and increased flows (see Figure 7.6), which drive a lower relative ecosystem condition reported for than Baseline 2007. By contrast, in the Delta, the higher flows contribute to greater flooding and increased habitat availability, and thus improved river condition relative to Baseline 2007.

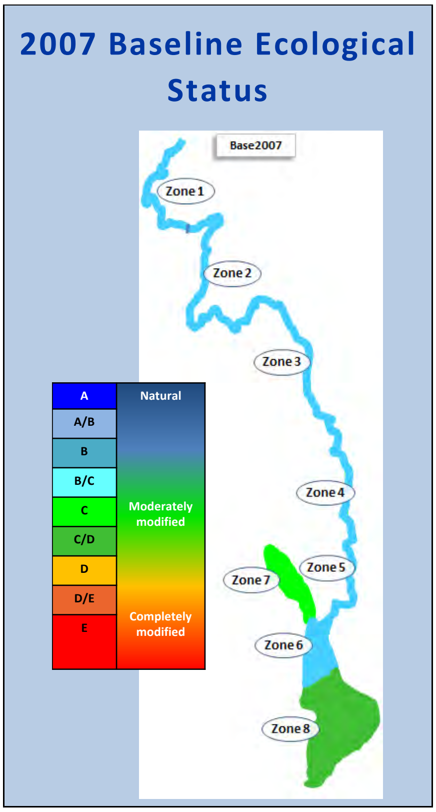


Figure 7.28 Estimated Baseline 2007 ecological conditions of the mainstream ecosystems the LMB

The predicted ecosystem conditions associated with H1b-nomainHPP are between one half and one category better than those associated with Scenario 2040CC, and between one half and one category poorer than 2007 Baseline (Figure 7.28).

The small predicted differences between Scenario 2040CC and the H3_HPP are insufficiently large to affect the predicted overall ecosystem health in the mainstream ecosystems of the LMB (Figure 7.29).

[129] Sarkkula, J., Koponen, J., Lauri, H., Virtanen, M. and Kummu, M. 2010. Origin, fate and impact of the Mekong sediments; Mekong River Commission/Information and Knowledge Management Programme, Detailed Modelling Support Project, Contract #001-2009, Work package 02/3, Finnish Environment Institute, Helsinki, 53 pp.

Figure 7.29 Mekong River condition predicted for the hydropower change sub-scenarios

The key messages from the hydropower sub-scenarios are:

- The connectivity-related impacts, such as trapping of sediment, disruption of migration paths and alteration of flow regimes, related to mainstream hydropower dams are substantial and far-reaching, and overshadow those of all other planned water-resource developments in the LMB.
- The sediment flushing measures included in H3_HPP yielded slight improvements in predicted river condition relative to Scenario 2040CC in the lower reaches of the LMB.
- The effectiveness of fish passages in preserving upstream ***and*** downstream migration of fish and other organisms past dam walls ***and through reservoirs*** is fundamental in determining the influence hydropower development on ecosystem integrity (see Section 4.1.2). In the Council Study, the effectiveness of fish passages in the main channel dams were assessed at 50%.

8 Summary and conclusions

In accordance with the instructions from the National Mekong Commission for the Council Study, and building on the considerable body of knowledge generated by MRC and others over the years, BioRA adopted a systematic and systemic approach to investigating the potential ecosystem changes related to water-resource development in the LMB. Much of the effort focussed on capturing and consolidating the existing information into the DSS, and on developing and conveying an understanding of the underlying functioning of the ecosystem and hence the processes that drive ecosystem change. In common with the other disciplines and themes of the Council Study, considerable effort and resources were also devoted to promote capacity and ensure technology transfer to river specialists and managers in the Member Countries. In BioRA, this was done through the inclusion of lead specialists from the region; mentoring of regional specialists on the BioRA team; workshops on the BioRA process and the development and use of the DSS, and regular feedback and information meetings with the RTWG. The modelling for the Council Study both in the Modelling Team and in BioRA was based, as far as is possible, on actual data from the Mekong River, and provides insights into the processes affecting the flow of water, sediments and biota on a catchment wide basis, the degree to which this will be affected by development and the impacts of this on a range of indicators representing the living aquatic ecosystems.

The resultant BioRA DSS is a resource that can be used over and over again for predicting ecosystem change in the LMB in response to planned water-resource developments; and can be updated and approved on the basis of ongoing monitoring and other data.

8.1 Predictions of change

In the Council Study, the BioRA DSS predicted how the physical characteristics of the river would change with planned developments, how ecosystem services and biodiversity could be impacted, and provided a summary of these changes to the social and economic teams for use in evaluating how these changes could affect people, and local and wider economies.

The results highlight that for the LMB as a whole, based on the modelled hydrological and hydraulic data, the main development scenarios would most impact the aquatic ecosystems by creating barriers to the upstream/downstream migration of biota; decreasing the downstream movement of sediments; and largely changing the overall nature of the river environment from flowing to still water. The results also illustrate that river ecosystems are complex living systems that can occasionally change in unexpected ways, such as the predicted increase in fish biomass in Zone 5 under Scenario 2040 driven by increases in generalist and exotic species. It is clear that the level of development represented by the 2040 scenarios would reduce the ability of the LMB aquatic ecosystems to cope with drier and/or more extreme climatic futures, and thus increase environmental risk for the people of the LMB. Major infrastructure could also face environmental extremes that it was not designed to withstand, as the combined effects of climate change and loss of flood attenuation by floodplains take effect.

The loss of connectivity, such as trapping of sediment, disruption of migration paths and alteration of flow regimes, caused by possible large instream hydropower dams would trigger substantial and far-reaching impacts overshadowing those expected from all other planned water-resource developments in the LMB, such as those associated with agricultural landuse or irrigation. There would be substantial increases in channel erosion with loss of land and severe impacts on the availability of river and floodplain habitats as a result of trapping of sediment in HPP impoundments. There would also be a drop in floodplain productivity, which supports the food web for the system. As a result, fisheries will be severely affected, with a ~40% decline in fish biomass (Figure 8.1) across the basin, and some valued species, such as the white fish, declining by up to 80%, as a result of a drop in productivity and interference with migration patterns. This interference would increase the more downstream the barrier is located, and so the HPPs in the lower part of the basin are expected to have a greater overall negative effect on fisheries in the LMB as a whole. Predictions for the H3_HPP hydropower sub-scenario, which includes mitigation measures, suggest that sediment flushing past the dam wall could offer some relief from downstream sediment starvation, but this would not eliminate the problem and could cause other unintended impacts, such as flushed sediments smothering habitats, blocking gills other breathing parts of the aquatic life, and clogging irrigation structures. Similarly, the usefulness of fish passages intended to help fish move up and downstream past facilitate up- and downstream past in-channel HPP weirs and impoundments is a matter of considerable debate[130]. The prevailing view among specialists is that existing types and sizes of fish ladders will not accommodate the abundance and diversity of fish attempting to migrate up the mainstream Mekong River, and provide little or no assistance with downstream migration (and larval drift)[131].

Dams on tributaries can also substantially impact river ecosystem functioning, but their careful siting, design and/or operation would allow more mitigation than is possible for mainstream dams. For instance, recent studies have suggested that in the 3S basin, appropriate siting and design of new hydropower dams could deliver ~70% of the potential power generation capacity with only a ~15% loss of sediments supplied to the Mekong River[132]. Experience from other basins suggests that avoiding important migration routes or securing protection of alternative tributary migration routes

130 Agostinho, A.A. Marques, E.E., Agostinho, C.S., de Almeida, D.A., de Oliveira, R.J. de Melo, J.R.B. 2007. Fish ladder of Lajeado Dam: migrations on one–way routes? Neotropical Ichthyology, 5(2). On-line version ISSN 1982-0224.; Dugan, P., Barlow, C., Agostinho, A.A. and Winemiller, K.O. 2010. Fish Migration, Dams and Loss of Ecosystem Services in the Mekong Basin. AMBIO A Journal of the Human Environment 39(4):344-8; Nunn, A.D. and Cowx, I.G. 2012. Restoring River Connectivity: Prioritizing Passage Improvements for Diadromous Fishes and Lampreys. Ambio, 41(4): 402–409.

131 International Centre for Environmental Management (ICEM) 2010. MRC Strategic Environmental Assessment (SEA) of hydropower on the Mekong mainstream: summary of the final report, Hanoi, Viet Nam.

132 Schmidt, R.J.P., Castelletti, A., Bizzi, S. and Kondolf, G.M. 2017. CASCADE – Enabling strategic portfolio optimization of dam sediment trapping and hydropower production. Presentation to the World Hydropower Congress, Addis Ababa, 9-11 May 2017.

and spawning grounds will also reduce, but not eliminate, the impacts of in-channel dams on basin-wide fish migration[133].

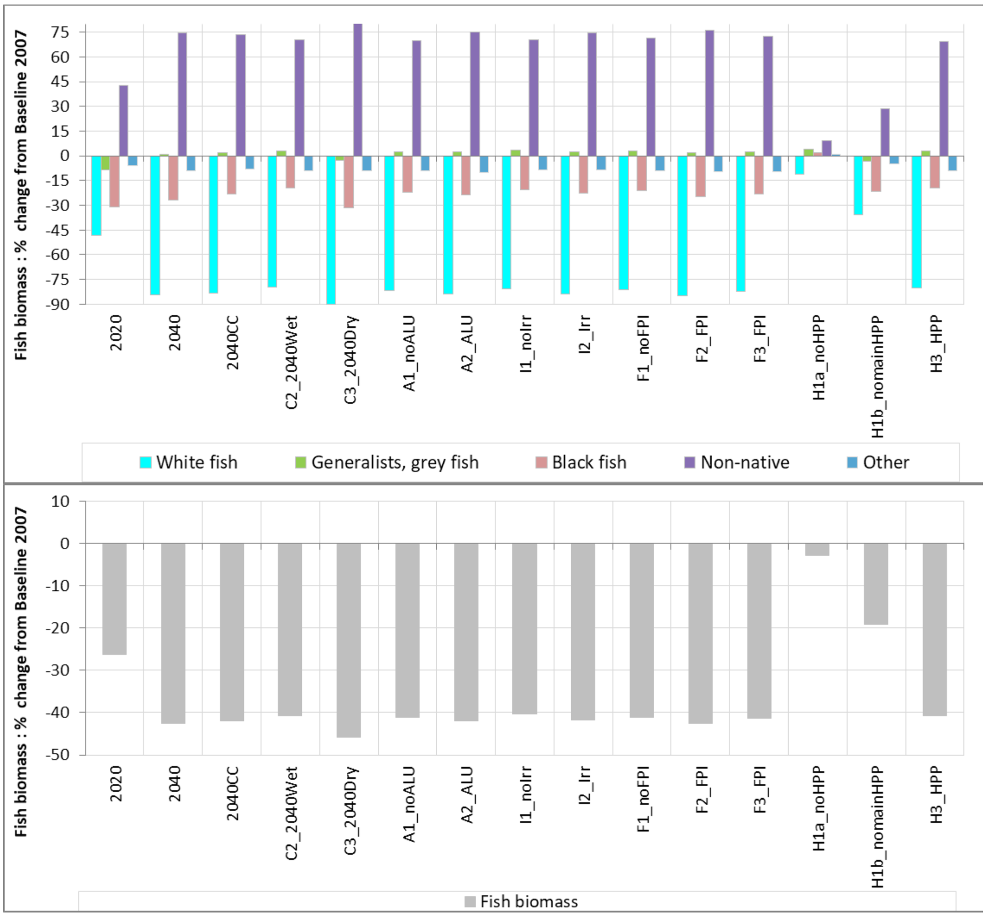


Figure 8.1 LMB-wide predicted changes in fish guilds (top) and biomass (bottom) for the main development scenarios and sub-scenarios assessed in the Council Study.

The additional impacts on river condition caused by the other sectors considered in the Council Study are difficult to distinguish (Figure 8.2) because they are smaller and less easily identified? It was not possible to capture the full nature and extent of some of these impacts, such as the effects of herbicides and pesticides in the agriculture and land-use sector. These could have a substantial impact on the plants and animals at the base of the food chain in the LMB, but were not included in the assessment because no details were available to build into the scenarios. Other potentially major impacts excluded from the Council Study were the loss of aquatic habitat through urbanisation, expansion of agriculture, and/or flood protection infrastructure; the effects of methane production from HPP reservoirs; the effects of operating the HPPs for peak-power production; the effects of sand mining; and over-harvesting of river resources.

[133] E.g., Opperman, J.J. and Harrison, D. 2008. Pursuing sustainability and finding profits: integrated planning at the system scale. Hydrovision, 2008 Sacramento, CA. HCI Publications.

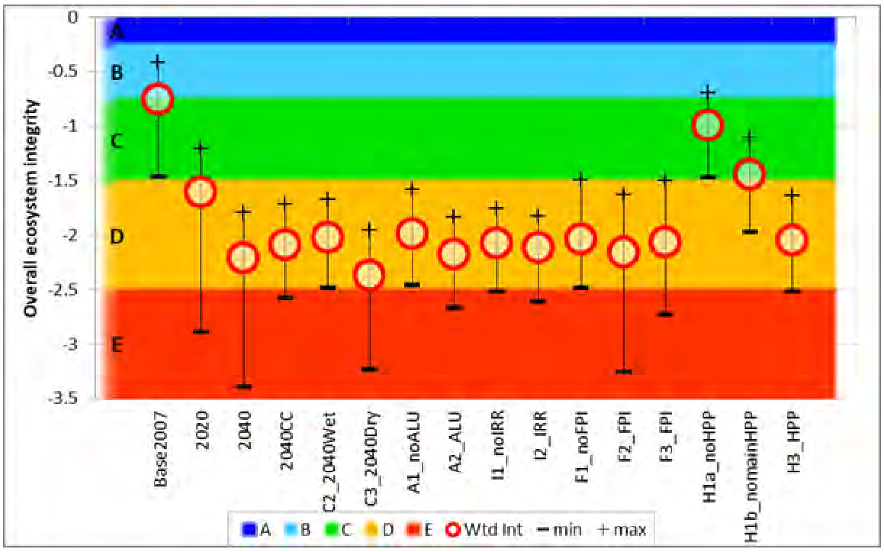


Figure 8.2 Predicted changes in basin-wide ecosystem condition for the main development scenarios and sub-scenarios assessed in the Council Study.

The ecosystem predictions made in this Council Study are based on incomplete data and knowledge[134], and none of the scenarios directly represent conditions up to or including the period of the Study (2014-2017). By 2015, however, a mix of the predicted changes had already started to appear in response to existing water-resource developments and other pressures. For instance: sediment trapping in the UMB has necessitated bank stabilisation and reinforcement again bank erosion for large sections of the river downstream of Chaing Saen, and; exotic species fish species already make up >20% of the fish catch in Zones 1 and 2. This supports the prediction that further development, of the kind envisaged in the 2040 scenarios, will lead to fundamental, irreversible and, likely, unsustainable changes to the aquatic resources of the LMB. In the shorter term, changes described under the 2020 scenario are already emerging or are poised to emerge as the numerous dams in that scenario come on line over the next few years.

8.2 Basin-wide strategic planning

The information, tools and skills generated by the Council Study[135] can support a fresh approach to considering the development potential of the LMB, whereby environmental and social risks are integrated into the Internal Rate of Return (IRR) of water-resource development projects. This would ensure better ecological and social returns as well as economic ones for individual water-resource investments[136], thereby supporting the principles of Integrated Water Resource Management

[134] And apparent inconsistencies in the modelling of inundation and in the sedimentation in the Delta (Zone 8), and to a lesser extent in Zones 3, 5, 6, and 7.

[135] In combination with other new and innovative tools.

[136] E.g., Opperman, J.J. and Harrison, D. 2008. Pursuing sustainability and finding profits: integrated planning at the system scale. Hydrovision, 2008 Sacramento, CA. HCI Publications; Schmidt, R.J.P., Castelletti, A., Bizzi, S. and Kondolf, G.M. 2017.

(IWRM). The degree of river regulation already underway in the UMB and LMB means that large-scale basin-wide greenfield planning is not possible, but the outcomes of the Council Study do allow a more strategic and systematic approach to basin planning. Location, design and operation of infrastructure can now be assessed in a basin-wide context and mitigation directed to where it will provide the greatest benefit.

The relationships that define the outcomes of the BioRA DSS are easily viewed and interrogated, and can be updated as more knowledge becomes available. Thus, quite apart from its use to predict potential change in the Council Study, the BioRA DSS is a source of teaching, learning and information about river responses to development, and the reasons for them. Whatever water-resource developments are pursued, the LMB, in common with all river basins in the world, faces an uncertain future. Understanding how and why aquatic ecosystems respond in the way that they do will be essential for negotiating that future. The BioRA DSS can, and should, be used as a tool for building the understanding and capacity essential for resilience planning and adaptive management of the LMB.

The BioRA DSS is a new and powerful tool to enable bold basin-wide planning and help to make big, wise responsible choices about water-resource development in the LMB. To this end, with the acknowledgement of the investment by the NMC and the MRC in the development of the BioRA DSS and the progress of some member countries in advancing these, the recommended next steps are:

1. Promote uptake of the knowledge and outputs of the Council Study in the LMB.
2. Use the BioRA DSS to assist in guiding broad-scale planning and management of the aquatic ecosystems of the LMB[137], including:
    a. the location of new infrastructure,
    b. adaptation and mitigation measures;
    c. design and evaluation of mitigation options and offsets for existing and future water-resource developments.
3. Establish guidelines for decision-making processes to transparently use the outcomes of the Council Study.
4. Promote ownership and use of BioRA DSS through:
    a. targeted presentations to National Mekong Commission, universities, other stakeholders;
    b. aligning MRC ecosystem monitoring efforts to provide information for the most relevant of the relationships described in the BioRA DSS, e.g., those that describe the links between sediment supply, erosion, habitat availability, vegetation, OAAs and fish;
    c. designating two to three BioRA champions in each member country to be the custodians of the DSS. These people should have a background in the biophysical aspects of aquatic ecosystems and an aptitude for modelling complex relationships;

CASCADE – Enabling strategic portfolio optimization of dam sediment trapping and hydropower production. Presentation to the World Hydropower Congress, Addis Ababa, 9-11 May 2017.

[137] WorldBank Group. 2017. Good Practice Handbook: Environmental Flows for Hydropower Projects. Washington.

d. make bursaries available for MSc or PhD studies focusing on testing and refining the response curves that define the relationships in the BioRA DSS.

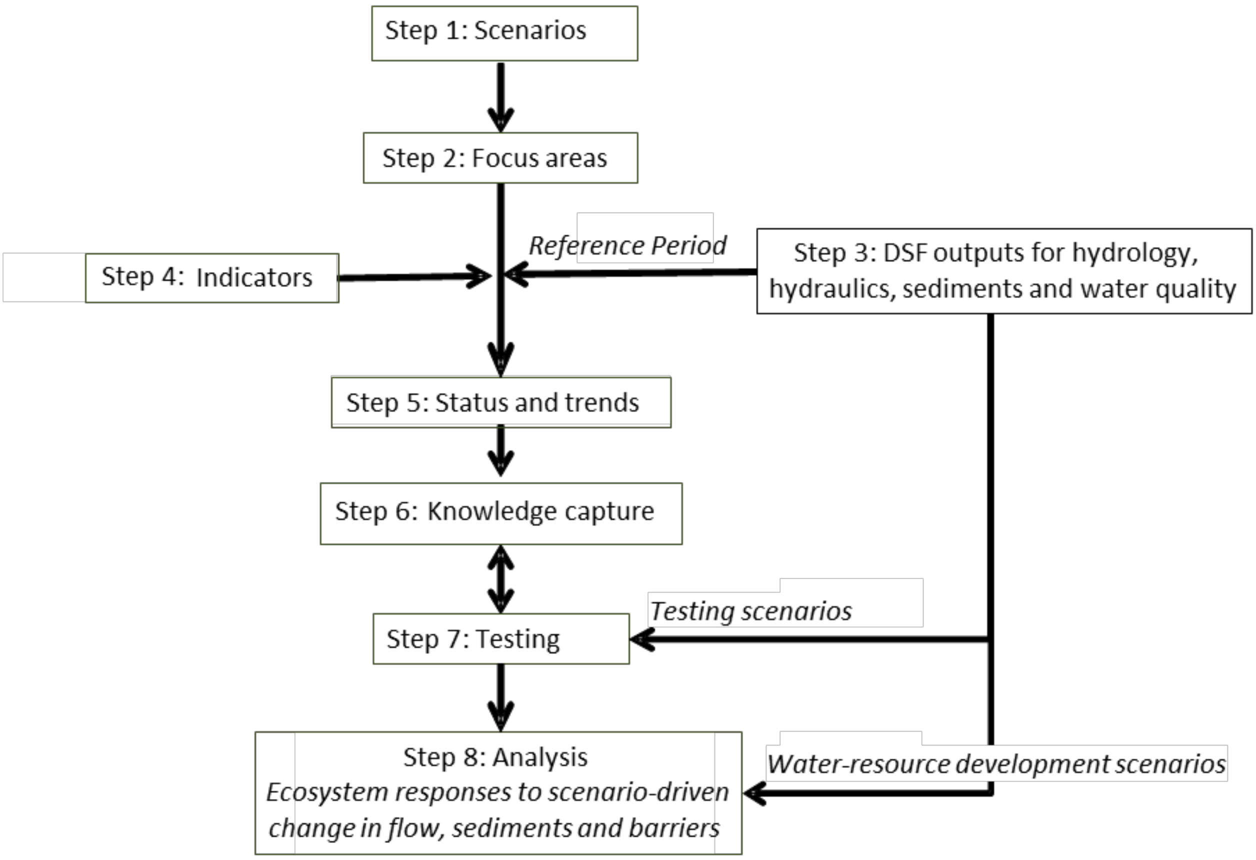
5. Increase investment in stakeholder programmes aimed at enhancing awareness and understanding of the economic, cultural[138] and spiritual values of the river systems of the LMB, the underlying functioning that supports these and the potential consequences of disrupting them.

[138] Appadurai, A. 1996. Modernity At Large: Cultural Dimensions of Globalization. Minneapolis: University of Minnesota Press.

Appendix A The BioRA process

A.1. *The BioRA process*

The BioRA process comprised eight main steps. These are illustrated in Appendix Figure 1, and discussed in the sub-sections that follow.



Appendix Figure 1 The steps in the DRIFT/BioRA process

Step 1: Scenarios

The Council Study scenarios described a range of potential water-resource developments in the Mekong Basin. They comprised a 2007 Baseline scenario, three main development scenarios, and a range of thematic sub-scenarios. The main development scenarios were:

- Early Development (2007);
- Definite Future Development (2020), and;
- Planned Development (2040).

The thematic variations included in the sub-scenarios, including climate change variations, were applied to the 2040CC scenario.

Appendix Table 1 Parameters for the main development scenarios

Scenarios		Level of Development for water-related sectors[139]						Climate	Floodplain settlement
		ALU	DIW	FPF	HPP	IRR	NAV		
2007	Baseline Scenario 2007	2007	2007	2007	2007	2007	2007	1985-2008	2007
2020	Definite Future Scenario 2020	2020	2020	2020	2020	2020	2020	1985-2008	2020
2040	Planned Development Scenario 2040	2040	2040	2040	2040	2040	2040	1985-2008	2040
2040CC	Planned Development Scenario 2040	2040	2040	2040	2040	2040	2040	Mean warmer & wetter	2040

Step 2: Focus areas

See Section 2.

Step 3: Model hydrology, hydraulics, sediments, WQ

For BioRA, hydrology, hydraulics, sediments and water quality (nutrients and salinity) time-series data for each focus area for the Reference and Development scenarios were modelled using the MRC Decision Support Framework (DSF), plus other models such as the WUP-FIN suite of models, and eWater Source to supplement DSF.

For the most part, these data were at a daily time-step.

Step 4: Select BioRA indicators

The BioRA DSS comprised two main types of indicators:

- Modelled indicators comprising:
    - flow indicators

139 ALU = Agric/Landuse Change; DIW = Domestic and Industrial Water Use; FPF = flood protection infrastructure; HPP = hydropower; IRR = irrigation; and NAV = Navigation.

- sediment indicators
- water quality indicators

- Ecosystem indicators.

The modelled indicators were provided by the Modelling Team. Ecosystem indicators were modelled in the DSS using the response curves.

The suite of BioRA indicators used in the DSS is given in Section 2.2. The indicators are described in more detail with reasons for their selection provided in the BioRA Technical Report Series: Volume 1: Specialists' Report.

Step 5: Status and trends

The Status and Trends Assessments:

- described the present ecological status of the Lower Mekong River;
- described the past ecological status of the Lower Mekong River – both as a reference point from which to make predictions and to establish trends that were used later in the analyses;
- described the future ecological status of the Lower Mekong River in the absence of the water-resource developments included in the scenarios.

The results of the Status and Trends Assessments are provided in the BioRA Technical Report Series: Volume 1: Specialists' Report.

Step 6: Knowledge Capture

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 Reference hydrological data for the focus areas, and calculating the seasonal flow indicators;
- importing the 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;
- generating the response curves for each indicator;
- entering explanations of the response in each indicator to a change in each linked indicator;
- testing and adjusting through the evaluation of the outputs for a series of Testing Scenarios.

The specialist teams constructed response curves for each of the links delineated for each indicator. To do this, the data collected and the understanding developed by MRC and other organisations over the last two decades were augmented with life-history information for key species and expert opinion. The bulk of the response-curve construction was done at a series of Knowledge Capture Workshops (KCWs).

Response curves and the scoring system used in their construction are outlined in Section A.2.

Step 7: Testing

In testing, the BioRA DSS was validated using the outputs to a series of testing scenarios, which included hypothetical scenarios representative of extreme floods or drought.

The bulk of the testing was done at the KCWs and in the Testing Workshops. The outcomes of the testing are presented in BioRA Technical Report Series: Volume 3: Testing Report.

Step 8: Analysis

Using the modelled times series of changes in flow, sediment and water quality for each of the development scenarios, the BioRA DSS was run to predict how each indicator would change relative to the 2007 Baseline under each of the development scenarios (See Section A.1.1).

For each development scenario, the predicted changes in the river ecosystem were provided as:

1. estimated mean percentage change from 2007 Baseline 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).

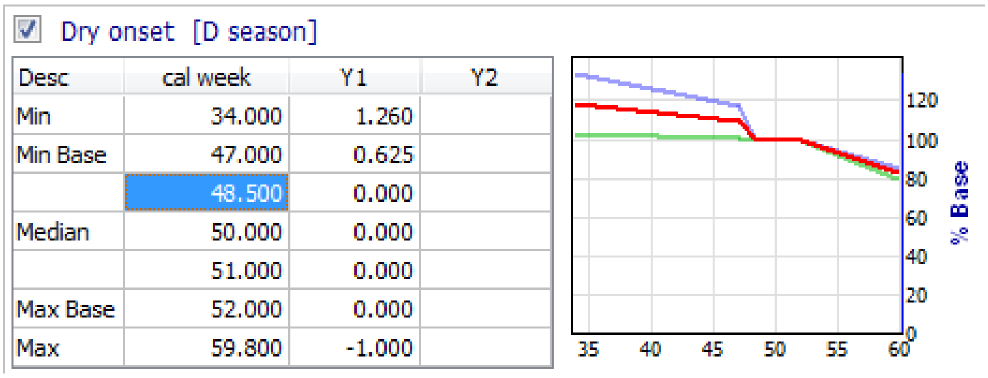
The results of the scenario analyses are presented in BioRA Technical Report Series: Volume 4: Assessment of Planned Development Scenarios.

A.2. Response curves and scoring system

Response curves

Response curves depict the relationship between a biophysical indicator and a driving variable (e.g., flow). In the Council Study, response curves linked an ecosystem indicator to other indicators deemed to be driving change. The aim was not try to capture every conceivable link, but rather to restrict the linkages to those that were most meaningful and could be used to predict the bulk of the likely responses to a change in the flow or sediment regimes of the river.

A response curve for the relationship between relative fish (e.g., rhithron-dwelling fish[140]) abundance (given as a severity rating – see Section 0) and a modelled indicator, in this case, onset of the wet season, is shown in Appendix Figure 2. In Appendix Figure 2, an early or late start to the wet season would lead to decreased abundance.



Desc	cal week	Y1	Y2
Min	34.000	1.260	
Min Base	47.000	0.625	
	48.500	0.000	
Median	50.000	0.000	
	51.000	0.000	
Max Base	52.000	0.000	
Max	59.800	-1.000	

Appendix Figure 2 **Example of a response curve – in this case of the relationship between the calendar week when the dry season begins and the abundance of rhithron-dwelling fish.**

The units on the x-axis depend on the driving indicator under consideration. For instance, in the case of dry season onset (Appendix Figure 2), these are calendar weeks.

The y-axis may refer to abundance as in Appendix Figure 2, but also to other measures such as concentration or area, depending on the indicator. Response curves were constructed using severity ratings (Section 0).

The response curves were used to evaluate scenarios by taking the value of the flow indicator for any one scenario and reading off the resultant values for the biophysical indicators from their respective response curves. Once this was done the DSS combined these values to predict the overall change in each biophysical indicator and in the overall ecosystem under each scenario.

[140] Fish that live in riffles

The time-series approach meant that the response curves were used to predict the likely seasonal change in an ecosystem indicator in response to the flow/sediment conditions experienced in that, or possibly preceding, seasons. For instance, the kind of question typically asked to facilitate setting the Min 5-day dry season discharge response curve for Rhithron fish species are:

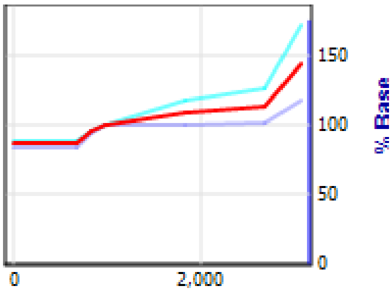
- 'If the dry season discharge declines from baseline values, what will be the consequences for the abundance of rhithron species?'
  - Do rhithron species use the main river in the dry season?
  - Do the available data show that rhithron species abundances change noticeably over the climatic range covered in the baseline, i.e., are they noticeably more abundant in wet years than in dry years, or vice versa?
  - What kinds of habitats do adults of rhithron species use in the main river?
  - Do they breed in the dry season?
  - Do they breed in the main river or in the tributaries?
  - Where do they lay their eggs?
  - What sorts of habitat do fry, fingerlings and juveniles use in the main river?
  - At what discharge(s) does the favoured habitat(s) disappear?
  - What is the consequence of these habitats not being available for one season?
  - If discharge reaches zero for one season, are there pools that the fish will be able to survive in?
  - Can they survive for a dry season in pools?
  - Do lower or higher dry season flows affect fishing pressure?
  - What do the adults/juveniles/fingerlings/fry eat?
  - How will the food base be affected by changes in dry season lowflows?
  - Etc.

For instance, often, a species such as rhithron-dwelling fish will be expected to survive even an extremely-dry dry season, with possibly only minor changes (5-10%) in overall abundance, resulting in a response curve similar to that shown in Appendix Figure 3, which predicts a 10-20% seasonal decline in fish abundance if dry season flows drop to zero, even though the lowest 5-day minimum ever recorded at the site[141] under the 2007 Baseline Scenario is 683.4 m^3/s. If, however, the flows drop to this level in the dry season year after year, then the cumulative effect on trout populations is likely to be far greater. The time-series enable the DSS to capture this cumulative effect.

[141] FA2 – see Section 3

Dry Min 5day Q (TLS=depth) [D season]

Desc	m3/s (TLS=m)	Y1	Y2
Min	0.000	-0.800	
Min Base	683.396	-0.800	
	831.602	-0.300	
Median	979.807	0.000	
	1825.609	0.620	
Max Base	2671.411	1.000	
Max	3072.122	2.000	



Appendix Figure 3 **Response curve for rhithron fish to the dry season discharge.**

Scoring system

Into the foreseeable future, predictions of river change will be based on limited knowledge. Most river scientists, particularly when using sparse data, are thus reluctant to quantify predictions: it is relatively easy to predict the nature and direction of ecosystem change, but more difficult to predict its timing and intensity. To calculate the implications of loss of resources to subsistence and other users in order to facilitate discussion and trade-offs, it is nevertheless necessary to quantify these predictions as accurately as possible.

To aid this, two types of information were generated for each biophysical indicator, *viz*.:

- Severity ratings, which described increase/decreases for an indicator in response to changes in the modelled indicators, and;
- Integrity ratings, which indicated whether the predicted change was a move towards or away from the natural ecosystem condition, i.e., how the change influences overall ecosystem condition.

The severity ratings were used to construct the response curves. The Integrity ratings were used to predict changes in overall ecosystem condition/health.

Severity ratings

The severity ratings represented a continuous scale from -5 (large reduction) to +5 (very large change; Appendix Table 2[142]), where the + or – denoted an increase or decrease in abundance or extent. These ratings were converted to percentages using the relationships provided in Appendix Table 2. The scale accommodated uncertainty, as each rating encompasses a range of percentages;

[142] Brown, C.A., Joubert, A.R., Beuster, J. Greyling, A. and King, J.M. 2013. DRIFT: DSS software development for Integrated Flow Assessments. FINAL REPORT to the South African Water Research Commission. February 2013.

however, greater uncertainty could also be expressed through providing a range of severity ratings (i.e., a range of ranges) for any one predicted change[143].

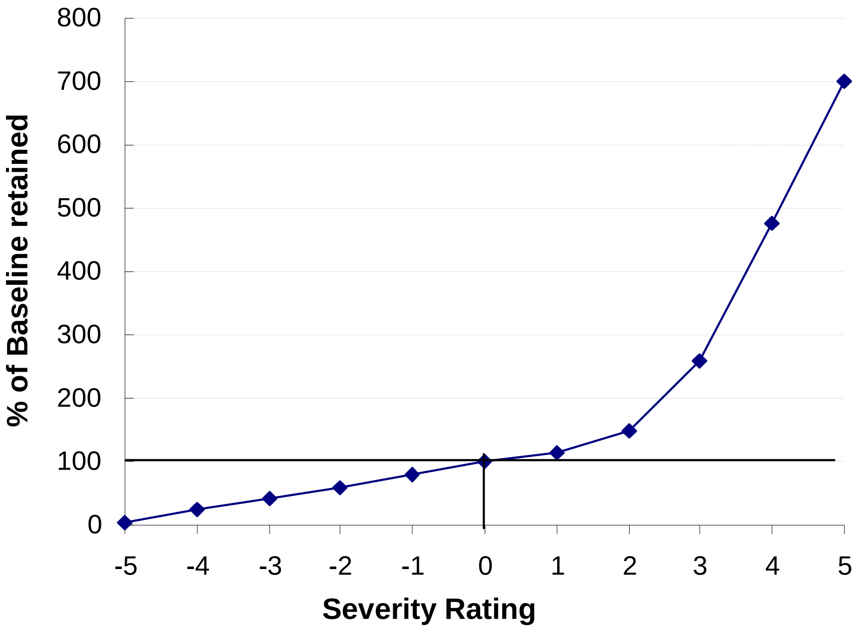
Note that the percentages applied to severity ratings associated with gains in abundance are strongly non-linear[144] and that negative and positive percentage changes are not symmetrical (Appendix Figure 4)[145].

For each year of the hydrological record, and for each ecosystem indicator, the severity rating corresponding to the value of a driving indicator was read off its Response Curve and converted to a percentage change. The severity ratings for each driving indicator were then combined to produce an overall change in abundance for each season, which provided an indication of how abundance, area or concentration of an indicator was expected to change under the given flow conditions over time, relative to the changes that would have been expected under baseline conditions.

Appendix Table 2 DRIFT severity ratings and their associated abundances and losses – a negative score means a loss in abundance relative to baseline, a positive means a gain.

Severity rating	Severity	% abundance change
5	Critically severe	501% gain to ∞ up to pest proportions
4	Severe	251-500% gain
3	Moderate	68-250% gain
2	Low	26-67% gain
1	Negligible	1-25% gain
0	None	no change
-1	Negligible	80-100% retained
-2	Low	60-79% retained
-3	Moderate	40-59% retained
-4	Severe	20-39% retained
-5	Critically severe	0-19% retained includes local extinction

[143] King, J.M., Brown, C.A. and Sabet, H. 2003. A scenario-based holistic approach to environmental flow assessments for regulated rivers. *Rivers Research and Application*s 19 (5-6). 619-640.
144 The non-linearity was necessary because the scores had to be able to show that a critically-severe loss equated to local extinction whilst a critically severe gain equated to proliferation to pest proportions.
[145] King, J.M., Brown, C.A. and Sabet, H. 2003. A scenario-based holistic approach to environmental flow assessments for regulated rivers. *Rivers Research and Application*s 19 (5-6). 619-640.



Appendix Figure 4 **The relationship between severity ratings and percentage abundance lost or retained as used in DRIFT and adopted for the DSS. (Baseline is always = 100%).**

Integrity ratings

Integrity ratings are on a scale from 0 to -5.

The integrity ratings were calculated by assigning a positive or negative sign to changes in abundance depending on whether an increase in abundance was a move towards natural or away. The integrity ratings for each indicator were then combined to provide a discipline level Integrity score. Discipline level integrity scores were in turn combined to provide an overall site level Integrity Score, which was used to place a flow scenario within a classification of overall river condition, using the South African Eco-classification categories A to F (Appendix Table 3)[146][147].

The ecological condition of a river is defined as its ability to support and maintain a balanced, integrated composition of physico-chemical and habitat characteristics, as well as biotic components on a temporal and spatial scale that are comparable to the natural characteristics of ecosystems of the region. As an example, if the baseline ecological status of a river was a B-category, and there was a decrease in an indigenous fish species, this would cause the integrity score to be more negative, representing movement in the direction of categories C to F.

---

[146] Kleynhans, C.J. 1999. A procedure for the determination of the ecological reserve for the purposes of the national water balance model for South African Rivers. Institute for Water Quality Studies. Department of Water Affairs and Forestry, Pretoria, South Africa.

[147] Brown, C.A. and Joubert, A. 2003. Using multicriteria analysis to develop environmental flow scenarios for rivers targeted for water-resource development. *Water SA* 29(4): 365-374.

Appendix Table 3 Definitions of the ecological status ratings[148]

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/F	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.

Overall Integrity Scores were calculated for the ecosystem as a whole, i.e., the combined effect of changes in the indicators at each site. The categories represent points along a continuum, thus the 'divisions' between the categories are only guides as to the general position at which the ecological condition might be expected to shift from one category to the next. Furthermore, the integrity categories provide an indication of the relative categories associated with each scenario and should not be misconstrued as an absolute prediction of future condition.

A.3. Major assumptions and limitations

Predicting the effect of flow, sediment and connectivity changes on rivers is difficult because the actual trajectory and magnitude of the change is additionally dependent on so many other variables, such as climate, sediment supply and human use of the system. Thus, several assumptions and limitations applied.

A major assumption was that the Reference Period (1985-2008) flow, sediment and water quality time-series closely approximated the actual conditions in the river over the period of record. Should this not be the case, then the set of circumstances that support the predictions will have changed, which would affect the predictions.

The main limitation was the paucity of data. This is a universal problem, as ecosystems are complex and we will probably never have complete certainty of their present and possible future characteristics. Instead it is essential to push ahead cautiously and aid decision-making, using best available information. The alternative is that water resource development decisions are made without consideration of the consequences for the supporting ecosystems, eventually probably making management of sustainability impossible. Data paucity was addressed in the BioRA process

---

[148] Kleynhans, C.J. 1996. A qualitative procedure for the assessment of the habitat integrity status of the Luvuvhu River. *Journal of Aquatic Ecosystem Health* 5: 41 – 54.

by accessing every kind of knowledge available - general scientific understanding, international scientific literature, local wisdom and specific data from the river under consideration or from similar ones – and capturing these in a structured process that is transparent, with the DSS inputs and outputs checked, workshopped and approved at every step. The response curves (and the reasoning used to construct them) are available for scrutiny within the DSS and they, as well as the BioRA DSS, can be updated as new information becomes available.

Other limitations were:

- The predictions were based on a 23-year horizon (1985-2008). This is insufficient time to capture the full extent of some changes, particularly those related to sediment budgets.
- It was neither known what the river was like in its pristine condition nor exactly how abundant each ecosystem aspect (sand bars, fish, etc.) was then or at the time of the study. To address this, all predictions were made relative to the 2007 Baseline (there will be a little more, or a lot less, than then, and so on).

These inherent uncertainties meant that the trends and relative position of the scenarios are more reliable predictors of the impacts of the scenarios than are their absolute values.

Appendix B Modelled BioRA indicators (river reaches)

Appendix Table 4 BioRA FA 1: Modelled BioRA indicators (river reaches)

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noALU	A2_ALU	I1_noIRR	I2_IRR	F1_noFPI	F2_FPI	F3_FPI	H1a_noHPP	H1b_no mainHPP	H3_HPP
Mean annual runoff	3232	3239	3233	3223	3460	2699	3224	3219	3235	3219	3222.6	3222.6	3222.6	3203.1	3225.5	3218.7
Dry onset	49.0	49.0	49.0	51.5	49.0	48.0	51.5	49.0	52.0	49.0	51.5	51.5	51.5	50.0	49.0	52.0
Dry duration	193.5	185.5	189.5	187.0	183.0	196.5	187.0	187.0	185.0	187.0	187.0	187.0	187.0	202.0	186.5	185.0
Dry Min 5day Q	861	1160	1154	1187	1171	1091	1186	1186	1189	1186	1186.6	1186.6	1186.6	841.2	1186.2	1170.6
Wet onset	27.5	29.0	29.0	30.0	28.5	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	29.0	30.0	30.0
Wet duration	122.5	113.0	112.5	118.0	117.5	90.0	118.0	118.0	118.0	118.0	118.0	118.0	118.0	121.0	118.5	117.5
Wet Max 5day Q	10384	9947	9893	10737	11196	7337	10803	10713	10703	10713	10737	10737	10737	11618	10748	10861
Flood volume	68664	61298	61061	63163	68566	39404	63084	63047	63214	63047	63163	63163	63163	69249	63112	62944
T1: T1 onset	24.5	24.0	24.0	28.0	24.0	24.0	28.0	28.0	27.5	28.0	28.0	28.0	28.0	27.0	28.0	27.5
T2: T2 onset	45.0	45.0	45.0	47.0	45.5	43.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	46.5	47.0	47.0
D: av ChVelocity	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.7	0.7
W: av ChVelocity	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
D: av Ch Depth	13.3	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	13.2	14.1	14.0
W: ave Ch Depth	21.5	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	21.7	21.2	20.9
D: ave Wetted perimeter	340.1	344.6	344.6	344.6	344.6	344.6	344.6	344.6	344.6	344.6	344.6	344.6	344.6	339.9	345.0	344.6
D: av Shear stress	51.3	55.4	55.4	55.4	55.4	55.4	55.4	55.4	55.4	55.4	55.4	55.4	55.4	51.4	56.1	55.4
W:av Ch Shear stress	106.7	102.2	102.2	102.2	102.2	102.2	102.2	102.2	102.2	102.2	102.2	102.2	102.2	107.2	103.3	102.2
D: ave Sediment load	21002	225	224	230	231	213	230	230	231	230	230	230	230	12767	3474	229
T1: ave Sediment load	237813	732	728	631	697	737	631	630	633	630	631	631	631	85505	16032	638
W: ave Sediment load	557956	51770	51492	48880	56588	36982	48919	48878	48971	48878	48880	48880	48880	529676	150728	49386
T2: ave Sediment load	86672	1725	1722	1894	1740	1476	1893	1892	1903	1892	1894	1894	1894	77649	19542	1883
W: ave Sediment Onset	30.0	32.0	32.0	33.0	32.5	32.5	33.0	33.0	33.0	33.0	33.00	33.00	33.00	31.50	32.00	33.00
W: ave Sediment Duration	68.0	40.0	40.0	40.5	39.0	40.0	40.5	41.0	40.5	41.0	40.50	40.50	40.50	68.50	61.50	41.00
D: ave Total Phosphorous	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01
W: ave Total Phosphorous	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0	0	0	0	0	0
D: ave Total Nitrogen	0.28	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0	0	0	0	0	0
W: ave Total Nitrogen	0.74	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	1	1	1	1	1	1

Appendix Table 5 BioRA FA 2: Modelled BioRA indicators (river reaches)

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noAL U	A2_ALU	I1_noIrr	I2_Irr	F1_noFPI	F2_FPI	F3_FPI	H1a_noH PP	H1b_no mainHPP	H3_HPP
Mean annual runoff	4792	4630	4615	4796	4867	3921	4789	4781	4815	4781	4795.5	4795.5	4795.5	4701.3	4794.2	4979.6
Dry onset	49.0	50.0	49.0	50.5	50.0	49.0	50.5	51.0	52.0	51.0	50.5	50.5	50.5	50.0	50.5	51.0
Dry duration	180.5	176.5	174.0	173.5	169.0	183.0	173.5	177.5	173.0	177.5	173.5	173.5	173.5	188.0	174.5	165.0
Dry Min 5day Q	996	1348	1431	1463	1463	1305	1463	1403	1471	1403	1463.2	1463.2	1463.2	954.0	1456.4	1470.1
Wet onset	27.0	28.5	28.5	29.0	28.0	28.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0
Wet duration	125.0	111.0	110.5	120.5	117.0	99.5	120.5	118.5	121.5	118.5	120.5	120.5	120.5	122.5	121.5	125.0
Wet Max 5day Q	15457	14798	14681	15543	16332	10961	15529	15727	15585	15727	15543	15543	15543	16302	15379	16174
Flood volume	103023	91699	90893	97204	99856	68348	96991	97789	97547	97789	97204	97204	97204	104955	97363	102921
T1: T1 onset	21.5	23.0	23.0	24.0	22.5	22.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.5	24.0	23.0
T2: T2 onset	45.0	45.0	45.0	47.0	45.0	43.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0
D: av ChVelocity	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
W: av ChVelocity	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
D: av Ch Depth	5.4	5.8	5.8	5.8	5.8	5.7	5.8	5.8	5.9	5.8	5.8	5.8	5.8	5.3	5.9	5.9
W: ave Ch Depth	12.4	11.9	11.8	11.9	12.3	10.6	11.9	11.9	11.9	11.9	11.9	11.9	11.9	12.4	11.9	12.2
D: ave Wetted perimeter	1205.2	1211.1	1211.8	1212.3	1212.1	1210.1	1212.4	1211.0	1212.7	1211.0	1212.4	1212.4	1212.4	1204.2	1212.6	1212.6
D: av Shear stress	3.4	4.0	4.1	4.1	4.1	3.9	4.1	4.0	4.1	4.0	4.1	4.1	4.1	3.3	4.1	4.1
T1: av Ch Shear stress	5.5	5.2	5.2	4.9	5.2	5.2	4.9	4.6	4.9	4.6	4.9	4.9	4.9	4.7	4.9	5.0
W:av Ch Shear stress	7.8	7.5	7.5	7.5	7.8	6.8	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.8	7.5	7.7
T2: ave Ch Shear stress	5.2	5.4	5.4	5.8	5.5	5.1	5.8	5.6	5.8	5.6	5.8	5.8	5.8	5.7	5.8	5.8
D: ave Sediment load	11 877	6 512	2 752	2 841	2 266	2 354	2 908	2 394	2 667	2 489	2 841	2 841	2 841	10 788	9 522	2 392
T1: ave Sediment load	64 028	22 180	11 325	8 324	10 777	9 674	8 197	7 207	6 093	7 252	8 324	8 324	8 324	29 913	18 570	11 076
Wt: ave Sediment load	397 088	106 628	51 802	58 280	55 828	29 634	52 829	54 499	53 564	56 037	58 280	58 280	58 280	349 564	135 184	56 765
T2: ave Sediment load	72 919	19 973	8 721	12 963	7 466	6 482	11 886	11 163	11 082	10 643	12 963	12 963	12 963	90 036	36 990	10 238
W: ave Sediment Onset	30.5	30.0	30.5	32.5	31.0	28.0	32.0	32.0	32.0	32.0	32.50	32.50	32.50	32.00	32.00	32.00
W: ave Sediment Duration	63.5	66.5	61.5	66.0	53.5	80.5	64.5	69.0	70.0	64.5	66.00	66.00	66.00	66.50	73.50	64.00
D: ave Total Phosphorous	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01
W: ave Total Phosphorous	0.09	0.07	0.08	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0	0	0	0	0	0
D: ave Total Nitrogen	0.29	0.21	0.16	0.13	0.14	0.13	0.14	0.13	0.14	0.13	0	0	0	0	0	0
W: ave Total Nitrogen	0.77	0.63	0.88	0.61	0.61	0.60	0.66	0.65	0.66	0.65	1	1	1	1	1	1

Appendix Table 6 BioRA FA 3: Modelled BioRA indicators (river reaches)

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noALU	A2_ALU	I1_noIrr	I2_Irr	F1_noFPI	F2_FPI	F3_FPI	H1a_noHPP	H1b_nomainHPP	H3_HPP
Mean annual runoff	7852	7500	7480	7902	7868	6687	7913	7865	7988	7865	7902.1	7902.1	7902.1	7843.2	7926.1	8148.2
Dry onset	49.0	50.0	50.0	51.5	50.0	49.0	51.5	50.5	52.0	50.5	51.5	51.5	51.5	50.0	51.5	52.0
Dry duration	170.5	163.0	166.0	160.5	162.0	171.5	160.5	163.0	157.0	163.0	160.5	160.5	160.5	167.5	160.5	155.5
Dry Min 5day Q	1345	1862	1977	2080	2032	1827	2073	1960	2143	1960	2080.1	2080.1	2080.1	1228.1	2077.7	2106.6
Wet onset	23.0	25.0	25.5	26.0	25.5	25.5	26.0	26.0	26.0	26.0	26.0	26.0	26.0	25.0	26.0	25.5
Wet duration	149.5	139.5	138.5	143.0	140.5	123.5	143.0	143.5	144.5	143.5	143.0	143.0	143.0	149.0	144.5	146.0
Wet Max 5day Q	23394	22073	22092	22557	23806	19215	22474	22726	22517	22726	22557	22557	22557	23366	22616	23158
Flood volume	191675	167611	164974	181163	178663	137042	181186	182464	182449	182464	181163	181163	181163	194377	182037	188190
T1: T1 onset	21.0	21.5	22.0	22.0	21.0	21.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.5	22.0
T2: T2 onset	44.0	45.0	44.5	47.0	45.0	43.0	46.5	46.5	47.0	46.5	47.0	47.0	47.0	46.5	47.0	47.0
D: av ChVelocity	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
W: av ChVelocity	1.2	1.2	1.2	1.2	1.2	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
D: av Ch Depth	3.5	3.9	3.9	4.0	4.0	3.8	4.0	3.9	4.0	3.9	4.0	4.0	4.0	3.4	4.0	4.0
W: ave Ch Depth	9.6	9.1	9.0	9.2	9.4	8.4	9.2	9.2	9.3	9.2	9.2	9.2	9.2	9.6	9.2	9.4
D: ave Wetted perimeter	1459.9	1464.8	1465.3	1465.9	1465.4	1463.8	1465.9	1464.9	1466.3	1464.9	1465.9	1465.9	1465.9	1458.9	1466.0	1466.3
D: av Shear stress	3.0	3.0	3.0	3.1	3.1	3.0	3.1	2.7	3.1	2.7	3.1	3.1	3.1	2.9	3.1	3.1
T1: av Ch Shear stress	3.9	3.4	3.5	3.3	3.6	3.5	3.3	3.2	3.3	3.2	3.3	3.3	3.3	3.4	3.3	3.4
W:av Ch Shear stress	5.4	5.0	5.0	5.1	5.2	4.6	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.3	5.1	5.2
T2: ave Ch Shear stress	3.8	3.8	3.8	4.1	3.8	3.6	4.1	4.2	4.1	4.2	4.1	4.1	4.1	4.0	4.1	4.2
W: av FP Area inundation	26	17	16	20	20	5	21	21	21	21	31.3	20.3	20.3	25.2	20.3	19.6
W: ave FP Depth	1.6	1.6	1.6	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.6	1.5	1.5
W: av FP Onset inundation	20.0	20.0	20.0	20.0	1.0	1.0	20.0	19.0	1.0	1.0	19.5	20.0	1.0	1.0	1.0	1.0
Annual: FP Duration inundation	222.0	232.0	232.0	231.0	248.0	248.0	228.0	233.5	248.0	248.0	231.5	231.0	248.0	248.0	248.0	248.0
D: ave Sediment load	12903	16111	15860	17477	17043	13595	17753	16970	18037	16876	17668	17668	17668	16945	19198	19124
T1: ave Sediment load	110934	65876	65022	48994	76012	65977	52018	49638	51559	49836	48994	48994	48994	70779	55771	55876
Wt: ave Sediment load	572058	301539	249126	280402	286153	187205	281386	284970	285004	285629	280402	280402	280402	565879	336078	297753
T2: ave Sediment load	98658	76400	68293	94197	74413	50266	93978	96372	99173	94691	94197	94197	94197	146702	107866	101998
W: ave Sediment Onset	30.0	30.0	30.0	31.0	30.0	29.0	31.0	31.0	31.0	31.0	31.00	31.00	31.00	31.00	31.00	31.00
W: ave Sediment Duration	64.0	70.0	71.5	75.5	70.0	76.5	75.5	75.0	75.5	75.0	75.50	75.50	75.50	69.50	74.00	75.00
D: ave Total Phosphorous	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01
W: ave Total Phosphorous	0.08	0.07	0.07	0.07	0.06	0.06	0.07	0.07	0.07	0.07	0	0	0	0	0	0

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noAL U	A2_ALU	I1_noIrr	I2_Irr	F1_noFPI	F2_FPI	F3_FPI	H1a_noH PP	H1b_no mainHPP	H3_HPP
D: ave Total Nitrogen	0.25	0.20	0.19	0.16	0.16	0.15	0.16	0.16	0.17	0.16	0	0	0	0	0	0
W: ave Total Nitrogen	0.58	0.47	0.64	0.44	0.49	0.45	0.48	0.48	0.48	0.48	0	0	0	1	0	0
W: FP AVE SiltClay	203.7	262.0	266.5	280.4	319.5	319.5	278.5	283.7	273.4	283.7	280	280	280	241	280	184
W: FP TOT SiltClay	1296	1182	1181	1131	1208	1036	1133	1123	1142	1123	1131	1131	1131	1206	1129	270

Appendix Table 7 BioRA FA 4: Modelled BioRA indicators (river reaches)

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noALU	A2_ALU	I1_noIrr	I2_Irr	F1_noFPI	F2_FPI	F3_FPI	H1a_noHPP	H1b_no mainHPP	H3_HPP
Mean annual runoff	10593	10445	10237	10648	10538	8986	10643	10583	11073	10583	10648.2	10648.2	10648.2	10637.0	10684.8	10830.4
Dry onset	49.0	50.0	50.0	51.0	50.0	49.0	51.0	50.5	52.0	50.0	51.0	51.0	51.0	50.0	51.0	51.0
Dry duration	173.5	164.5	175.0	169.5	173.5	182.0	169.5	175.0	156.5	175.0	169.5	169.5	169.5	173.0	170.0	166.5
Dry Min 5day Q	1461	2081	2020	1992	2028	1826	2005	1915	2547	1915	1992.1	1992.1	1992.1	1113.9	2048.6	2064.8
Wet onset	25.0	26.0	27.0	27.0	26.5	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	26.0
Wet duration	135.5	133.0	128.5	137.5	130.5	117.5	137.0	137.0	142.5	137.0	137.5	137.5	137.5	138.0	138.5	145.5
Wet Max 5day Q	35265	34805	34601	36186	36833	30937	36119	36223	36423	36223	36186	36186	36186	37950	36125	36380
Flood volume	257288	236745	232358	248813	244395	193068	248249	248544	263499	248544	248813	248813	248813	277891	249397	265605
T1: T1 onset	21.5	22.0	23.0	23.0	23.0	23.0	24.0	23.5	23.0	23.5	23.5	23.5	23.5	23.0	23.5	23.0
T2: T2 onset	45.0	45.0	45.0	47.0	45.0	43.5	47.0	47.0	47.0	47.0	47.0	47.0	47.0	46.5	47.0	47.0
D: av ChVelocity	1.3	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.2	1.3	1.4
W: av ChVelocity	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
D: av Ch Depth	1.8	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	1.7	2.1	2.1
W: ave Ch Depth	5.5	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.5	5.3	5.2
D: ave Wetted perimeter	1297.9	1370.0	1370.0	1370.0	1370.0	1370.0	1370.0	1370.0	1370.0	1370.0	1370.0	1370.0	1370.0	1253.3	1373.5	1370.0
D: av Shear stress	6.8	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	5.9	8.2	8.3
T1: av Ch Shear stress	14.8	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	12.7	11.2	13.3
W:av Ch Shear stress	16.2	16.2	16.2	16.2	16.2	16.2	16.2	16.2	16.2	16.2	16.2	16.2	16.2	16.2	16.1	16.2
T2: ave Ch Shear stress	13.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.1	15.1	14.2
D: ave Sediment load	25227	4230	3807	3803	3849	3730	3801	3699	4327	3699	3806	3806	3806	4522	3032	3984
T1: ave Sediment load	368171	90315	78041	67179	84059	75241	66829	66620	72234	66620	67179	67179	67179	176455	58545	80724
Wt: ave Sediment load	861725	348363	343652	343904	359758	306237	343210	344050	349669	344050	343904	343904	343904	852895	351261	346861
T2: ave Sediment load	76811	24400	23716	31490	23558	19777	31539	31194	33533	31194	31490	31490	31490	126154	57924	31987
W: ave Sediment Onset	29.0	30.0	30.0	31.0	30.0	30.0	31.0	31.0	31.0	31.0	31.00	31.00	31.00	31.00	31.00	30.00
W: ave Sediment Duration	67.0	59.5	58.5	59.5	59.0	59.0	59.5	59.5	60.0	59.5	59.50	59.50	59.50	65.00	66.00	62.50
D: ave Total Phosphorous	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
W: ave Total Phosphorous	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0	0	0	0	0	0
D: ave Total Nitrogen	0.22	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0	0	0	0	0	0
W: ave Total Nitrogen	0.55	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0	0	0	1	0	0

Appendix Table 8 BioRA FA 5: Modelled BioRA indicators (river reaches)

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noAL U	A2_ALU	I1_noIrr	I2_Irr	F1_noFPI	F2_FPI	F3_FPI	H1a_noH PP	H1b_no mainHPP	H3_HPP
Mean annual runoff	13048	12956	13273	12787	13174	11734	13333	13201	13673	13201	12787.2	13225.9	13178.6	12963.6	13290.5	13399.8
Dry onset	49.0	51.0	51.0	50.5	50.0	49.0	51.0	51.0	52.0	51.0	50.5	51.0	51.0	49.5	51.5	51.5
Dry duration	177.5	174.0	172.0	171.5	171.0	183.5	171.5	175.0	152.5	175.0	171.5	172.0	172.0	187.0	176.5	172.0
Dry Min 5day Q	1938	2725	2572	2642	2617	2466	2651	2512	3236	2512	2641.9	2570.4	2570.2	1488.3	2709.0	2705.5
Wet onset	25.0	27.0	28.5	27.0	27.0	27.5	28.0	28.5	28.0	28.5	27.0	28.5	28.5	27.0	28.0	26.0
Wet duration	138.0	130.5	127.5	124.5	126.5	116.0	129.0	127.5	133.0	127.5	124.5	127.5	127.5	134.5	131.5	143.0
Wet Max 5day Q	39847	38689	39399	38913	40909	36849	39407	39396	39553	39396	38913	39146	38727	41387	39275	39913
Flood volume	311638	295510	303148	286755	295617	253861	305689	302875	312009	302875	286755	301819	300464	326395	308225	316944
T1: T1 onset	22.0	23.0	24.0	23.0	23.0	23.0	23.5	24.0	23.0	24.0	23.0	24.0	24.0	24.0	25.0	24.5
T2: T2 onset	45.0	45.0	47.0	45.0	45.0	44.0	47.0	47.0	47.0	47.0	45.0	47.0	47.0	46.0	47.0	47.0
D: av ChVelocity	0.3	0.3	0.3	0.4	0.3	0.3	0.4	0.3	0.4	0.3	0.4	0.4	0.4	0.3	0.4	0.3
W: av ChVelocity	1.3	1.3	1.2	1.3	1.3	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.2	1.3	1.3	1.3
D: av Ch Depth	23.7	24.4	24.3	24.6	24.4	24.2	24.6	24.5	24.8	24.5	24.6	24.7	24.7	23.4	24.5	24.5
W: ave Ch Depth	32.3	31.9	31.8	32.1	32.0	31.1	32.1	32.1	32.2	32.1	32.1	32.3	32.4	32.5	32.1	32.2
D: ave Wetted perimeter	564.9	657.7	650.7	680.4	657.0	631.1	682.0	668.1	716.8	668.1	680.4	691.0	671.4	524.8	672.7	666.2
D: av Shear stress	0.5	0.7	0.7	0.8	0.8	0.7	0.8	0.7	0.9	0.7	0.8	0.8	0.8	0.4	0.8	0.8
T1: av Ch Shear stress	2.6	2.0	1.6	1.2	1.8	1.4	1.3	1.2	1.4	1.2	1.2	1.2	1.2	1.8	1.4	1.6
W:av Ch Shear stress	6.7	6.3	6.2	6.5	6.4	5.7	6.5	6.5	6.6	6.5	6.5	6.2	6.0	6.8	6.5	6.6
T2: ave Ch Shear stress	1.9	2.1	2.1	2.8	2.1	1.9	2.8	2.7	2.9	2.7	2.8	2.6	2.6	2.3	2.8	2.8
W: av FP Area inundation	305	261	254	275	273	203	287	283	288	283	289.9	275.4	275.4	308.7	283.7	290.3
W: ave FP Depth	2.2	2.0	1.9	2.0	5.2	4.4	5.4	5.3	5.4	5.3	2.0	2.0	2.0	2.2	2.0	2.1
W: av FP Onset inundation	23.0	24.5	23.0	25.0	24.5	24.5	25.5	25.5	24.5	24.5	25.0	25.0	25.0	25.0	25.0	25.0
Annual: FP Duration inundation	184.0	186.5	182.5	182.5	183.5	183.5	183.0	179.5	183.5	183.5	182.5	182.5	182.5	182.5	182.5	182.5
D: ave Sediment load	26 699	5 667	1 924	1 839	1 854	1 709	1 933	1 863	2 104	1 863	1839	1920	1919	18730	4178	2043
T1: ave Sediment load	155 592	85 174	3 417	3 687	5 136	3 599	3 182	3 123	3 566	3 123	3687.1	3009.3	3010.0	######	57964.9	21044.7
Wt: ave Sediment load	886 302	305 560	28 924	31 246	32 184	28 555	31 739	31 595	33 092	31 595	31 246	30 954	30 750	923 123	335 693	116 694
T2: ave Sediment load	202 522	15 470	5 904	5 351	4 906	4 210	6 873	6 725	7 079	6 725	5 351	6 831	6 834	114 566	50 280	16 618
W: ave Sediment Onset	31.0	29.5	30.0	30.0	30.0	29.0	30.5	30.5	30.5	30.5	30.00	30.50	30.50	31.00	31.00	30.50
W: ave Sediment Duration	66.0	61.5	71.5	70.0	71.0	65.5	70.5	70.0	71.0	70.0	70.00	71.00	71.00	67.50	67.00	67.00
D: ave Total Phosphorous	0.04	0.03	0.01	0.01	0.02	0.02	0.02	0.02	0.18	0.02	0.01	0.01	0.01	0.05	0.19	0.02
W: ave Total Phosphorous	0.09	0.06	0.03	0.03	0.03	0.03	0.03	0.03	0.20	0.03	0	0	0	0	0	0

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noAL U	A2_ALU	I1_noIrr	I2_Irr	F1_noFPI	F2_FPI	F3_FPI	H1a_noH PP	H1b_no mainHPP	H3_HPP
D: ave Total Nitrogen	0.22	0.19	0.18	0.18	0.18	0.18	0.18	0.18	5.04	0.18	0	0	0	0	12	0
W: ave Total Nitrogen	0.49	0.33	0.23	0.19	0.19	0.19	0.19	0.19	13.33	0.19	0	0	0	1	145	0
W: FP AVE SiltClay	105.2	49.6	4.7	5.6	1.0	1.2	1.4	1.5	1.3	1.5	6	6	6	156	215	24
W: FP TOT SiltClay	14740	4963	477	451	121	108	129	138	138	138	451	451	451	17197	9086	2384

Appendix Table 9 BioRA FA 6: Modelled BioRA indicators (river reaches)

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noALU	A2_ALU	I1_noIrr	I2_Irr	F1_noFPI	F2_FPI	F3_FPI	H1a_noHPP	H1b_no mainHPP	H3_HPP
Mean annual runoff	12.3	12.3	12.2	12.3	12.3	11.8	12.4	12.3	11.8	11.8	12.3	12.5	12.5	12.3	12.3	12.3
Dry onset	49.0	49.0	49.0	50.0	49.0	47.5	51.0	50.0	47.5	47.5	50.0	51.0	51.0	50.0	50.0	50.0
Dry duration	191.5	198.0	201.0	195.5	195.0	216.0	190.5	195.0	216.0	216.0	195.5	179.0	178.5	189.5	189.5	189.5
Dry Min 5day Q	9	9	9	9	9	9	9	9	9	9	8.9	9.0	9.0	8.5	8.5	8.5
Wet onset	31.0	31.0	31.5	32.0	32.0	32.5	32.0	32.0	32.5	32.5	32.0	32.0	32.0	31.0	31.0	31.0
Wet duration	135.5	132.0	130.5	134.0	132.5	110.0	136.0	134.0	110.0	110.0	134.0	141.0	142.5	141.5	141.5	141.5
Wet Max 5day Q	17	16	16	17	17	16	17	17	16	16	17	17	17	17	17	17
Flood volume	181	173	172	179	178	142	184	179	142	142	179	194	196	191	191	191
W: ave FA6 FloodVolume	36477.4	33797.9	33490.8	33364.2	35173.4	30485.1	32799.2	33871.1	33939.2	33871.1	33364.2	37567.2	41671.4	37520.7	33756.4	34197.5
T1: T1 onset	24.5	25.0	26.0	27.0	25.5	26.5	27.0	27.0	26.5	26.5	27.0	26.5	26.5	25.0	25.0	25.0
T2: T2 onset	49.5	50.0	50.0	51.5	50.0	48.5	51.5	51.5	48.5	48.5	51.5	52.5	52.5	51.0	51.0	51.0
D: av ChVelocity	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	2247.1	0.3	0.3	0.3	0.3	0.3	0.3	0.3
W: av ChVelocity	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	5007.1	0.5	0.5	0.5	0.6	0.5	0.5	0.5
D: av Ch Depth	10.1	10.2	10.2	10.5	10.4	9.9	10.5	10.4	10.6	10.4	10.5	10.7	10.7	10.2	10.5	10.5
W: ave Ch Depth	15.6	15.2	15.2	15.4	15.4	14.5	15.5	15.4	15.4	15.4	15.4	15.6	15.7	15.6	15.4	15.4
D: ave Wetted perimeter	567.0	617.1	608.4	659.0	620.0	568.1	672.1	654.2	692.9	654.2	659.0	702.5	686.8	578.6	657.6	656.1
D: av Shear stress	1.5	1.3	1.3	1.6	1.5	1.0	1.8	1.7	1.6	1.7	1.6	1.5	1.5	1.9	1.7	1.7
T1: av Ch Shear stress	1.4	1.0	0.9	0.7	0.8	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.8	1.2	0.8	0.9
W:av Ch Shear stress	2.8	2.6	2.6	2.6	2.9	2.4	2.6	2.6	2.6	2.6	2.6	2.4	2.6	2.8	2.6	2.6
T2: ave Ch Shear stress	5.7	4.8	4.8	5.3	5.3	4.3	5.5	5.5	5.2	5.5	5.3	4.9	5.1	6.5	5.4	5.4
W: av FP Area inundation	7481	6581	5082	5500	5514	4103	5624	5505	5608	5505	7332.7	4032.9	6309.3	5872.8	5506.9	5515.2
W: ave FP Depth	2.0	1.8	1.9	1.9	1.9	1.7	1.9	1.9	1.9	1.9	1.9	2.0	2.1	2.0	1.9	1.9
W: av FP Onset inundation	27.0	9.0	9.0	9.0	30.0	31.0	31.0	31.0	30.5	31.0	30.0	31.0	30.5	29.5	31.0	30.0
Annual: FP Duration inundation	181.5	315.0	315.0	315.0	148.5	134.5	153.5	152.0	155.0	152.0	165.5	144.0	157.0	160.0	152.5	154.5
D: ave Sediment conc	262.9	121.7	18.1	19.1	21.0	14.1	27.3	27.3	21.7	27.3	19.1	18.7	20.0	239.3	112.0	45
T1: ave Sediment conc	331.7	145.5	11.6	10.8	12.7	11.3	11.2	11.2	11.7	11.2	11	11	11	379	143	49
W: ave Sediment conc	200.0	81.3	9.5	10.6	10.2	10.1	10.8	10.8	10.8	10.8	11	11	11	218	86	32
T2: ave Sediment conc	44.1	13.1	2.4	1.1	3.5	0.7	1.4	1.4	1.1	1.4	1	3	3	32	3	2
D: ave Sediment load	27 460	11 398	2 564	1 799	2 368	1 585	2 997	2 823	2 321	2 823	1799	2339	2525	27839	11084	4972
T1: ave Sediment load	78 669	31 145	1 920	2 117	2 198	1 867	1 927	1 966	2 208	1 966	2117.5	2233.9	2302.5	84137.9	25889.6	9601.7
Wt: ave Sediment load	85 328	36 245	3 952	4 202	4 345	3 794	4 461	4 532	4 415	4 532	4201.5	4682.4	5525.9	96647.2	38764.7	13967.6

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noAL U	A2_ALU	I1_noIrr	I2_Irr	F1_noFPI	F2_FPI	F3_FPI	H1a_noH PP	H1b_no mainHPP	H3_HPP
T2: ave Sediment load	22 608	6 504	1 380	524	1 878	287	708	683	548	683	524.35	1599.68	1840.85	######	1445.71	1016.62
W: ave Sediment Onset	14.0	15.5	11.5	15.0	11.5	11.0	13.0	13.0	14.0	13.0	15.00	12.50	14.50	22.00	17.00	15.00
W: ave Sediment Duration	157.5	150.5	178.5	175.5	180.0	190.0	175.5	176.5	172.5	176.5	175.50	177.00	177.50	125.50	138.50	166.00
D: ave Total Phosphorous	1.22	1.13	0.51	0.73	0.71	0.57	0.76	0.79	0.84	0.80	0.73	0.71	0.53	2.01	1.75	1.23
W: ave Total Phosphorous	27.77	18.00	8.55	9.77	10.18	7.84	9.99	10.55	10.78	10.57	10	11	11	34	23	16
D: ave Total Nitrogen	2.01	1.89	1.66	2.17	1.95	1.58	2.25	2.14	2.28	2.14	2	2	2	2	2	2
W: ave Total Nitrogen	40.54	26.67	15.88	20.69	18.17	13.35	17.90	17.95	18.32	17.93	21	22	24	49	33	23
W: FP AVE SiltClay	177.0	64.6	6.6	7.0	6.9	6.6	7.1	7.4	7.4	7.4	7	7	7	203	80	25
W: FP TOT SiltClay	1393746	491676	45410	53003	54201	38747	54037	55305	56378	55378	53003	57710	62121	######	559687	186153
W: FP Sedimentation	2242302	792583	72098	84606	85973	59478	86491	88270	90101	88387	84606	92948	102078	######	882807	297411
D:av Secchi depth	1.3	1.7	2.1	2.1	2.1	2.2	2.1	2.1	2.1	2.1	2	2	2	1	2	2
T1:av Secchi depth	0.0	0.0	1.4	1.4	1.3	1.4	1.4	1.4	1.4	1.4	1	1	1	0	0	0

Appendix Table 10 BioRA FA 7: Modelled BioRA indicators (river reaches)

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noAL U	A2_ALU	I1_noIrr	I2_Irr	F1_noFPI	F2_FPI	F3_FPI	H1a_noH PP	H1b_no mainHPP	H3_HPP
Mean annual runoff	4.8	4.7	4.6	4.6	4.7	4.1	4.8	4.6	4.7	4.6	4.6	4.8	4.9	4.8	4.7	4.6
Dry onset	50.0	49.0	49.0	51.0	50.0	48.5	51.0	51.0	51.0	51.0	51.0	51.0	51.0	51.0	51.0	51.0
Dry duration	203.0	208.5	213.0	204.0	204.0	227.5	190.5	201.5	189.0	201.5	204.0	164.5	163.5	197.5	201.0	204.0
Dry Min 5day Depth	1	1	1	1	1	1	1	1	1	1	1.4	1.4	1.4	1.3	1.4	1.4
Wet onset	34.0	35.0	35.0	36.0	35.0	36.0	35.0	36.0	35.0	36.0	36.0	35.0	35.0	35.0	36.0	36.0
Wet duration	122.0	114.5	112.5	115.0	114.5	87.5	118.5	115.0	117.0	115.0	115.0	120.0	121.0	122.0	116.5	115.0
Wet Max 5day Depth	9	9	9	9	9	8	9	9	9	9	9	9	9	9	9	9
Flood volume	86	78	77	81	81	56	86	81	83	81	81	89	90	87	82	81
T1: T1 onset	26.0	27.0	28.0	29.0	28.0	29.0	29.0	29.0	28.5	29.0	29.0	28.0	28.0	28.0	29.0	29.0
T2: T2 onset	51.0	50.5	50.5	52.5	51.0	49.0	52.5	52.5	52.5	52.5	52.5	52.5	52.5	52.0	52.5	52.5
W: av FP Area inundation	8137	7777	7864	7709	8103	6371	7630	7901	7988	7934	7989.9	8281.6	8408.4	8173.6	7927.3	7973.2
W: ave FP Depth	3.1	3.0	3.0	3.0	3.1	2.5	2.9	3.1	3.1	3.1	3.1	3.2	3.2	3.1	3.1	3.1
W: av FP Onset inundation	25.5	26.0	26.0	29.0	28.0	31.5	31.0	29.5	29.0	29.0	29.0	30.0	29.5	28.5	29.0	28.5
Annual: FP Duration inundation	195.0	187.0	183.0	170.5	177.0	153.5	156.5	162.5	168.0	164.0	171.0	163.5	164.0	169.0	165.0	171.0
D: ave Sediment load	12290	6611	3348	4524	3716	3856	5973	4649	3942	4649	3942	3867	4079	20703	9454	5974
T1: ave Sediment load	17148	11169	4518	5638	4655	3957	6121	5218	5165	5219	5165.5	5190.9	4997.2	16307.1	9175.7	6204.7
Wt: ave Sediment load	11324	8102	1761	1927	1638	1289	1740	1739	1695	1739	1695.3	1598.8	1551.3	12803.2	5659.3	2765.1
T2: ave Sediment load	1908	1773	1146	1195	1097	764	1084	1148	1115	1148	1115.00	1095.00	1100.50	2589.50	1691.00	1232.50
W: ave Sediment Onset	21.0	21.0	19.5	18.0	18.5	12.0	15.0	17.0	19.0	17.0	19.00	17.00	16.50	19.00	18.50	18.00
W: ave Sediment Duration	97.5	104.0	108.0	110.5	97.5	140.5	111.5	102.0	107.5	102.0	107.50	105.50	104.50	111.00	124.00	113.00
D: ave Total Phosphorous	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
W: ave Total Phosphorous	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100	100	100	100	100	100
D: ave Total Nitrogen	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100	100	100	100	100	100
W: ave Total Nitrogen	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100	100	100	100	100	100
W: FP Sedimentation	12858	9825	5643	5927	5661	3591	5449	5715	5820	5665	5753	5832	5917	14038	8909	6306
Area <3.5m (TLS:Grass)	4756	4723	4711	4720	4722	4552	4728	4709	4722	4709	4717	4754	4741	4754	4717	4720
Area >3.5m (TLS: HM, FF)	2870	2498	2462	2696	2737	1692	2906	2719	2779	2719	2693	3037	3162	3037	2750	2761
Max Flood Depth	25.6	23.7	24.2	23.3	25.5	16.2	22.6	24.7	25.0	24.8	25	27	28	26	25	25
D:av Secchi depth	1.5	1.7	1.9	1.6	1.7	1.1	1.2	1.4	1.6	1.4	2	1	1	1	1	1
T1:av Secchi depth	0.1	0.3	1.0	0.7	0.9	0.9	0.6	0.7	0.8	0.7	1	1	1	0	0	0

Appendix Table 11 BioRA FA 8a: Modelled BioRA indicators (river reaches)

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noALU	A2_ALU	I1_noIrr	I2_Irr	F1_noFPI	F2_FPI	F3_FPI	H1a_noHPP	H1b_no mainHPP	H3_HPP
Mean annual runoff	3135	2877	2607	3410	3382	2836	3460	3400	3486	3400	3781.1	1876.4	2727.3	2919.5	2867.2	2885.5
Dry onset	50.0	50.0	50.0	52.0	51.0	50.0	52.0	52.0	52.0	52.0	52.0	51.0	52.0	51.0	51.0	52.0
Dry duration	230.5	235.5	240.0	224.0	218.5	237.5	222.5	223.5	220.0	223.5	219.0	239.0	225.5	225.5	225.0	224.0
Dry Min 5day Area	154	158	139	170	173	171	171	169	171	169	189.1	1.0	1.5	143.7	140.5	147.8
Wet onset	31.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	34.5	32.0	32.0	32.0	32.0
Wet duration	130.5	126.5	124.0	140.0	138.5	126.0	140.5	139.5	141.0	139.5	141.0	109.0	137.5	135.0	136.5	136.0
Wet Max 5day Area	10257	9602	8887	9982	9934	9086	10047	9988	10016	9988	11091	5495	7996	8435	8316	8329
Flood volume	85 404	77 378	70 453	90 638	89 656	72 750	92 087	90 516	92 064	90 516	101 124	43 208	72 041	76 446	74 587	74 484
T1: T1 onset	31.0	32.0	32.0	32.0	31.0	32.0	32.0	32.0	32.0	32.0	32.0	33.0	32.0	31.0	32.0	32.0
T2: T2 onset	49.5	50.0	49.5	52.0	51.0	50.0	52.0	51.5	52.0	51.5	52.0	50.5	51.5	51.0	51.5	51.5
W: av FP Area inundation	7267	6646	6087	7246	7256	6173	7360	7251	7360	7251	8051.2	3959.5	5815.7	6301.6	6046.1	6074.6
W: ave FP Depth	0.8	0.7	0.7	0.8	0.8	0.6	0.8	0.8	0.8	0.8	0.8	0.7	0.8	0.9	0.8	0.8
W: av FP Onset inundation	31.0	32.0	33.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	36.0	32.5	32.0	32.0	33.0
Annual: FP Duration inundation	131.0	126.5	120.0	147.0	137.5	128.0	147.5	146.0	155.5	146.0	149.0	94.0	138.0	132.5	146.0	135.0
D: ave Total Phosphorous	1.12	0.96	0.34	0.95	0.95	0.76	1.06	1.04	1.15	1.05	0.95	0.95	0.92	2.73	2.51	1.70
W: ave Total Phosphorous	24.48	17.32	8.24	10.48	10.54	9.28	10.78	11.38	11.59	11.42	10	11	10	35	25	17
D: ave Total Nitrogen	1.74	1.48	1.06	3.01	2.55	2.07	3.11	2.93	3.24	2.93	3	3	3	4	3	3
W: ave Total Nitrogen	37.74	25.63	15.37	21.45	19.05	15.72	18.53	18.73	19.01	18.72	21	22	22	50	35	24
W: FP AVE SiltClay	125.4	41.1	4.3	4.6	4.6	3.9	4.7	4.8	4.9	4.8	5	4	5	145	51	16
W: FP TOT SiltClay	942893	311037	29707	39051	38648	26554	39955	40646	41578	40697	39051	37711	38172	######	415841	131010
W: FP Sedimentation	1288461	423701	40220	53390	52766	35354	54447	55287	56604	55369	53390	51241	51853	######	566739	178507
Max Flood Depth (	2.6	2.6	2.5	2.7	2.7	2.5	2.8	2.7	2.8	2.7	3	2	2	3	3	3
Area 0.05-0.3m in wet	10647	9366	9065	10547	10530	9873	10589	10556	10590	10556	10547	10571	10333	10637	10558	10596
Area 0.3-0.55m >110d	11	58	1	112	144	145	110	116	121	116	112	81	95	110	119	111
Area 0.05-0.3m in wet	10647	9366	9065	10547	10530	9873	10589	10556	10590	10556	10547	10571	10333	10637	10558	10596
Area 0.3-0.55m >110d	11	58	1	112	144	145	110	116	121	116	112	81	95	110	119	111
Area 0.3-0.55 m <110 d	10303	9307	8994	10003	10011	8799	10068	9989	10028	9989	10003	9879	9506	10107	10008	10054
Area>0.55m in dry	362.2	150.6	126.6	418.1	263.0	71.7	438.5	412.8	440.6	412.8	418	414	359	422	416	427
Max depth >2.75m	162.0	126.0	87.5	170.5	183.5	20.0	211.5	172.5	188.5	172.5	171	64	67	267	172	191
Inund >200d	446	386	195	753	751	686	782	754	816	754	753	688	685	752	760	794
ave Salinity	6.5	1.2	3.0	3.5	3.0	3.9	3.8	4.4	3.3	3.8	4	4	4	4	3	4

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noALU	A2_ALU	I1_noIrr	I2_Irr	F1_noFPI	F2_FPI	F3_FPI	H1a_noHPP	H1b_no mainHPP	H3_HPP
MAX Salinity	28.8	19.9	19.0	30.6	42.7	30.4	30.4	30.4	30.4	30.4	30	35	27	30	30	30
Area Salinity<1g/l all yr	11900	12222	11709	7252	12252	8461	7743	7865	7607	7790	7828	7165	7075	8446	7786	7934
Area Salinity<4g/l all yr	12332	12358	12128	9602	12473	10552	9539	10291	10002	9527	9579	8815	8938	10419	9836	9684
Area Salinity>4g/l (1-4 mnth)	27	383	183	225	142	280	277	305	266	293	284	232	324	217	294	278
Area Salinity>4g/l (4-6 mnth)	0	0	0	0	170	0	0	0	0	0	0	0	0	0	0	0
Area Salinity>4g/l (>6 mnth)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0	0	0

Appendix C Uncertainty ranges for BioRA indicators (river reaches) predicted by DSS

Appendix Table 12 BioRA Zone 1: Uncertainty ranges for BioRA indicators

<table>
<tr><th></th><th>Base2007</th><th>2020</th><th>2040</th><th>2040CC</th><th>C2_2040 Wet</th><th>C3_2040 Dry</th><th>A1_noALU</th><th>A2_ALU</th><th>I1_noIRR</th><th>I2_IRR</th><th>F1_noFPI</th><th>F2_FPI</th><th>F3_FPI</th><th>H1a_noHPP</th><th>H1b_nomainHPP</th><th>H3_HPP</th></tr>
<tr><td colspan="17">Geomorphology</td></tr>
<tr><td>Erosion (bank / bed incision)</td><td>-15 | +19</td><td>+37 |+203</td><td>+37 |+203</td><td>+39 |+202</td><td>+37 |+204</td><td>+32 |+203</td><td>+38 |+197</td><td>+40 |+206</td><td>+39 |+202</td><td>+39 |+202</td><td>+39 |+202</td><td>+39 |+202</td><td>+39 |+202</td><td>-22 | +24</td><td>+7 |+127</td><td>+39 |+202</td></tr>
<tr><td>Average bed sediment size in the dry season</td><td>-13 | +4</td><td>+71 |+187</td><td>+71 |+187</td><td>+73 |+190</td><td>+68 |+181</td><td>+78 |+202</td><td>+73 |+190</td><td>+73 |+190</td><td>+73 |+190</td><td>+73 |+190</td><td>+73 |+190</td><td>+73 |+190</td><td>+73 |+190</td><td>-9 | +12</td><td>+49 |+142</td><td>+73 |+190</td></tr>
<tr><td>Availability exposed sandy habitat in dry season</td><td>-4 | +4</td><td>-68 | -45</td><td>-68 | -45</td><td>-69 | -45</td><td>-68 | -45</td><td>-69 | -45</td><td>-68 | -45</td><td>-69 | -45</td><td>-69 | -45</td><td>-69 | -45</td><td>-69 | -45</td><td>-69 | -45</td><td>-69 | -45</td><td>-3 | +12</td><td>-37 | -24</td><td>-69 | -45</td></tr>
<tr><td>Availability inundated sandy habitat in dry season</td><td>-6 | +2</td><td>-91 | -65</td><td>-91 | -65</td><td>-91 | -66</td><td>-90 | -65</td><td>-92 | -66</td><td>-91 | -65</td><td>-92 | -66</td><td>-91 | -66</td><td>-91 | -66</td><td>-91 | -66</td><td>-91 | -66</td><td>-91 | -66</td><td>-7 | +6</td><td>-49 | -34</td><td>-91 | -66</td></tr>
<tr><td>Availability exposed rocky habitat in dry season</td><td>-4 | +7</td><td>+16 |+109</td><td>+16 |+109</td><td>+16 |+109</td><td>+17 |+110</td><td>+15 |+105</td><td>+16 |+108</td><td>+16 |+110</td><td>+16 |+109</td><td>+16 |+109</td><td>+16 |+109</td><td>+16 |+109</td><td>+16 |+109</td><td>-7 | +6</td><td>+4 | +56</td><td>+16 |+108</td></tr>
<tr><td>Availability inundated rocky habitat in dry season</td><td>-3 | +3</td><td>+11 | +76</td><td>+11 | +76</td><td>+11 | +76</td><td>+11 | +77</td><td>+9 | +73</td><td>+10 | +75</td><td>+11 | +76</td><td>+11 | +76</td><td>+11 | +76</td><td>+11 | +76</td><td>+11 | +76</td><td>+11 | +76</td><td>-7 | -1</td><td>+3 | +43</td><td>+11 | +76</td></tr>
<tr><td>Depth of bedrock pools in dry season</td><td>-11 | +15</td><td>-14 | +50</td><td>-14 | +50</td><td>-13 | +49</td><td>-13 | +52</td><td>-19 | +47</td><td>-13 | +49</td><td>-13 | +49</td><td>-13 | +49</td><td>-13 | +49</td><td>-13 | +49</td><td>-13 | +49</td><td>-13 | +49</td><td>-17 | +20</td><td>-18 | +37</td><td>-13 | +49</td></tr>
<tr><td>Water clarity</td><td>0 | 0</td><td>+59 | +60</td><td>+59 | +60</td><td>+59 | +60</td><td>+59 | +60</td><td>+59 | +60</td><td>+59 | +60</td><td>+59 | +60</td><td>+59 | +60</td><td>+59 | +60</td><td>+59 | +60</td><td>+59 | +60</td><td>+59 | +60</td><td>0 | 0</td><td>+6 | +19</td><td>+59 | +60</td></tr>
<tr><td colspan="17">Vegetation</td></tr>
<tr><td>Ch: Riparian trees</td><td>-1 | -1</td><td>+0 | +4</td><td>+0 | +4</td><td>-2 | +0</td><td>-3 | -2</td><td>+22 | +68</td><td>-2 | +1</td><td>-2 | +0</td><td>-2 | +1</td><td>-2 | +1</td><td>-2 | +0</td><td>-2 | +0</td><td>-2 | +0</td><td>-6 | -4</td><td>-2 | +0</td><td>-2 | -1</td></tr>
<tr><td>Ch: Extent upper bank vegetation</td><td>-3 | +7</td><td>-10 | -5</td><td>-10 | -5</td><td>-9 | -5</td><td>-9 | -3</td><td>-27 | -18</td><td>-8 | -5</td><td>-9 | -5</td><td>-9 | -5</td><td>-9 | -5</td><td>-9 | -5</td><td>-9 | -5</td><td>-9 | -5</td><td>-4 | +8</td><td>-10 | -6</td><td>-9 | -5</td></tr>
<tr><td>Ch: Extent lower bank vegetation</td><td>-3 | +1</td><td>-13 | +27</td><td>-13 | +27</td><td>-13 | +27</td><td>-14 | +26</td><td>-11 | +29</td><td>-12 | +27</td><td>-13 | +27</td><td>-14 | +26</td><td>-13 | +27</td><td>-13 | +27</td><td>-13 | +27</td><td>-13 | +27</td><td>-6 | -2</td><td>-16 | +14</td><td>-13 | +27</td></tr>
</table>

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noALU	A2_ALU	I1_noIRR	I2_IRR	F1_noFPI	F2_FPI	F3_FPI	H1a_noHPP	H1b_nomainHPP	H3_HPP
Ch: Weeds, grasses on sandbanks and sandbars	-1 | +3	-14 | -3	-14 | -2	-17 | -11	-18 | -12	+6 | +47	-17 | -11	-17 | -11	-17 | -11	-17 | -11	-17 | -11	-17 | -11	-17 | -11	-2 | +1	-14 | -9	-17 | -11
Ch: Biomass algae	0 | +0	+2 | +39	+2 | +39	+2 | +39	+2 | +38	+3 | +39	+2 | +38	+3 | +39	+2 | +39	+2 | +39	+2 | +39	+2 | +39	+2 | +39	-2 | -1	-7 | 0	+2 | +39
Extent invasive riparian vegetation	-1 | +4	-2 | +26	-3 | +27	+0 | +34	+1 | +41	-59 | -18	-1 | +11	+1 | +52	+0 | +34	+0 | +33	+0 | +34	+0 | +34	+0 | +34	+1 | +42	+1 | +40	+1 | +36
Extent invasive floating/submerged vegetation	0 | 0	0 | 0	0 | 0	0 | 0	0 | 0	0 | 0	0 | 0	0 | 0	0 | 0	0 | 0	0 | 0	0 | 0	0 | 0	0 | 0	0 | 0	0 | 0
Comp: Indigenous vegetation biomass	-2 | +2	-12 | +11	-12 | +12	-13 | +9	-14 | +9	-8 | +26	-13 | +9	-13 | +9	-13 | +9	-13 | +9	-13 | +9	-13 | +9	-13 | +9	-5 | +1	-14 | +3	-13 | +9
Comp: Overall vegetation biomass	-2 | +2	-12 | +11	-12 | +12	-13 | +9	-14 | +9	-8 | +26	-13 | +9	-13 | +9	-13 | +9	-13 | +9	-13 | +9	-13 | +9	-13 | +9	-5 | +1	-14 | +3	-13 | +9
MacroInvertebrates																
Insects on stones	-2 | +1	+1 | +29	+1 | +29	+2 | +31	+2 | +30	+1 | +27	+2 | +31	+2 | +31	+2 | +31	+2 | +31	+2 | +31	+2 | +31	+2 | +31	-3 | +1	+0 | +16	+2 | +30
Insects on sand	-2 | +1	-10 | +16	-10 | +16	-9 | +18	-9 | +17	-11 | +14	-9 | +18	-9 | +18	-9 | +18	-9 | +18	-9 | +18	-9 | +18	-9 | +18	-3 | +1	-6 | +8	-10 | +17
Burrowing mayflies	-1 | +1	-85 | -45	-85 | -45	-88 | -45	-81 | -40	-95 | -54	-88 | -45	-88 | -45	-88 | -45	-88 | -45	-88 | -45	-88 | -45	-88 | -45	-2 | +1	-60 | -30	-88 | -46
Snail abundance	-1 | +1	-1 | +19	-1 | +19	-1 | +19	-1 | +19	-1 | +19	-1 | +19	-1 | +19	-1 | +19	-1 | +19	-1 | +19	-1 | +19	-1 | +19	-2 | 0	-2 | +7	-1 | +19
Diversity of snails	-2 | 0	-59 | -41	-59 | -41	-58 | -41	-59 | -43	-55 | -33	-56 | -39	-59 | -42	-58 | -41	-58 | -41	-58 | -41	-58 | -41	-58 | -41	-3 | -2	-15 | -11	-58 | -40
Bivalves abundance	-1 | +3	-92 | -83	-92 | -83	-95 | -86	-87 | -79	-100| -95	-95 | -86	-95 | -86	-95 | -86	-95 | -86	-95 | -86	-95 | -86	-95 | -86	-4 | -1	-81 | -61	-95 | -86
Shrimps and crabs	-2 | +3	-11 | +22	-11 | +22	-11 | +22	-11 | +22	-12 | +22	-12 | +22	-11 | +22	-12 | +22	-11 | +22	-11 | +22	-11 | +22	-11 | +22	-3 | +1	-9 | +14	-11 | +22
Littoral invertebrate diversity	-3 | +4	-64 | -10	-64 | -10	-64 | -6	-63 | -6	-64 | -17	-63 | -5	-65 | -7	-64 | -5	-64 | -6	-64 | -6	-64 | -6	-64 | -6	-3 | +6	-17 | +28	-64 | -8
Benthic invertebrate diversity	-1 | +3	-78 | -10	-78 | -11	-77 | -6	-71 | -3	-90 | -24	-78 | -6	-78 | -6	-77 | -4	-78 | -6	-77 | -6	-77 | -6	-77 | -6	+0 | +6	-52 | -3	-79 | -8
Zooplankton abundance	-2 | +5	-2 | +18	-2 | +18	-1 | +18	+0 | +25	-13 | +7	-1 | +17	-1 | +18	-1 | +18	-1 | +18	-1 | +18	-1 | +18	-1 | +18	-4 | +3	-2 | +6	-1 | +18
Comp: Benthic invertebrate biomass	-2 | +2	-33 | -7	-33 | -7	-34 | -7	-31 | -5	-36 | -11	-34 | -7	-34 | -7	-34 | -7	-34 | -7	-34 | -7	-34 | -7	-34 | -7	-3 | +0	-26 | -8	-34 | -7
Comp: Dry season insect emergence	-2 | +1	-31 | +0	-31 | +0	-32 | +1	-30 | +2	-35 | -5	-32 | +1	-32 | +1	-32 | +2	-32 | +1	-32 | +1	-32 | +1	-32 | +1	-3 | +1	-22 | -2	-32 | +1
Fish																

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noALU	A2_ALU	I1_noIRR	I2_IRR	F1_noFPI	F2_FPI	F3_FPI	H1a_noHPP	H1b_nomainHPP	H3_HPP
Rhithron resident	-5 | +5	-34 | +18	-34 | +19	-34 | +19	-36 | +16	-31 | +21	-31 | +21	-36 | +19	-36 | +18	-34 | +20	-34 | +19	-34 | +19	-34 | +19	-11 | +4	-24 | +21	-35 | +18
Main channel resident (long distance white)	-8 | +15	-100| -79	-100|-100	-100|-100	-100| -96	-100|-100	-100|-100	-100|-100	-100|-100	-100|-100	-100|-100	-100|-100	-100|-100	-40 | -16	-92 | -48	-100|-100
Main channel spawner (short distance white)	-4 | +8	-100| -64	-100| -93	-100| -98	-100| -88	-100|-100	-100| -98	-100| -98	-100| -97	-100| -98	-100| -98	-100| -98	-100| -98	-19 | -4	-48 | -25	-100| -98
Eurytopic (generalist)	-7 | +10	-46 | +19	-32 | +47	-30 | +48	-34 | +42	-39 | +61	-29 | +49	-30 | +48	-31 | +48	-30 | +48	-30 | +48	-30 | +48	-30 | +48	-13 | +12	-46 | -10	-30 | +48
Non-native	-1 | +2	+38 |+124	+59 |+167	+61 |+170	+58 |+164	+62 |+171	+60 |+168	+62 |+171	+61 |+170	+61 |+170	+61 |+170	+61 |+170	+61 |+170	+6 | +22	+15 | +58	+61 |+170
Comp: Fish Biomass	-3 | +6	-60 | -7	-78 | -13	-80 | -14	-77 | -11	-81 | -15	-80 | -14	-80 | -14	-80 | -14	-80 | -14	-80 | -14	-80 | -14	-80 | -14	-13 | +4	-31 | +0	-80 | -15
Comp: Sensitive indigenous fish biomass	-4 | +7	-92 | -50	-100| -73	-100| -77	-100| -70	-100| -79	-100| -76	-100| -77	-100| -76	-100| -76	-100| -77	-100| -77	-100| -77	-18 | -3	-45 | -17	-100| -77
Herpetofauna																
Ranid	-2 | +1	-5 | 0	-5 | -1	-5 | -1	-5 | +0	-6 | +5	-2 | +1	-8 | -3	-5 | -1	-5 | -1	-5 | -1	-5 | -1	-5 | -1	-7 | -2	-8 | -3	-5 | -1
Aquatic serpents	-6 | +8	-19 | +1	-14 | +21	-11 | +24	-12 | +22	-26 | +22	-6 | +26	-16 | +21	-12 | +23	-11 | +24	-11 | +24	-11 | +24	-11 | +24	-11 | +8	-25 | -12	-12 | +23
Species richness of riparian/FP amphibians	+1 | +2	-30 | -20	-31 | -21	-34 | -23	-29 | -20	-33 | -24	-33 | -23	-34 | -24	-33 | -23	-34 | -23	-34 | -23	-34 | -23	-34 | -23	-4 | -1	-22 | -15	-33 | -23
Species richness of riparian/FP reptiles	+1 | +2	-48 | -31	-22 | -7	-23 | -6	-27 | -12	-9 | +5	-22 | -5	-24 | -6	-24 | -7	-23 | -6	-23 | -6	-23 | -6	-23 | -6	+1 | +3	-52 | -37	-24 | -6
Birds																
Medium/large ground-nesting channel spp	-3 | +3	-21 | -3	-21 | -3	-22 | -2	-23 | -4	-21 | -5	-15 | +3	-27 | -5	-22 | -2	-21 | -1	-22 | -2	-22 | -2	-22 | -2	-10 | +2	-16 | +2	-22 | -3
Bank / hole nesting species	0 | +0	-1 | +2	-1 | +1	-1 | +2	-1 | +3	-1 | 0	0 | +4	-3 | +2	-1 | +3	-1 | +2	-1 | +2	-1 | +2	-1 | +2	-1 | +0	-1 | +3	-1 | +2
Small non-flocking landbird;seasonally flooded veg	-1 | +1	0 | +8	0 | +8	0 | +9	0 | +8	0 | +7	0 | +9	0 | +9	0 | +9	0 | +9	0 | +9	0 | +9	0 | +9	-2 | +1	0 | +6	0 | +8
Overall bird abundance	-1 | +1	-7 | +2	-7 | +2	-7 | +3	-8 | +2	-8 | +1	-5 | +5	-10 | +2	-8 | +3	-7 | +3	-7 | +3	-7 | +3	-7 | +3	-5 | +1	-6 | +4	-8 | +3

Appendix Table 13 BioRA Zone 2: Uncertainty ranges for BioRA indicators

<table>
<tr><th></th><th>Base2007</th><th>2020</th><th>2040</th><th>2040CC</th><th>C2_2040 Wet</th><th>C3_2040 Dry</th><th>A1_noALU</th><th>A2_ALU</th><th>I1_noIRR</th><th>I2_IRR</th><th>F1_noFPI</th><th>F2_FPI</th><th>F3_FPI</th><th>H1a_noHPP</th><th>H1b_nomainHPP</th><th>H3_HPP</th></tr>
<tr><td colspan="17">Geomorphology</td></tr>
<tr><td>Erosion (bank / bed incision)</td><td>-17 | +11</td><td>-2 | +80</td><td>+10 |+122</td><td>+5 |+115</td><td>+13 |+135</td><td>-2 |+110</td><td>+5 |+111</td><td>+5 |+119</td><td>+6 |+119</td><td>+3 |+114</td><td>+5 |+115</td><td>+5 |+115</td><td>+5 |+115</td><td>-25 | +14</td><td>-10 | +57</td><td>+8 |+120</td></tr>
<tr><td>Average bed sediment size in the dry season</td><td>-9 | +5</td><td>+30 | +98</td><td>+50 |+131</td><td>+47 |+128</td><td>+51 |+131</td><td>+50 |+131</td><td>+48 |+128</td><td>+48 |+128</td><td>+49 |+128</td><td>+48 |+128</td><td>+47 |+128</td><td>+47 |+128</td><td>+47 |+128</td><td>-8 | +8</td><td>+20 | +77</td><td>+49 |+128</td></tr>
<tr><td>Availability exposed sandy habitat in dry season</td><td>-4 | +8</td><td>-26 | -12</td><td>-43 | -26</td><td>-40 | -27</td><td>-48 | -32</td><td>-34 | -20</td><td>-39 | -26</td><td>-42 | -26</td><td>-42 | -29</td><td>-39 | -24</td><td>-40 | -27</td><td>-40 | -27</td><td>-40 | -27</td><td>-5 | +10</td><td>-19 | -12</td><td>-42 | -29</td></tr>
<tr><td>Availability inundated sandy habitat in dry season</td><td>-3 | +3</td><td>-20 | -15</td><td>-31 | -23</td><td>-29 | -21</td><td>-34 | -25</td><td>-25 | -18</td><td>-28 | -20</td><td>-30 | -22</td><td>-30 | -21</td><td>-28 | -20</td><td>-29 | -21</td><td>-29 | -21</td><td>-29 | -21</td><td>-6 | 0</td><td>-14 | -10</td><td>-30 | -21</td></tr>
<tr><td>Availability exposed rocky habitat in dry season</td><td>-6 | +6</td><td>+4 | +57</td><td>+7 | +81</td><td>+6 | +76</td><td>+7 | +83</td><td>+5 | +70</td><td>+6 | +73</td><td>+6 | +79</td><td>+6 | +78</td><td>+6 | +75</td><td>+6 | +76</td><td>+6 | +76</td><td>+6 | +76</td><td>-5 | +14</td><td>+3 | +40</td><td>+6 | +77</td></tr>
<tr><td>Availability inundated rocky habitat in dry season</td><td>-5 | +1</td><td>+0 | +33</td><td>+3 | +52</td><td>+4 | +51</td><td>+4 | +55</td><td>+2 | +44</td><td>+3 | +49</td><td>+3 | +51</td><td>+4 | +53</td><td>+3 | +49</td><td>+4 | +51</td><td>+4 | +51</td><td>+4 | +51</td><td>-6 | +3</td><td>+1 | +26</td><td>+4 | +53</td></tr>
<tr><td>Depth of bedrock pools in dry season</td><td>-13 | +11</td><td>-14 | +20</td><td>-13 | +20</td><td>-16 | +20</td><td>-10 | +20</td><td>-23 | +20</td><td>-16 | +20</td><td>-17 | +20</td><td>-16 | +20</td><td>-18 | +20</td><td>-16 | +20</td><td>-16 | +20</td><td>-16 | +20</td><td>-23 | +14</td><td>-18 | +20</td><td>-13 | +20</td></tr>
<tr><td>Water clarity</td><td>-2 | -1</td><td>+6 | +15</td><td>+43 | +56</td><td>+46 | +55</td><td>+49 | +57</td><td>+60 | +67</td><td>+48 | +59</td><td>+57 | +61</td><td>+54 | +60</td><td>+51 | +58</td><td>+46 | +55</td><td>+46 | +55</td><td>+46 | +55</td><td>-1 | -1</td><td>+1 | +3</td><td>+48 | +60</td></tr>
</table>

<table>
<tr><th></th><th>Base2007</th><th>2020</th><th>2040</th><th>2040CC</th><th>C2_2040 Wet</th><th>C3_2040 Dry</th><th>A1_noALU</th><th>A2_ALU</th><th>I1_noIRR</th><th>I2_IRR</th><th>F1_noFPI</th><th>F2_FPI</th><th>F3_FPI</th><th>H1a_noHPP</th><th>H1b_nomainHPP</th><th>H3_HPP</th></tr>
<tr><td colspan="17">Vegetation</td></tr>
<tr><td>Ch: Riparian trees</td><td>-1 | 0</td><td>+3 | +10</td><td>+3 | +10</td><td>0 | +3</td><td>-3 | +2</td><td>+23 | +88</td><td>+0 | +3</td><td>0 | +2</td><td>-1 | +2</td><td>0 | +2</td><td>0 | +3</td><td>0 | +3</td><td>0 | +3</td><td>-4 | -2</td><td>0 | +3</td><td>-2 | +1</td></tr>
<tr><td>Ch: Extent upper bank vegetation</td><td>-4 | +5</td><td>-19 | -13</td><td>-21 | -14</td><td>-16 | -10</td><td>-13 | -7</td><td>-41 | -30</td><td>-16 | -10</td><td>-15 | -9</td><td>-16 | -10</td><td>-14 | -9</td><td>-16 | -10</td><td>-16 | -10</td><td>-16 | -10</td><td>-5 | +2</td><td>-16 | -10</td><td>-13 | -7</td></tr>
<tr><td>Ch: Extent lower bank vegetation</td><td>-3 | +0</td><td>-17 | -4</td><td>-17 | +9</td><td>-21 | +5</td><td>-19 | +12</td><td>-11 | +9</td><td>-21 | +4</td><td>-16 | +8</td><td>-23 | +6</td><td>-16 | +6</td><td>-21 | +5</td><td>-21 | +5</td><td>-21 | +5</td><td>-6 | -2</td><td>-24 | -10</td><td>-24 | +5</td></tr>
<tr><td>Ch: Extent herbaceous marsh</td><td>-1 | +0</td><td>+0 | +9</td><td>+0 | +13</td><td>0 | +16</td><td>0 | +16</td><td>+0 | +9</td><td>+0 | +17</td><td>0 | +12</td><td>0 | +18</td><td>+0 | +12</td><td>0 | +16</td><td>0 | +16</td><td>0 | +16</td><td>-2 | -1</td><td>0 | +14</td><td>0 | +18</td></tr>
<tr><td>Ch: Weeds, grasses on sandbanks and sandbars</td><td>-1 | +2</td><td>-3 | +4</td><td>-7 | +1</td><td>-9 | -4</td><td>-10 | -6</td><td>0 | +22</td><td>-8 | -4</td><td>-8 | -4</td><td>-9 | -5</td><td>-8 | -4</td><td>-9 | -4</td><td>-9 | -4</td><td>-9 | -4</td><td>-2 | +1</td><td>-5 | -1</td><td>-11 | -6</td></tr>
<tr><td>Ch: Biomass algae</td><td>+0 | +3</td><td>-7 | +1</td><td>-1 | +42</td><td>-4 | +40</td><td>0 | +47</td><td>+10 | +68</td><td>-1 | +46</td><td>+2 | +53</td><td>+1 | +50</td><td>+0 | +49</td><td>-4 | +40</td><td>-4 | +40</td><td>-4 | +40</td><td>-1 | +2</td><td>-6 | -2</td><td>-2 | +44</td></tr>
<tr><td>Extent invasive riparian vegetation</td><td>-1 | +4</td><td>-7 | +34</td><td>-6 | +32</td><td>-1 | +43</td><td>+0 | +42</td><td>-63 | -15</td><td>-2 | +21</td><td>+0 | +55</td><td>0 | +45</td><td>-1 | +38</td><td>-1 | +43</td><td>-1 | +43</td><td>-1 | +43</td><td>+1 | +37</td><td>-1 | +51</td><td>+1 | +49</td></tr>
<tr><td>Extent invasive floating/submerged vegetation</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td></tr>
<tr><td>Comp: Indigenous vegetation biomass</td><td>-2 | +2</td><td>-13 | -3</td><td>-14 | +2</td><td>-16 | 0</td><td>-15 | +3</td><td>-13 | +6</td><td>-16 | 0</td><td>-13 | +1</td><td>-17 | +0</td><td>-13 | +1</td><td>-16 | 0</td><td>-16 | 0</td><td>-16 | 0</td><td>-5 | -1</td><td>-17 | -7</td><td>-17 | +0</td></tr>
<tr><td>Comp: Overall vegetation biomass</td><td>-2 | +2</td><td>-13 | -3</td><td>-14 | +2</td><td>-16 | 0</td><td>-15 | +3</td><td>-13 | +6</td><td>-16 | 0</td><td>-13 | +1</td><td>-17 | +0</td><td>-13 | +1</td><td>-16 | 0</td><td>-16 | 0</td><td>-16 | 0</td><td>-5 | -1</td><td>-17 | -7</td><td>-17 | +0</td></tr>
<tr><td colspan="17">Macroinvertebrates</td></tr>
<tr><td>Insects on stones</td><td>-2 | +2</td><td>+0 | +15</td><td>+1 | +30</td><td>+1 | +31</td><td>+1 | +33</td><td>0 | +35</td><td>+2 | +33</td><td>+0 | +32</td><td>+2 | +35</td><td>+0 | +31</td><td>+1 | +31</td><td>+1 | +31</td><td>+1 | +31</td><td>-3 | +1</td><td>+2 | +20</td><td>+1 | +33</td></tr>
<tr><td>Insects on sand</td><td>-2 | +2</td><td>-4 | +11</td><td>-5 | +23</td><td>-4 | +24</td><td>-5 | +25</td><td>-6 | +27</td><td>-3 | +26</td><td>-6 | +24</td><td>-4 | +27</td><td>-5 | +24</td><td>-4 | +24</td><td>-4 | +24</td><td>-4 | +24</td><td>-4 | +1</td><td>0 | +17</td><td>-4 | +25</td></tr>
<tr><td>Burrowing mayflies</td><td>-2 | +1</td><td>-28 | -6</td><td>-56 | -15</td><td>-51 | -11</td><td>-56 | -13</td><td>-62 | -15</td><td>-53 | -11</td><td>-54 | -12</td><td>-53 | -10</td><td>-54 | -12</td><td>-51 | -11</td><td>-51 | -11</td><td>-51 | -11</td><td>-3 | +1</td><td>-14 | +7</td><td>-54 | -12</td></tr>
<tr><td>Snail abundance</td><td>-2 | +2</td><td>-2 | +6</td><td>-3 | +16</td><td>-3 | +15</td><td>-3 | +18</td><td>-3 | +24</td><td>-3 | +17</td><td>-3 | +19</td><td>-3 | +19</td><td>-3 | +18</td><td>-3 | +15</td><td>-3 | +15</td><td>-3 | +15</td><td>-2 | +1</td><td>-2 | +7</td><td>-3 | +17</td></tr>
<tr><td>Diversity of snails</td><td>-2 | +2</td><td>-10 | -7</td><td>-16 | 0</td><td>-15 | -1</td><td>-19 | -1</td><td>-13 | +16</td><td>-15 | +2</td><td>-16 | +4</td><td>-16 | +3</td><td>-15 | +3</td><td>-15 | -1</td><td>-15 | -1</td><td>-15 | -1</td><td>-3 | +0</td><td>-7 | -5</td><td>-17 | +0</td></tr>
<tr><td>Bivalves abundance</td><td>-3 | +3</td><td>-40 | -27</td><td>-66 | -44</td><td>-61 | -41</td><td>-67 | -44</td><td>-70 | -44</td><td>-64 | -43</td><td>-63 | -41</td><td>-63 | -41</td><td>-63 | -42</td><td>-61 | -41</td><td>-61 | -41</td><td>-61 | -41</td><td>-4 | +1</td><td>-28 | -18</td><td>-65 | -43</td></tr>
<tr><td>Shrimps and crabs</td><td>-5 | +5</td><td>-4 | +29</td><td>-13 | +24</td><td>-11 | +28</td><td>-12 | +27</td><td>-15 | +26</td><td>-11 | +29</td><td>-12 | +28</td><td>-11 | +30</td><td>-12 | +27</td><td>-11 | +28</td><td>-11 | +28</td><td>-11 | +28</td><td>-6 | +2</td><td>+1 | +38</td><td>-12 | +28</td></tr>
<tr><td>Littoral invertebrate diversity</td><td>-1 | +3</td><td>+1 | +51</td><td>-8 | +53</td><td>-3 | +63</td><td>-16 | +47</td><td>+1 | +48</td><td>-1 | +65</td><td>-6 | +52</td><td>-4 | +64</td><td>-5 | +53</td><td>-3 | +63</td><td>-3 | +63</td><td>-3 | +63</td><td>-1 | +6</td><td>+11 | +74</td><td>-6 | +61</td></tr>
</table>

<table>
<tr><th></th><th>Base2007</th><th>2020</th><th>2040</th><th>2040CC</th><th>C2_2040 Wet</th><th>C3_2040 Dry</th><th>A1_noALU</th><th>A2_ALU</th><th>I1_noIRR</th><th>I2_IRR</th><th>F1_noFPI</th><th>F2_FPI</th><th>F3_FPI</th><th>H1a_noHPP</th><th>H1b_nomainHPP</th><th>H3_HPP</th></tr>
<tr><td>Benthic invertebrate diversity</td><td>-1 | +3</td><td>-20 | +8</td><td>-59 | +1</td><td>-51 | +7</td><td>-58 | +5</td><td>-69 | -2</td><td>-54 | +7</td><td>-56 | +5</td><td>-54 | +9</td><td>-56 | +4</td><td>-51 | +7</td><td>-51 | +7</td><td>-51 | +7</td><td>-1 | +5</td><td>+1 | +27</td><td>-54 | +7</td></tr>
<tr><td>Zooplankton abundance</td><td>-2 | +4</td><td>-4 | +3</td><td>-1 | +6</td><td>+1 | +8</td><td>+2 | +10</td><td>-12 | +4</td><td>+2 | +9</td><td>+2 | +9</td><td>+3 | +10</td><td>+2 | +9</td><td>+1 | +8</td><td>+1 | +8</td><td>+1 | +8</td><td>-2 | +4</td><td>-1 | +6</td><td>+3 | +11</td></tr>
<tr><td>Comp: Benthic invertebrate biomass</td><td>-3 | +3</td><td>-13 | +5</td><td>-24 | +6</td><td>-21 | +8</td><td>-24 | +8</td><td>-26 | +9</td><td>-22 | +9</td><td>-23 | +8</td><td>-22 | +10</td><td>-23 | +8</td><td>-21 | +8</td><td>-21 | +8</td><td>-21 | +8</td><td>-4 | +1</td><td>-7 | +12</td><td>-23 | +8</td></tr>
<tr><td>Comp: Dry season insect emergence</td><td>-2 | +2</td><td>-11 | +7</td><td>-20 | +13</td><td>-18 | +14</td><td>-20 | +15</td><td>-23 | +16</td><td>-18 | +16</td><td>-20 | +15</td><td>-19 | +18</td><td>-19 | +14</td><td>-18 | +14</td><td>-18 | +14</td><td>-18 | +14</td><td>-3 | +1</td><td>-4 | +15</td><td>-19 | +15</td></tr>
<tr><td colspan="17">Fish</td></tr>
<tr><td>Rhithron resident</td><td>-3 | +7</td><td>-19 | +19</td><td>-25 | +17</td><td>-28 | +16</td><td>-29 | +15</td><td>-31 | +13</td><td>-25 | +17</td><td>-29 | +14</td><td>-28 | +16</td><td>-28 | +15</td><td>-28 | +16</td><td>-28 | +16</td><td>-28 | +16</td><td>-10 | +7</td><td>-16 | +26</td><td>-31 | +13</td></tr>
<tr><td>Main channel resident (long distance white)</td><td>-9 | +13</td><td>-100| -65</td><td>-100|-100</td><td>-100|-100</td><td>-100|-100</td><td>-100|-100</td><td>-100|-100</td><td>-100|-100</td><td>-100|-100</td><td>-100|-100</td><td>-100|-100</td><td>-100|-100</td><td>-100|-100</td><td>-40 | -16</td><td>-100| -52</td><td>-100|-100</td></tr>
<tr><td>Main channel spawner (short distance white)</td><td>-5 | +10</td><td>-58 | -30</td><td>-100| -69</td><td>-100| -78</td><td>-100| -72</td><td>-100| -90</td><td>-100| -74</td><td>-100| -80</td><td>-100| -74</td><td>-100| -80</td><td>-100| -77</td><td>-100| -78</td><td>-100| -78</td><td>-15 | -2</td><td>-40 | -13</td><td>-100| -70</td></tr>
<tr><td>Eurytopic (generalist)</td><td>-8 | +11</td><td>-30 | +42</td><td>-8 | +92</td><td>-12 | +89</td><td>-13 | +87</td><td>-22 | +85</td><td>-10 | +89</td><td>-9 | +91</td><td>-10 | +89</td><td>-9 | +91</td><td>-12 | +89</td><td>-12 | +89</td><td>-12 | +89</td><td>-1 | +29</td><td>-25 | +35</td><td>-10 | +88</td></tr>
<tr><td>Non-native</td><td>-2 | +5</td><td>+25 | +99</td><td>+55 |+165</td><td>+57 |+171</td><td>+56 |+169</td><td>+60 |+178</td><td>+56 |+164</td><td>+58 |+175</td><td>+56 |+168</td><td>+57 |+171</td><td>+57 |+171</td><td>+57 |+171</td><td>+57 |+171</td><td>+7 | +34</td><td>+18 | +77</td><td>+56 |+166</td></tr>
<tr><td>Comp: Fish Biomass</td><td>-6 | +10</td><td>-55 | -12</td><td>-89 | -26</td><td>-95 | -31</td><td>-95 | -29</td><td>-100| -38</td><td>-91 | -29</td><td>-94 | -32</td><td>-92 | -29</td><td>-93 | -32</td><td>-94 | -30</td><td>-95 | -31</td><td>-95 | -31</td><td>-17 | +2</td><td>-45 | -4</td><td>-92 | -28</td></tr>
<tr><td>Comp: Sensitive indigenous fish biomass</td><td>-6 | +10</td><td>-68 | -32</td><td>-100| -63</td><td>-100| -68</td><td>-100| -66</td><td>-100| -77</td><td>-100| -65</td><td>-100| -71</td><td>-100| -66</td><td>-100| -70</td><td>-100| -68</td><td>-100| -68</td><td>-100| -68</td><td>-21 | -5</td><td>-54 | -18</td><td>-100| -64</td></tr>
<tr><td colspan="17">Herpetofauna</td></tr>
<tr><td>Ranid</td><td>-5 | +5</td><td>-18 | -9</td><td>-16 | -7</td><td>-20 | -12</td><td>-14 | -4</td><td>-15 | -6</td><td>-17 | -10</td><td>-21 | -13</td><td>-20 | -12</td><td>-19 | -11</td><td>-20 | -12</td><td>-20 | -12</td><td>-20 | -12</td><td>-18 | -9</td><td>-24 | -15</td><td>-18 | -9</td></tr>
<tr><td>Aquatic serpents</td><td>-8 | +11</td><td>-30 | -12</td><td>-27 | +22</td><td>-23 | +25</td><td>-23 | +28</td><td>-45 | -7</td><td>-17 | +31</td><td>-26 | +24</td><td>-23 | +25</td><td>-21 | +29</td><td>-23 | +25</td><td>-23 | +25</td><td>-23 | +25</td><td>-12 | +17</td><td>-26 | -10</td><td>-22 | +30</td></tr>
<tr><td>Aquatic Turtles</td><td>-6 | +8</td><td>-38 | -19</td><td>-50 | -6</td><td>-48 | -6</td><td>-58 | -14</td><td>-46 | -9</td><td>-44 | -3</td><td>-48 | -5</td><td>-50 | -7</td><td>-44 | -2</td><td>-48 | -6</td><td>-48 | -6</td><td>-48 | -6</td><td>-5 | +17</td><td>-30 | -15</td><td>-51 | -8</td></tr>
<tr><td>Species richness of riparian/FP amphibians</td><td>-2 | +1</td><td>-32 | -22</td><td>-35 | -23</td><td>-41 | -29</td><td>-33 | -22</td><td>-28 | -19</td><td>-38 | -26</td><td>-40 | -28</td><td>-42 | -29</td><td>-38 | -26</td><td>-41 | -29</td><td>-41 | -29</td><td>-41 | -29</td><td>-18 | -10</td><td>-39 | -26</td><td>-41 | -25</td></tr>
<tr><td>Species richness of riparian/FP reptiles</td><td>-10 | +7</td><td>-67 | -33</td><td>-44 | -9</td><td>-57 | -26</td><td>-49 | -10</td><td>-45 | -11</td><td>-51 | -21</td><td>-54 | -23</td><td>-58 | -26</td><td>-49 | -19</td><td>-57 | -26</td><td>-57 | -26</td><td>-57 | -26</td><td>-19 | -1</td><td>-72 | -45</td><td>-57 | -26</td></tr>
<tr><td colspan="17">Birds</td></tr>
<tr><td>Medium/large ground-nesting channel spp</td><td>-2 | +4</td><td>-7 | +19</td><td>-12 | +21</td><td>-11 | +27</td><td>-13 | +24</td><td>-10 | +12</td><td>-4 | +32</td><td>-17 | +15</td><td>-12 | +28</td><td>-11 | +20</td><td>-11 | +27</td><td>-11 | +27</td><td>-11 | +27</td><td>-12 | +4</td><td>-7 | +37</td><td>-16 | +25</td></tr>
<tr><td>Bank / hole nesting species</td><td>-1 | 0</td><td>-1 | +3</td><td>-1 | +4</td><td>-1 | +6</td><td>-1 | +5</td><td>-1 | +1</td><td>0 | +7</td><td>-3 | +2</td><td>-1 | +6</td><td>-1 | +4</td><td>-1 | +6</td><td>-1 | +6</td><td>-1 | +6</td><td>-3 | -1</td><td>-1 | +7</td><td>-1 | +6</td></tr>
</table>

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noALU	A2_ALU	I1_noIRR	I2_IRR	F1_noFPI	F2_FPI	F3_FPI	H1a_noHPP	H1b_nomainHPP	H3_HPP
Natural rocky crevice nester in channels	-3 | +2	-1 | +22	-1 | +26	-1 | +27	-1 | +28	-1 | +18	+0 | +28	-1 | +23	-1 | +28	-1 | +23	-1 | +27	-1 | +27	-1 | +27	-4 | +2	-1 | +27	-1 | +27
Small non-flocking landbird;seasonally flooded veg	-1 | +0	-2 | 0	+2 | +2	+1 | +2	+2 | +3	+1 | +3	+0 | +2	+1 | +2	+1 | +2	+1 | +2	+1 | +2	+1 | +2	+1 | +2	-2 | -1	-2 | 0	+0 | +1
Overall bird abundance	-1 | +1	-2 | +11	-3 | +13	-3 | +15	-3 | +15	-3 | +9	-1 | +17	-5 | +11	-3 | +16	-3 | +12	-3 | +15	-3 | +15	-3 | +15	-5 | +1	-3 | +17	-4 | +15
Mammals																
Otters	-9 | +6	-53 | -35	-71 | -48	-85 | -59	-74 | -49	-88 | -61	-73 | -50	-88 | -62	-82 | -57	-82 | -57	-85 | -59	-85 | -59	-85 | -59	-36 | -23	-54 | -35	-81 | -56

Appendix Table 14 BioRA Zone 3: Uncertainty ranges for BioRA indicators

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noALU	A2_ALU	I1_noIRR	I2_IRR	F1_noFPI	F2_FPI	F3_FPI	H1a_noHPP	H1b_nomainHPP	H3_HPP
Geomorphology																
Erosion (bank / bed incision)	-16 | +9	-14 | +58	-15 | +62	-21 | +55	-15 | +60	-24 | +65	-21 | +25	-23 | +53	-22 | +54	-23 | +53	-21 | +55	-21 | +55	-21 | +55	-35 | +29	-26 | +48	-21 | +55
Average bed sediment size in the dry season	-9 | +2	+14 | +67	+22 | +84	+18 | +75	+17 | +69	+29 |+108	+17 | +74	+17 | +72	+17 | +73	+16 | +72	+18 | +75	+18 | +75	+18 | +75	-9 | +2	+8 | +51	+16 | +68
Availability exposed sandy habitat in dry season	-2 | +3	-15 | -9	-16 | -8	-15 | -10	-15 | -9	-13 | -5	-6 | -2	-12 | -8	-15 | -10	-12 | -8	-15 | -10	-15 | -10	-15 | -10	-7 | +3	-12 | -8	-15 | -10
Availability inundated sandy habitat in dry season	-2 | +2	-11 | -7	-11 | -8	-10 | -6	-10 | -6	-10 | -7	-4 | +0	-9 | -5	-10 | -6	-9 | -5	-10 | -6	-10 | -6	-10 | -6	-7 | -3	-8 | -5	-10 | -6
Availability exposed rocky habitat in dry season	-2 | +2	+0 | +21	+0 | +23	0 | +18	0 | +19	+0 | +22	-2 | +6	0 | +16	-1 | +18	0 | +16	0 | +18	0 | +18	0 | +18	-1 | +14	-1 | +15	-1 | +18
Availability inundated rocky habitat in dry season	-3 | +1	+1 | +20	+1 | +21	+1 | +20	+1 | +19	0 | +16	-1 | +7	+1 | +17	+1 | +20	+1 | +17	+1 | +20	+1 | +20	+1 | +20	-3 | +8	+1 | +17	+1 | +21
Depth of bedrock pools in dry season	-14 | +14	-20 | +16	-21 | +17	-25 | +18	-18 | +18	-27 | +15	-25 | +18	-26 | +17	-25 | +18	-26 | +18	-25 | +18	-25 | +18	-25 | +18	-31 | +7	-28 | +16	-23 | +19
Water clarity	-2 | -1	0 | +0	0 | +0	0 | 0	0 | +1	+0 | +1	0 | 0	0 | 0	0 | 0	0 | 0	0 | 0	0 | 0	0 | 0	-1 | 0	-1 | 0	0 | +0
Vegetation																
Ch: Riparian trees	-1 | +3	-2 | +9	-1 | +10	-5 | +7	-3 | +1	0 | +33	-5 | +7	-2 | +8	-6 | +6	-1 | +9	-5 | +7	-5 | +7	-5 | +7	-1 | +6	-7 | +6	-6 | +3
Ch: Extent upper bank vegetation	-3 | +4	-18 | -12	-20 | -14	-17 | -9	-17 | -8	-32 | -23	-16 | -8	-14 | -7	-17 | -8	-14 | -7	-17 | -9	-17 | -9	-17 | -9	-2 | +9	-17 | -8	-15 | -4
Ch: Extent lower bank vegetation	-1 | +0	-7 | -1	-6 | -1	-9 | -2	-9 | -2	-6 | -2	-8 | -5	-6 | -1	-13 | -5	-6 | -1	-9 | -2	-9 | -2	-9 | -2	-4 | -1	-9 | -3	-11 | -4
Ch: Extent herbaceous marsh	0 | +1	-1 | +15	0 | +17	0 | +18	0 | +18	-1 | +11	+0 | +18	-1 | +15	-1 | +18	0 | +16	0 | +18	0 | +18	0 | +18	-2 | 0	0 | +18	-1 | +19

<table>
<tr><th></th><th>Base2007</th><th>2020</th><th>2040</th><th>2040CC</th><th>C2_2040 Wet</th><th>C3_2040 Dry</th><th>A1_noALU</th><th>A2_ALU</th><th>I1_noIRR</th><th>I2_IRR</th><th>F1_noFPI</th><th>F2_FPI</th><th>F3_FPI</th><th>H1a_noHPP</th><th>H1b_nomainHPP</th><th>H3_HPP</th></tr>
<tr><td>Ch: Weeds, grasses on sandbanks and sandbars</td><td>+0 | +3</td><td>+1 | +11</td><td>+2 | +12</td><td>-1 | +7</td><td>-4 | +1</td><td>+11 | +34</td><td>+0 | +8</td><td>0 | +7</td><td>-2 | +6</td><td>0 | +7</td><td>-1 | +7</td><td>-1 | +7</td><td>-1 | +7</td><td>+1 | +4</td><td>0 | +7</td><td>-2 | +5</td></tr>
<tr><td>Ch: Biomass algae</td><td>0 | +2</td><td>-9 | -6</td><td>-11 | -7</td><td>-14 | -10</td><td>-12 | -8</td><td>-12 | -6</td><td>-13 | -9</td><td>-13 | -9</td><td>-15 | -11</td><td>-12 | -9</td><td>-14 | -10</td><td>-14 | -10</td><td>-14 | -10</td><td>-3 | +1</td><td>-8 | -6</td><td>-15 | -10</td></tr>
<tr><td>FP: Extent of flooded forest</td><td>-6 | +4</td><td>-26 | -14</td><td>-30 | -18</td><td>-31 | -20</td><td>-39 | -24</td><td>-87 | -74</td><td>-29 | -19</td><td>-38 | -25</td><td>-55 | -38</td><td>-56 | -39</td><td>-18 | -7</td><td>-31 | -20</td><td>-56 | -39</td><td>-43 | -27</td><td>-57 | -39</td><td>-52 | -36</td></tr>
<tr><td>FP: Extent of herbaceous marsh</td><td>-10 | +14</td><td>-26 | -4</td><td>-28 | -7</td><td>-25 | -5</td><td>-28 | -3</td><td>-59 | -33</td><td>-18 | +0</td><td>-33 | -11</td><td>-32 | -11</td><td>-32 | -11</td><td>-18 | +7</td><td>-25 | -5</td><td>-33 | -11</td><td>-26 | -5</td><td>-33 | -11</td><td>-35 | -19</td></tr>
<tr><td>FP: Extent of grassland</td><td>-4 | +8</td><td>-13 | +1</td><td>-14 | 0</td><td>-13 | +3</td><td>-14 | +5</td><td>-37 | -13</td><td>-9 | +5</td><td>-17 | 0</td><td>-18 | -2</td><td>-18 | -1</td><td>-9 | +7</td><td>-13 | +3</td><td>-19 | -2</td><td>-14 | -2</td><td>-19 | -2</td><td>-21 | -10</td></tr>
<tr><td>FP: Biomass algae</td><td>-3 | +3</td><td>-12 | -7</td><td>-14 | -9</td><td>-16 | -11</td><td>-16 | -10</td><td>-19 | -12</td><td>-16 | -11</td><td>-16 | -11</td><td>-18 | -12</td><td>-17 | -11</td><td>-16 | -11</td><td>-16 | -11</td><td>-17 | -12</td><td>-8 | -3</td><td>-10 | -7</td><td>-18 | -12</td></tr>
<tr><td>Extent invasive riparian vegetation</td><td>-2 | +4</td><td>+1 | +36</td><td>+1 | +40</td><td>+1 | +43</td><td>+1 | +43</td><td>+6 | +99</td><td>+0 | +23</td><td>+2 | +61</td><td>+2 | +57</td><td>+1 | +55</td><td>+0 | +31</td><td>+1 | +43</td><td>+2 | +57</td><td>+1 | +46</td><td>+2 | +59</td><td>+2 | +62</td></tr>
<tr><td>Extent invasive floating/submerged vegetation</td><td>-2 | 0</td><td>+3 | +19</td><td>+4 | +21</td><td>+2 | +18</td><td>+2 | +18</td><td>+4 | +26</td><td>0 | +2</td><td>+4 | +31</td><td>+2 | +18</td><td>+2 | +18</td><td>+2 | +18</td><td>+2 | +18</td><td>+2 | +18</td><td>-1 | +15</td><td>+2 | +18</td><td>+0 | +17</td></tr>
<tr><td>Comp: Indigenous vegetation biomass</td><td>-5 | +8</td><td>-15 | 0</td><td>-17 | -2</td><td>-15 | +0</td><td>-17 | +1</td><td>-39 | -16</td><td>-12 | +3</td><td>-20 | -3</td><td>-21 | -5</td><td>-21 | -4</td><td>-11 | +6</td><td>-15 | +0</td><td>-21 | -4</td><td>-16 | -3</td><td>-22 | -5</td><td>-23 | -11</td></tr>
<tr><td>Comp: Overall vegetation biomass</td><td>-3 | +5</td><td>-5 | +18</td><td>-6 | +20</td><td>-5 | +21</td><td>-6 | +22</td><td>-13 | +38</td><td>-5 | +10</td><td>-7 | +29</td><td>-8 | +25</td><td>-7 | +24</td><td>-4 | +18</td><td>-5 | +21</td><td>-8 | +25</td><td>-6 | +20</td><td>-8 | +25</td><td>-9 | +24</td></tr>
<tr><td colspan="17">Macroinvertebrates</td></tr>
<tr><td>Insects on stones</td><td>-1 | +2</td><td>-3 | +7</td><td>-4 | +7</td><td>-5 | +5</td><td>-4 | +6</td><td>-4 | +5</td><td>-5 | +5</td><td>-4 | +5</td><td>-6 | +5</td><td>-4 | +5</td><td>-5 | +5</td><td>-5 | +5</td><td>-5 | +5</td><td>-2 | +0</td><td>-3 | +7</td><td>-6 | +5</td></tr>
<tr><td>Insects on sand</td><td>-1 | +3</td><td>-4 | +7</td><td>-4 | +7</td><td>-5 | +7</td><td>-5 | +7</td><td>-5 | +5</td><td>-5 | +7</td><td>-4 | +7</td><td>-5 | +7</td><td>-4 | +7</td><td>-5 | +7</td><td>-5 | +7</td><td>-5 | +7</td><td>-3 | +1</td><td>-2 | +9</td><td>-5 | +7</td></tr>
<tr><td>Burrowing mayflies</td><td>-3 | +2</td><td>-27 | -11</td><td>-35 | -17</td><td>-32 | -15</td><td>-30 | -13</td><td>-47 | -26</td><td>-30 | -13</td><td>-32 | -15</td><td>-32 | -15</td><td>-30 | -14</td><td>-32 | -15</td><td>-32 | -15</td><td>-32 | -15</td><td>-6 | -2</td><td>-20 | -6</td><td>-30 | -14</td></tr>
<tr><td>Snail abundance</td><td>-3 | +5</td><td>-8 | +2</td><td>-9 | +1</td><td>-10 | -1</td><td>-8 | +3</td><td>-16 | -7</td><td>-10 | -1</td><td>-8 | +0</td><td>-10 | -1</td><td>-9 | 0</td><td>-8 | +4</td><td>-10 | -1</td><td>-10 | -1</td><td>-4 | +1</td><td>-7 | +1</td><td>-10 | -1</td></tr>
<tr><td>Diversity of snails</td><td>-5 | +11</td><td>-18 | -11</td><td>-20 | -13</td><td>-19 | -13</td><td>-19 | -11</td><td>-21 | -15</td><td>-13 | -8</td><td>-16 | -11</td><td>-19 | -13</td><td>-17 | -11</td><td>-18 | -9</td><td>-19 | -13</td><td>-19 | -13</td><td>-9 | +0</td><td>-14 | -9</td><td>-20 | -13</td></tr>
<tr><td>Neotricula aperta abundance</td><td>-1 | +2</td><td>-3 | -1</td><td>-4 | -2</td><td>-5 | -3</td><td>-4 | -2</td><td>-4 | -2</td><td>-5 | -4</td><td>-4 | -2</td><td>-6 | -3</td><td>-5 | -3</td><td>-5 | -3</td><td>-5 | -3</td><td>-5 | -3</td><td>-1 | +1</td><td>-3 | -1</td><td>-6 | -3</td></tr>
<tr><td>Bivalves abundance</td><td>-8 | +12</td><td>-39 | -21</td><td>-49 | -29</td><td>-47 | -29</td><td>-40 | -21</td><td>-77 | -56</td><td>-44 | -27</td><td>-45 | -28</td><td>-46 | -29</td><td>-44 | -27</td><td>-43 | -20</td><td>-47 | -29</td><td>-47 | -29</td><td>-11 | +5</td><td>-30 | -18</td><td>-45 | -28</td></tr>
<tr><td>Shrimps and crabs</td><td>-3 | +8</td><td>-8 | +12</td><td>-9 | +12</td><td>-8 | +13</td><td>-6 | +15</td><td>-19 | +0</td><td>-8 | +13</td><td>-7 | +13</td><td>-7 | +13</td><td>-7 | +13</td><td>-6 | +17</td><td>-8 | +13</td><td>-8 | +13</td><td>-4 | +4</td><td>-6 | +10</td><td>-7 | +12</td></tr>
<tr><td>Littoral invertebrate diversity</td><td>-2 | +4</td><td>-3 | +20</td><td>-3 | +20</td><td>-4 | +20</td><td>-4 | +20</td><td>-4 | +18</td><td>-2 | +19</td><td>-3 | +22</td><td>-4 | +20</td><td>-3 | +19</td><td>-4 | +20</td><td>-4 | +20</td><td>-4 | +20</td><td>-5 | +3</td><td>-1 | +22</td><td>-4 | +20</td></tr>
</table>

<table>
<tr><th></th><th>Base2007</th><th>2020</th><th>2040</th><th>2040CC</th><th>C2_2040 Wet</th><th>C3_2040 Dry</th><th>A1_noALU</th><th>A2_ALU</th><th>I1_noIRR</th><th>I2_IRR</th><th>F1_noFPI</th><th>F2_FPI</th><th>F3_FPI</th><th>H1a_noHPP</th><th>H1b_nomainHPP</th><th>H3_HPP</th></tr>
<tr><td>Benthic invertebrate diversity</td><td>-5 | +7</td><td>-20 | +0</td><td>-29 | -5</td><td>-24 | -3</td><td>-19 | +2</td><td>-56 | -27</td><td>-23 | -2</td><td>-23 | -2</td><td>-24 | -2</td><td>-22 | -2</td><td>-22 | +2</td><td>-24 | -3</td><td>-24 | -3</td><td>-10 | +0</td><td>-13 | +4</td><td>-22 | -1</td></tr>
<tr><td>Zooplankton abundance</td><td>-4 | +2</td><td>-7 | -4</td><td>-8 | -4</td><td>-8 | -2</td><td>-7 | -1</td><td>-14 | -7</td><td>-7 | -1</td><td>-8 | -3</td><td>-8 | -2</td><td>-8 | -2</td><td>-8 | -2</td><td>-8 | -2</td><td>-8 | -2</td><td>-5 | +1</td><td>-5 | 0</td><td>-8 | +0</td></tr>
<tr><td>Comp: Benthic invertebrate biomass</td><td>-3 | +5</td><td>-13 | -1</td><td>-16 | -3</td><td>-16 | -3</td><td>-14 | -1</td><td>-25 | -12</td><td>-15 | -3</td><td>-15 | -3</td><td>-16 | -3</td><td>-15 | -3</td><td>-15 | -1</td><td>-16 | -3</td><td>-16 | -3</td><td>-5 | +1</td><td>-10 | +0</td><td>-16 | -3</td></tr>
<tr><td>Comp: Dry season insect emergence</td><td>-2 | +2</td><td>-11 | +1</td><td>-14 | -1</td><td>-14 | -1</td><td>-13 | 0</td><td>-19 | -6</td><td>-13 | -1</td><td>-13 | -1</td><td>-14 | -1</td><td>-13 | -1</td><td>-14 | -1</td><td>-14 | -1</td><td>-14 | -1</td><td>-4 | 0</td><td>-8 | +3</td><td>-14 | 0</td></tr>
<tr><td colspan="17">Fish</td></tr>
<tr><td>Rhithron resident</td><td>-5 | +9</td><td>-12 | +39</td><td>-2 | +53</td><td>-16 | +39</td><td>-12 | +41</td><td>-16 | +50</td><td>-11 | +42</td><td>-12 | +40</td><td>-19 | +37</td><td>-10 | +41</td><td>-15 | +40</td><td>-16 | +39</td><td>-16 | +39</td><td>-10 | +6</td><td>-12 | +35</td><td>-17 | +37</td></tr>
<tr><td>Main channel resident (long distance white)</td><td>-7 | +11</td><td>-100| -51</td><td>-100| -87</td><td>-100| -94</td><td>-100| -93</td><td>-100| -98</td><td>-100| -87</td><td>-100| -93</td><td>-100| -90</td><td>-100| -93</td><td>-100| -94</td><td>-100| -94</td><td>-100| -94</td><td>-36 | -8</td><td>-98 | -43</td><td>-100| -90</td></tr>
<tr><td>Main channel spawner (short distance white)</td><td>-3 | +7</td><td>-59 | -26</td><td>-99 | -53</td><td>-100| -58</td><td>-100| -58</td><td>-100| -67</td><td>-100| -55</td><td>-100| -59</td><td>-100| -55</td><td>-100| -59</td><td>-100| -58</td><td>-100| -58</td><td>-100| -58</td><td>-26 | -6</td><td>-53 | -19</td><td>-100| -55</td></tr>
<tr><td>Floodplain spawner (grey)</td><td>-13 | +16</td><td>-50 | +0</td><td>-44 | +14</td><td>-53 | -2</td><td>-47 | +5</td><td>-76 | -25</td><td>-49 | +2</td><td>-52 | -2</td><td>-51 | 0</td><td>-51 | -1</td><td>-47 | +8</td><td>-53 | -2</td><td>-55 | -2</td><td>-25 | +2</td><td>-49 | -3</td><td>-50 | +1</td></tr>
<tr><td>Floodplain resident (black)</td><td>-11 | +12</td><td>-53 | -9</td><td>-47 | +13</td><td>-58 | 0</td><td>-50 | +8</td><td>-79 | -27</td><td>-51 | +3</td><td>-57 | 0</td><td>-54 | +2</td><td>-55 | +1</td><td>-51 | +11</td><td>-58 | 0</td><td>-58 | -1</td><td>-21 | +8</td><td>-51 | -11</td><td>-54 | +3</td></tr>
<tr><td>Eurytopic (generalist)</td><td>-11 | +18</td><td>-25 | +58</td><td>+0 |+110</td><td>-4 |+104</td><td>0 |+108</td><td>-30 | +84</td><td>-3 |+102</td><td>-3 |+105</td><td>-3 |+104</td><td>-2 |+105</td><td>+1 |+113</td><td>-4 |+104</td><td>-5 |+103</td><td>-8 | +37</td><td>-24 | +51</td><td>-3 |+104</td></tr>
<tr><td>Anadromous</td><td>-2 | +7</td><td>-53 | -28</td><td>-100| -88</td><td>-100| -89</td><td>-100| -88</td><td>-100|-100</td><td>-100| -87</td><td>-100| -91</td><td>-100| -85</td><td>-100| -90</td><td>-100| -89</td><td>-100| -89</td><td>-100| -89</td><td>-6 | +6</td><td>-46 | -18</td><td>-100| -84</td></tr>
<tr><td>Non-native</td><td>-3 | +0</td><td>+7 | +50</td><td>+39 |+123</td><td>+49 |+144</td><td>+46 |+139</td><td>+54 |+154</td><td>+40 |+127</td><td>+49 |+143</td><td>+45 |+137</td><td>+48 |+141</td><td>+48 |+142</td><td>+49 |+144</td><td>+49 |+144</td><td>+2 | +17</td><td>+5 | +43</td><td>+45 |+137</td></tr>
<tr><td>Comp: Fish Biomass</td><td>-6 | +9</td><td>-63 | -16</td><td>-93 | -26</td><td>-98 | -31</td><td>-96 | -30</td><td>-100| -36</td><td>-95 | -28</td><td>-97 | -31</td><td>-97 | -29</td><td>-97 | -30</td><td>-97 | -29</td><td>-98 | -31</td><td>-98 | -31</td><td>-25 | +0</td><td>-59 | -12</td><td>-97 | -29</td></tr>
<tr><td>Comp: Sensitive indigenous fish biomass</td><td>-6 | +9</td><td>-75 | -31</td><td>-100| -57</td><td>-100| -64</td><td>-100| -63</td><td>-100| -69</td><td>-100| -59</td><td>-100| -64</td><td>-100| -61</td><td>-100| -63</td><td>-100| -63</td><td>-100| -64</td><td>-100| -64</td><td>-29 | -5</td><td>-70 | -25</td><td>-100| -61</td></tr>
</table>

<table>
<tr><th></th><th>Base2007</th><th>2020</th><th>2040</th><th>2040CC</th><th>C2_2040 Wet</th><th>C3_2040 Dry</th><th>A1_noALU</th><th>A2_ALU</th><th>I1_noIRR</th><th>I2_IRR</th><th>F1_noFPI</th><th>F2_FPI</th><th>F3_FPI</th><th>H1a_noHPP</th><th>H1b_nomainHPP</th><th>H3_HPP</th></tr>
<tr><td colspan="17">Herpetofauna</td></tr>
<tr><td>Ranid</td><td>-7 | +6</td><td>-18 | -7</td><td>-21 | -11</td><td>-22 | -10</td><td>-20 | -7</td><td>-35 | -19</td><td>-17 | -6</td><td>-27 | -15</td><td>-24 | -9</td><td>-25 | -13</td><td>-19 | -7</td><td>-22 | -10</td><td>-25 | -12</td><td>-19 | -7</td><td>-23 | -11</td><td>-26 | -10</td></tr>
<tr><td>Aquatic serpents</td><td>-6 | +7</td><td>-22 | -4</td><td>-15 | +17</td><td>-16 | +14</td><td>-14 | +18</td><td>-42 | -15</td><td>-9 | +19</td><td>-21 | +13</td><td>-17 | +14</td><td>-17 | +15</td><td>-11 | +22</td><td>-16 | +14</td><td>-18 | +13</td><td>-14 | +4</td><td>-23 | -5</td><td>-18 | +15</td></tr>
<tr><td>Aquatic Turtles</td><td>-4 | +11</td><td>-28 | -2</td><td>-22 | +28</td><td>-22 | +24</td><td>-20 | +28</td><td>-49 | -11</td><td>-10 | +31</td><td>-24 | +23</td><td>-25 | +22</td><td>-23 | +24</td><td>-16 | +32</td><td>-22 | +24</td><td>-25 | +21</td><td>-13 | +10</td><td>-28 | -4</td><td>-28 | +20</td></tr>
<tr><td>Semi-aquatic Turtles</td><td>+1 | +3</td><td>-24 | -14</td><td>-26 | -15</td><td>-22 | -11</td><td>-23 | -13</td><td>-49 | -30</td><td>-5 | +1</td><td>-28 | -15</td><td>-28 | -15</td><td>-25 | -13</td><td>-16 | -7</td><td>-22 | -11</td><td>-28 | -15</td><td>-16 | -8</td><td>-26 | -14</td><td>-33 | -20</td></tr>
<tr><td>Amphibians-human use</td><td>-4 | +2</td><td>-9 | -5</td><td>-11 | -7</td><td>-11 | -8</td><td>-10 | -5</td><td>-15 | -9</td><td>-9 | -6</td><td>-14 | -10</td><td>-11 | -6</td><td>-13 | -9</td><td>-11 | -7</td><td>-11 | -8</td><td>-12 | -8</td><td>-10 | -4</td><td>-11 | -8</td><td>-11 | -6</td></tr>
<tr><td>Aquatic/semi-aqu reptiles-human use</td><td>-5 | +9</td><td>-31 | -17</td><td>-17 | +3</td><td>-18 | +4</td><td>-14 | +12</td><td>-81 | -52</td><td>-12 | +17</td><td>-20 | +1</td><td>-17 | +7</td><td>-17 | +6</td><td>-13 | +13</td><td>-18 | +4</td><td>-20 | +1</td><td>-12 | +5</td><td>-29 | -14</td><td>-14 | +8</td></tr>
<tr><td>Species richness of riparian/FP amphibians</td><td>-2 | 0</td><td>-11 | -6</td><td>-12 | -8</td><td>-11 | -7</td><td>-11 | -6</td><td>-24 | -14</td><td>-7 | -4</td><td>-14 | -9</td><td>-14 | -6</td><td>-14 | -10</td><td>-8 | -5</td><td>-11 | -7</td><td>-14 | -10</td><td>-13 | -6</td><td>-14 | -9</td><td>-16 | -10</td></tr>
<tr><td>Species richness of riparian/FP reptiles</td><td>+0 | +3</td><td>-17 | -10</td><td>-2 | +7</td><td>-6 | +4</td><td>-1 | +8</td><td>-34 | -22</td><td>-1 | +7</td><td>-8 | +3</td><td>-9 | +3</td><td>-9 | +3</td><td>+1 | +9</td><td>-6 | +4</td><td>-10 | +2</td><td>-9 | -4</td><td>-25 | -16</td><td>-12 | +1</td></tr>
<tr><td colspan="17">Birds</td></tr>
<tr><td>Medium/large ground-nesting channel spp</td><td>-2 | +4</td><td>-11 | +5</td><td>-8 | +7</td><td>-10 | +6</td><td>-11 | +6</td><td>-10 | +3</td><td>-2 | +13</td><td>-14 | +4</td><td>-16 | +3</td><td>-9 | +7</td><td>-10 | +6</td><td>-10 | +6</td><td>-10 | +6</td><td>-15 | -3</td><td>-10 | +9</td><td>-14 | +4</td></tr>
<tr><td>Bank / hole nesting species</td><td>0 | 0</td><td>-2 | 0</td><td>-2 | 0</td><td>-2 | 0</td><td>-2 | 0</td><td>-2 | -1</td><td>0 | +1</td><td>-3 | 0</td><td>-2 | 0</td><td>-1 | 0</td><td>-2 | 0</td><td>-2 | 0</td><td>-2 | 0</td><td>-3 | -2</td><td>-1 | +0</td><td>-2 | 0</td></tr>
<tr><td>Natural rocky crevice nester in channels</td><td>-1 | +0</td><td>+0 | +4</td><td>+0 | +4</td><td>0 | +4</td><td>+0 | +4</td><td>-1 | +2</td><td>0 | +4</td><td>-1 | +3</td><td>0 | +3</td><td>0 | +3</td><td>0 | +4</td><td>0 | +4</td><td>0 | +4</td><td>-3 | -2</td><td>+0 | +5</td><td>0 | +4</td></tr>
<tr><td>Overall bird abundance</td><td>-1 | +1</td><td>-4 | +3</td><td>-3 | +4</td><td>-4 | +3</td><td>-4 | +3</td><td>-4 | +1</td><td>-1 | +6</td><td>-6 | +2</td><td>-6 | +2</td><td>-3 | +3</td><td>-4 | +3</td><td>-4 | +3</td><td>-4 | +3</td><td>-7 | -2</td><td>-4 | +5</td><td>-5 | +3</td></tr>
</table>

Appendix Table 15 BioRA Zone 4: Uncertainty ranges for BioRA indicators

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noALU	A2_ALU	I1_noIRR	I2_IRR	F1_noFPI	F2_FPI	F3_FPI	H1a_noHPP	H1b_nomainHPP	H3_HPP
Geomorphology																
Erosion (bank / bed incision)	-15 | +16	-3 | +76	-4 | +77	0 | +81	-4 | +76	-7 | +75	-1 | +80	+0 | +82	+1 | +81	-1 | +81	0 | +81	0 | +81	0 | +81	-21 | +27	-6 | +78	+5 | +87
Average bed sediment size in the dry season	-8 | +2	+30 | +93	+30 | +94	+30 | +93	+29 | +91	+35 |+104	+30 | +93	+30 | +93	+29 | +92	+30 | +93	+30 | +93	+30 | +93	+30 | +93	-10 | +1	+27 | +87	+30 | +93
Availability exposed sandy habitat in dry season	-4 | +3	-21 | -14	-21 | -15	-24 | -16	-21 | -14	-19 | -13	-23 | -16	-24 | -17	-24 | -16	-24 | -16	-24 | -16	-24 | -16	-24 | -16	-4 | +7	-22 | -16	-26 | -18
Availability inundated sandy habitat in dry season	-3 | +3	-20 | -14	-20 | -14	-23 | -16	-20 | -14	-19 | -13	-22 | -15	-23 | -16	-23 | -16	-23 | -16	-23 | -16	-23 | -16	-23 | -16	-7 | 0	-19 | -11	-25 | -17
Availability exposed rocky habitat in dry season	-4 | +5	+0 | +39	+0 | +39	+0 | +43	+0 | +38	0 | +37	+0 | +42	+0 | +43	+0 | +43	+0 | +43	+0 | +43	+0 | +43	+0 | +43	-3 | +14	-2 | +34	+0 | +46
Availability inundated rocky habitat in dry season	-4 | +4	+2 | +38	+2 | +39	+3 | +43	+2 | +38	+2 | +37	+3 | +42	+3 | +43	+3 | +43	+3 | +43	+3 | +43	+3 | +43	+3 | +43	-5 | +5	+3 | +40	+3 | +47
Depth of bedrock pools in dry season	-11 | +12	-11 | +20	-12 | +20	-11 | +20	-12 | +20	-14 | +20	-11 | +20	-11 | +20	-10 | +20	-11 | +20	-11 | +20	-11 | +20	-11 | +20	-20 | +12	-18 | +20	-8 | +20
Water clarity	-2 | 0	+4 | +22	+4 | +22	+4 | +22	+4 | +22	+4 | +22	+4 | +22	+4 | +22	+4 | +22	+4 | +22	+4 | +22	+4 | +22	+4 | +22	+1 | +9	+4 | +25	+4 | +22
Vegetation																
C: Riparian trees	-2 | +3	-2 | +8	-2 | +10	-5 | +5	-7 | -2	+11 | +50	-4 | +6	-5 | +5	-6 | +3	-5 | +5	-5 | +5	-5 | +5	-5 | +5	-7 | -1	-9 | +2	-5 | +3
C: Extent upper bank vegetation	-2 | +4	-19 | -11	-22 | -13	-16 | -7	-20 | -11	-29 | -20	-15 | -7	-16 | -8	-15 | -5	-16 | -8	-16 | -7	-16 | -7	-16 | -7	+2 | +17	-16 | -6	-11 | -2
C: Extent lower bank vegetation	-3 | +1	-25 | -10	-23 | -9	-24 | -8	-24 | -9	-22 | -8	-23 | -8	-23 | -7	-26 | -10	-23 | -7	-24 | -8	-24 | -8	-24 | -8	+3 | +9	-24 | -6	-25 | -7
C: Weeds, grasses on sandbanks and sandbars	-4 | +5	-6 | +10	-6 | +7	-10 | +0	-10 | -1	+3 | +29	-10 | +0	-10 | -1	-9 | +5	-10 | -1	-10 | +0	-10 | +0	-10 | +0	-5 | +8	-10 | +0	-11 | +1
C: Biomass algae	-1 | +0	-11 | -1	-9 | +1	-10 | 0	-9 | +0	-7 | +3	-10 | 0	-9 | +1	-14 | -4	-9 | +1	-10 | 0	-10 | 0	-10 | 0	-3 | +4	-10 | +1	-12 | -2

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noALU	A2_ALU	I1_noIRR	I2_IRR	F1_noFPI	F2_FPI	F3_FPI	H1a_noHPP	H1b_nomainHPP	H3_HPP
Extent invasive riparian vegetation	-2 | +1	0 | +13	0 | +15	+1 | +17	+2 | +22	-16 | -3	-2 | +7	+2 | +26	+1 | +17	+1 | +18	+1 | +17	+1 | +17	+1 | +17	-1 | +10	+1 | +22	+1 | +18
Extent invasive floating/submerged vegetation	-3 | 0	0 | +17	+1 | +20	-2 | +16	-1 | +17	+4 | +27	-3 | +1	-1 | +28	-3 | +14	-2 | +16	-2 | +16	-2 | +16	-2 | +16	-5 | +11	-2 | +15	-3 | +12
Comp: Indigenous vegetation biomass	-3 | +4	-7 | +6	-7 | +5	-10 | +1	-10 | -3	+2 | +32	-9 | +1	-10 | +0	-10 | +2	-10 | +1	-10 | +1	-10 | +1	-10 | +1	-4 | +5	-11 | 0	-10 | +1
Comp: Overall vegetation biomass	-3 | +3	-5 | +9	-4 | +9	-6 | +6	-7 | +5	-1 | +24	-7 | +2	-6 | +9	-7 | +7	-6 | +6	-6 | +6	-6 | +6	-6 | +6	-4 | +7	-8 | +6	-7 | +6
Macroinvertebrates																
Insects on stones	-1 | +2	-3 | +8	-2 | +8	-2 | +7	-2 | +8	-1 | +7	-2 | +8	-2 | +7	-4 | +7	-2 | +7	-2 | +7	-2 | +7	-2 | +7	-6 | -3	-2 | +8	-3 | +8
Insects on sand	-1 | +2	-6 | +4	-4 | +4	-5 | +3	-5 | +4	-3 | +3	-5 | +4	-5 | +3	-7 | +3	-5 | +3	-5 | +3	-5 | +3	-5 | +3	-5 | -2	-4 | +5	-6 | +3
Burrowing mayflies	-3 | 0	-44 | -30	-44 | -30	-44 | -31	-43 | -29	-47 | -36	-44 | -31	-43 | -31	-44 | -30	-43 | -31	-44 | -31	-44 | -31	-44 | -31	-7 | -3	-41 | -28	-44 | -31
Snail abundance	-1 | +2	-2 | +7	-1 | +8	-2 | +7	-1 | +7	0 | +9	-2 | +7	-1 | +8	-3 | +6	-1 | +8	-2 | +7	-2 | +7	-2 | +7	-1 | +1	-1 | +9	-2 | +7
Diversity of snails	-3 | +1	-9 | -6	-8 | -5	-9 | -6	-8 | -5	-6 | -4	-9 | -7	-8 | -6	-11 | -8	-9 | -6	-9 | -6	-9 | -6	-9 | -6	-2 | +2	-8 | -5	-11 | -8
Neotricula aperta abundance	-1 | +1	-2 | +1	-1 | +1	-2 | +1	-1 | +1	0 | +2	-3 | +0	0 | +2	-3 | 0	-1 | +2	-2 | +1	-2 | +1	-2 | +1	-1 | +2	-1 | +2	-2 | +1
Bivalves abundance	-6 | +5	-48 | -23	-47 | -21	-47 | -22	-47 | -20	-49 | -23	-47 | -22	-47 | -21	-48 | -25	-47 | -21	-47 | -22	-47 | -22	-47 | -22	-11 | +4	-45 | -18	-47 | -23
Shrimps and crabs	+0 | +2	-5 | +1	-5 | +1	-5 | +1	-4 | +1	-7 | 0	-5 | +1	-5 | +1	-5 | +1	-5 | +1	-5 | +1	-5 | +1	-5 | +1	-1 | +1	-5 | +2	-5 | +1
Macrobrachium	-1 | +3	-17 | -8	-103 | -70	-103 | -70	-103 | -70	-103 | -70	-103 | -70	-103 | -70	-103 | -70	-103 | -70	-103 | -70	-103 | -70	-103 | -70	-18 | -12	-28 | -13	-103 | -70
Littoral invertebrate diversity	-2 | +0	-9 | +1	-8 | +0	-9 | 0	-8 | +0	-7 | -1	-8 | +1	-10 | -2	-11 | +1	-9 | -1	-9 | 0	-9 | 0	-9 | 0	-5 | -2	-8 | +1	-10 | -1
Benthic invertebrate diversity	-1 | +1	-29 | -10	-29 | -11	-30 | -12	-27 | -9	-35 | -20	-28 | -11	-30 | -14	-30 | -11	-29 | -13	-30 | -12	-30 | -12	-30 | -12	-4 | -1	-27 | -10	-30 | -12
Zooplankton abundance	-5 | +6	-9 | +0	-9 | -2	-7 | +4	-8 | +3	-16 | -11	-6 | +5	-9 | +3	-8 | +9	-7 | +3	-7 | +4	-7 | +4	-7 | +4	-6 | +7	-7 | +4	-7 | +6
Comp: Benthic invertebrate biomass	-2 | +2	-16 | -5	-15 | -4	-15 | -5	-15 | -4	-15 | -5	-15 | -5	-15 | -4	-16 | -5	-15 | -5	-15 | -5	-15 | -5	-15 | -5	-4 | 0	-14 | -3	-16 | -5
Comp: Dry season insect emergence	-2 | +1	-18 | -6	-17 | -6	-17 | -7	-17 | -6	-17 | -9	-17 | -7	-17 | -7	-18 | -7	-17 | -7	-17 | -7	-17 | -7	-17 | -7	-6 | -2	-15 | -5	-18 | -7
Fish																
Rhithron resident	-4 | +3	-32 | +9	-29 | +10	-31 | +8	-30 | +9	-26 | +10	-28 | +10	-33 | +7	-39 | +7	-30 | +9	-31 | +8	-31 | +8	-31 | +8	-18 | -6	-30 | +9	-33 | +7

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noALU	A2_ALU	I1_noIRR	I2_IRR	F1_noFPI	F2_FPI	F3_FPI	H1a_noHPP	H1b_nomainHPP	H3_HPP
Main channel resident (long distance white)	-8 | +8	-91 | -39	-100| -90	-100| -90	-100| -89	-100|-100	-100| -89	-100| -93	-100| -84	-100| -92	-100| -90	-100| -90	-100| -90	-49 | -22	-90 | -39	-100| -84
Main channel spawner (short distance white)	-4 | +7	-41 | -10	-100| -74	-100| -73	-100| -72	-100| -83	-100| -72	-100| -76	-100| -69	-100| -75	-100| -74	-100| -74	-100| -74	-18 | -4	-41 | -12	-100| -67
Floodplain spawner (grey)	-9 | +6	-45 | -3	-47 | -9	-46 | -7	-46 | -7	-53 | -17	-43 | -5	-48 | -10	-44 | +2	-46 | -9	-46 | -7	-46 | -7	-46 | -7	-27 | -3	-43 | -2	-27 | +14
Floodplain resident (black)	-12 | +9	-64 | -19	-66 | -4	-65 | -5	-65 | -2	-71 | -4	-62 | -4	-68 | -7	-63 | -3	-65 | -5	-65 | -5	-65 | -5	-65 | -5	-21 | +9	-62 | -19	-54 | +7
Eurytopic (generalist)	-7 | +3	-38 | +10	-15 | +76	-13 | +77	-16 | +74	-16 | +83	-13 | +76	-13 | +79	-14 | +75	-12 | +78	-13 | +77	-13 | +77	-13 | +77	-3 | +23	-34 | +14	-15 | +71
Anadromous	-6 | +6	-45 | -3	-100| -87	-100| -86	-100| -85	-100| -99	-100| -85	-100| -88	-100| -80	-100| -88	-100| -86	-100| -86	-100| -86	-21 | -4	-47 | -6	-100| -77
Catadromous	-4 | +0	-65 | -47	-99 | -99	-99 | -99	-99 | -99	-99 | -99	-99 | -99	-99 | -99	-99 | -99	-99 | -99	-99 | -99	-99 | -99	-99 | -99	-15 | -10	-84 | -60	-99 | -98
Non-native	-1 | +2	+10 | +43	+40 |+126	+40 |+126	+39 |+124	+44 |+136	+36 |+121	+43 |+132	+38 |+122	+40 |+127	+40 |+127	+40 |+127	+40 |+127	+6 | +25	+11 | +44	+34 |+114
Comp: Fish Biomass	-5 | +6	-36 | +1	-69 | -5	-69 | -5	-69 | -5	-71 | -7	-68 | -5	-70 | -5	-69 | -3	-69 | -5	-69 | -5	-69 | -5	-69 | -5	-13 | +7	-34 | +1	-67 | -2
Comp: Sensitive indigenous fish biomass	-5 | +6	-44 | -7	-96 | -48	-96 | -47	-95 | -47	-98 | -55	-94 | -46	-98 | -50	-96 | -43	-96 | -49	-96 | -48	-96 | -48	-96 | -48	-22 | -5	-43 | -8	-92 | -39
Herpetofauna																
Ranid	-6 | +1	-13 | -3	-16 | -6	-19 | -11	-18 | -8	-15 | +3	-15 | -8	-23 | -14	-16 | -7	-20 | -12	-19 | -11	-19 | -11	-19 | -11	-14 | -4	-19 | -10	-13 | -5
Aquatic serpents	-7 | +0	-24 | -12	-16 | +8	-17 | +8	-19 | +5	-14 | +18	-11 | +11	-22 | +7	-17 | +8	-17 | +9	-17 | +8	-17 | +8	-17 | +8	-13 | +4	-25 | -13	-18 | +6
Aquatic Turtles	-6 | +5	-38 | -24	-39 | +1	-42 | +2	-41 | -2	-31 | +14	-36 | +6	-47 | -1	-42 | +0	-42 | +2	-42 | +2	-42 | +2	-42 | +2	-9 | +14	-41 | -24	-47 | -9
Semi-aquatic Turtles	-7 | +3	-36 | -20	-38 | -21	-43 | -21	-49 | -29	-19 | -1	-37 | -17	-49 | -26	-41 | -21	-44 | -22	-43 | -21	-43 | -21	-43 | -21	-7 | +6	-45 | -23	-47 | -33
Amphibians-human use	-5 | +1	-11 | -5	-14 | -7	-15 | -10	-14 | -6	-13 | -6	-11 | -7	-20 | -14	-12 | -8	-16 | -11	-15 | -10	-15 | -10	-15 | -10	-13 | -6	-15 | -9	-11 | -6
Aquatic/semi-aqu reptiles-human use	-11 | +8	-42 | -21	-16 | -3	-13 | +7	-20 | -1	-19 | +1	-8 | +14	-19 | +1	-12 | +11	-13 | +7	-13 | +7	-13 | +7	-13 | +7	-10 | +17	-41 | -14	-13 | +11
Species richness of riparian/FP amphibians	-1 | +0	-13 | -8	-15 | -10	-21 | -15	-17 | -11	-9 | -2	-21 | -15	-23 | -16	-20 | -14	-22 | -16	-21 | -15	-21 | -15	-21 | -15	-7 | -4	-19 | -13	-18 | -12
Species richness of riparian/FP reptiles	-2 | +0	-41 | -29	-14 | -6	-20 | -10	-21 | -11	+4 | +11	-19 | -10	-21 | -11	-20 | -10	-20 | -10	-20 | -10	-20 | -10	-20 | -10	0 | +2	-47 | -34	-14 | -6
Birds																
Medium/large ground-nesting channel spp	0 | +4	-14 | -9	-14 | -8	-15 | -9	-15 | -9	-11 | -6	-3 | -1	-23 | -15	-17 | -11	-14 | -9	-15 | -9	-15 | -9	-15 | -9	-13 | -1	-16 | -9	-17 | -11

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noALU	A2_ALU	I1_noIRR	I2_IRR	F1_noFPI	F2_FPI	F3_FPI	H1a_noHPP	H1b_nomainHPP	H3_HPP
Tree-nesting large waterbirds.	-3 | +1	-46 | -33	-96 | -77	-97 | -79	-95 | -76	-97 | -80	-94 | -72	-99 | -86	-95 | -73	-98 | -80	-97 | -79	-97 | -79	-97 | -79	-23 | -15	-53 | -38	-91 | -66
Bank / hole nesting species	0 | +1	-15 | -10	-28 | -20	-28 | -20	-27 | -19	-33 | -24	-17 | -12	-38 | -27	-25 | -18	-28 | -20	-28 | -20	-28 | -20	-28 | -20	-11 | -6	-16 | -11	-21 | -15
Flocking non-aerial pass of graminoid beds	-1 | +2	-3 | +3	-3 | +3	-4 | 0	-5 | -2	-1 | +21	-4 | +0	-5 | -1	-4 | +1	-5 | -1	-4 | 0	-4 | 0	-4 | 0	-3 | +2	-5 | 0	-4 | -1
Channel-using large spp: bankside forest	-2 | +2	-13 | +1	-14 | +2	-18 | -4	-22 | -14	-11 | +73	-7 | +5	-27 | -11	-20 | -8	-18 | -4	-18 | -4	-18 | -4	-18 | -4	-18 | -12	-20 | -11	-18 | -6
Natural rocky crevice nester in channels	-2 | +1	-1 | +9	-1 | +9	-1 | +9	-1 | +9	-1 | +7	0 | +9	-2 | +8	-1 | +9	-1 | +8	-1 | +9	-1 | +9	-1 | +9	-7 | -2	-1 | +8	-1 | +9
Dense woody vegetation / water interface	-1 | -1	-22 | -16	-22 | -16	-22 | -16	-22 | -16	-21 | -16	-11 | -8	-31 | -22	-24 | -17	-22 | -16	-22 | -16	-22 | -16	-22 | -16	-7 | -4	-21 | -16	-22 | -16
Small non-flocking landbird;seasonally flooded veg	-2 | +1	-18 | -10	-17 | -10	-17 | -10	-17 | -10	-15 | -10	-16 | -10	-16 | -10	-19 | -11	-16 | -9	-17 | -10	-17 | -10	-17 | -10	-2 | +11	-15 | -8	-17 | -10
Overall bird abundance	-2 | +1	-16 | -8	-24 | -15	-25 | -16	-26 | -17	-24 | -4	-19 | -11	-30 | -20	-26 | -16	-25 | -16	-25 | -16	-25 | -16	-25 | -16	-11 | -3	-19 | -11	-24 | -14
Mammals																
Irrawaddy dolphin	-5 | +5	-55 | -34	-100| -95	-99 | -95	-99 | -94	-100| -98	-99 | -93	-100| -96	-99 | -94	-100| -95	-99 | -95	-99 | -95	-99 | -95	-54 | -35	-88 | -63	-98 | -91
Otters	-5 | +3	-26 | -14	-44 | -27	-47 | -33	-49 | -35	-38 | +4	-39 | -26	-56 | -40	-43 | -29	-49 | -34	-47 | -33	-47 | -33	-47 | -33	-18 | -4	-34 | -24	-43 | -30
Hog deer	-1 | -1	-19 | -13	-24 | -16	-32 | -23	-24 | -18	-24 | -9	-22 | -16	-42 | -31	-27 | -20	-33 | -24	-33 | -24	-33 | -24	-33 | -24	-19 | -13	-32 | -23	-18 | -13

Appendix Table 16 BioRA Zone 5: Uncertainty ranges for BioRA indicators

<table>
<tr><th></th><th>Base2007</th><th>2020</th><th>2040</th><th>2040CC</th><th>C2_2040 Wet</th><th>C3_2040 Dry</th><th>A1_noALU</th><th>A2_ALU</th><th>I1_noIRR</th><th>I2_IRR</th><th>F1_noFPI</th><th>F2_FPI</th><th>F3_FPI</th><th>H1a_noHPP</th><th>H1b_nomainHPP</th><th>H3_HPP</th></tr>
<tr><td colspan="17">Geomorphology</td></tr>
<tr><td>Erosion (bank / bed incision)</td><td>-17 | +15</td><td>+5 | +109</td><td>+13 | +143</td><td>+11 | +150</td><td>+12 | +145</td><td>+5 | +132</td><td>+11 | +149</td><td>+11 | +148</td><td>+16 | +158</td><td>+11 | +148</td><td>+11 | +150</td><td>+10 | +145</td><td>+9 | +144</td><td>-20 | +31</td><td>-4 | +93</td><td>+17 | +148</td></tr>
<tr><td>Average bed sediment size in the dry season</td><td>-10 | +9</td><td>+32 | +112</td><td>+58 | +164</td><td>+60 | +167</td><td>+60 | +167</td><td>+51 | +156</td><td>+60 | +168</td><td>+60 | +167</td><td>+60 | +169</td><td>+60 | +167</td><td>+60 | +167</td><td>+57 | +162</td><td>+55 | +159</td><td>-12 | +9</td><td>+29 | +104</td><td>+53 | +153</td></tr>
<tr><td>Availability exposed sandy habitat in dry season</td><td>-5 | +6</td><td>-32 | -23</td><td>-51 | -37</td><td>-53 | -39</td><td>-53 | -38</td><td>-43 | -29</td><td>-54 | -39</td><td>-52 | -38</td><td>-62 | -45</td><td>-52 | -37</td><td>-53 | -39</td><td>-54 | -39</td><td>-53 | -39</td><td>-5 | +8</td><td>-29 | -21</td><td>-56 | -41</td></tr>
<tr><td>Availability inundated sandy habitat in dry season</td><td>-4 | +3</td><td>-25 | -16</td><td>-40 | -26</td><td>-39 | -23</td><td>-40 | -26</td><td>-34 | -24</td><td>-39 | -23</td><td>-39 | -23</td><td>-44 | -25</td><td>-38 | -23</td><td>-39 | -23</td><td>-38 | -21</td><td>-37 | -20</td><td>-4 | +8</td><td>-19 | -9</td><td>-41 | -24</td></tr>
<tr><td>Depth of bedrock pools in dry season</td><td>-18 | +19</td><td>-18 | +61</td><td>-21 | +65</td><td>-21 | +75</td><td>-21 | +68</td><td>-27 | +55</td><td>-20 | +75</td><td>-21 | +74</td><td>-19 | +78</td><td>-21 | +74</td><td>-21 | +75</td><td>-22 | +69</td><td>-24 | +66</td><td>-25 | +28</td><td>-21 | +59</td><td>-14 | +82</td></tr>
<tr><td>Water clarity</td><td>-1 | 0</td><td>+4 | +15</td><td>+75 | +75</td><td>+75 | +75</td><td>+75 | +75</td><td>+75 | +75</td><td>+75 | +75</td><td>+75 | +75</td><td>+75 | +75</td><td>+75 | +75</td><td>+75 | +75</td><td>+75 | +75</td><td>+75 | +75</td><td>-3 | -2</td><td>+4 | +17</td><td>+45 | +61</td></tr>
<tr><td colspan="17">Vegetation</td></tr>
<tr><td>C: Weeds, grasses on sandbanks and sandbars</td><td>-2 | +4</td><td>-10 | +0</td><td>-14 | -4</td><td>-14 | -3</td><td>-15 | -6</td><td>-4 | +14</td><td>-16 | -6</td><td>-15 | -5</td><td>-21 | -10</td><td>-15 | -5</td><td>-14 | -3</td><td>-17 | -6</td><td>-17 | -6</td><td>-3 | +3</td><td>-12 | -3</td><td>-17 | -8</td></tr>
<tr><td>C: Biomass algae</td><td>0 | +2</td><td>-9 | +0</td><td>+14 | +82</td><td>+15 | +81</td><td>+15 | +81</td><td>+17 | +84</td><td>+14 | +82</td><td>+15 | +83</td><td>+21 | +102</td><td>+15 | +83</td><td>+15 | +81</td><td>+14 | +82</td><td>+14 | +82</td><td>+4 | +7</td><td>-3 | +22</td><td>+1 | +50</td></tr>
<tr><td>FP: Extent of flooded forest</td><td>-1 | +1</td><td>-7 | -5</td><td>-9 | -6</td><td>-6 | -4</td><td>-5 | -4</td><td>-18 | -13</td><td>-2 | -1</td><td>-5 | -4</td><td>-3 | -2</td><td>-4 | -3</td><td>-5 | -3</td><td>-6 | -4</td><td>-6 | -4</td><td>-2 | 0</td><td>-4 | -3</td><td>-4 | -3</td></tr>
<tr><td>FP: Extent of herbaceous marsh</td><td>-3 | +5</td><td>-19 | -14</td><td>-30 | -22</td><td>-28 | -20</td><td>-30 | -21</td><td>-39 | -28</td><td>-25 | -15</td><td>-32 | -23</td><td>-29 | -19</td><td>-29 | -20</td><td>-28 | -18</td><td>-28 | -20</td><td>-28 | -20</td><td>-4 | +4</td><td>-6 | -1</td><td>-23 | -15</td></tr>
<tr><td>FP: Extent of grassland</td><td>-3 | +4</td><td>-20 | -14</td><td>-32 | -23</td><td>-29 | -21</td><td>-30 | -21</td><td>-40 | -28</td><td>-27 | -19</td><td>-32 | -22</td><td>-29 | -20</td><td>-30 | -21</td><td>-29 | -19</td><td>-29 | -21</td><td>-29 | -21</td><td>-2 | +13</td><td>-5 | +14</td><td>-24 | -17</td></tr>
<tr><td>FP: Biomass algae</td><td>-2 | +0</td><td>-6 | +2</td><td>+2 | +49</td><td>+2 | +48</td><td>-3 | +44</td><td>-2 | +46</td><td>-3 | +45</td><td>-2 | +46</td><td>+4 | +65</td><td>-2 | +46</td><td>+2 | +48</td><td>+2 | +49</td><td>+2 | +49</td><td>-1 | +3</td><td>+0 | +24</td><td>-3 | +33</td></tr>
<tr><td>Extent invasive riparian vegetation</td><td>-1 | +2</td><td>+0 | +37</td><td>+0 | +49</td><td>+0 | +46</td><td>+0 | +47</td><td>+0 | +49</td><td>+0 | +30</td><td>+0 | +59</td><td>+0 | +51</td><td>+0 | +46</td><td>+0 | +44</td><td>+0 | +48</td><td>+0 | +48</td><td>-2 | +14</td><td>0 | +23</td><td>+0 | +44</td></tr>
</table>

<table>
<tr><th></th><th>Base2007</th><th>2020</th><th>2040</th><th>2040CC</th><th>C2_2040 Wet</th><th>C3_2040 Dry</th><th>A1_noALU</th><th>A2_ALU</th><th>I1_noIRR</th><th>I2_IRR</th><th>F1_noFPI</th><th>F2_FPI</th><th>F3_FPI</th><th>H1a_noHPP</th><th>H1b_nomainHPP</th><th>H3_HPP</th></tr>
<tr><td>Extent invasive floating/submerged vegetation</td><td>-3 | 0</td><td>+1 | +17</td><td>0 | +17</td><td>+1 | +19</td><td>+0 | +18</td><td>+4 | +23</td><td>-2 | +1</td><td>+1 | +30</td><td>-1 | +16</td><td>0 | +17</td><td>+1 | +19</td><td>0 | +17</td><td>+0 | +17</td><td>-3 | +14</td><td>0 | +17</td><td>-1 | +15</td></tr>
<tr><td>Comp: Indigenous vegetation biomass</td><td>-2 | +4</td><td>-15 | -8</td><td>-24 | -15</td><td>-22 | -13</td><td>-23 | -14</td><td>-25 | -12</td><td>-21 | -13</td><td>-24 | -15</td><td>-25 | -15</td><td>-23 | -14</td><td>-22 | -12</td><td>-23 | -14</td><td>-23 | -14</td><td>-3 | +7</td><td>-8 | +4</td><td>-20 | -12</td></tr>
<tr><td>Comp: Overall vegetation biomass</td><td>-2 | +3</td><td>-9 | +5</td><td>-15 | +3</td><td>-14 | +4</td><td>-14 | +3</td><td>-15 | +6</td><td>-14 | -2</td><td>-15 | +7</td><td>-15 | +3</td><td>-14 | +3</td><td>-13 | +4</td><td>-14 | +3</td><td>-14 | +3</td><td>-3 | +10</td><td>-5 | +10</td><td>-13 | +4</td></tr>
<tr><td colspan="17">Macroinvertebrates</td></tr>
<tr><td>Insects on stones</td><td>-3 | +0</td><td>-14 | +1</td><td>-34 | +9</td><td>-34 | +9</td><td>-35 | +8</td><td>-24 | +15</td><td>-35 | +8</td><td>-33 | +9</td><td>-39 | +13</td><td>-33 | +9</td><td>-34 | +9</td><td>-32 | +10</td><td>-31 | +11</td><td>-7 | +0</td><td>-7 | +13</td><td>-38 | -4</td></tr>
<tr><td>Insects on sand</td><td>-1 | +2</td><td>0 | +12</td><td>+0 | +32</td><td>+1 | +33</td><td>+0 | +32</td><td>+0 | +32</td><td>0 | +32</td><td>+2 | +34</td><td>+3 | +41</td><td>+1 | +33</td><td>+1 | +33</td><td>+1 | +33</td><td>+1 | +33</td><td>-4 | +3</td><td>+3 | +20</td><td>+0 | +23</td></tr>
<tr><td>Burrowing mayflies</td><td>-3 | +0</td><td>-31 | -15</td><td>-64 | -19</td><td>-66 | -20</td><td>-66 | -20</td><td>-58 | -15</td><td>-64 | -19</td><td>-68 | -22</td><td>-65 | -13</td><td>-66 | -20</td><td>-66 | -20</td><td>-63 | -19</td><td>-61 | -17</td><td>-7 | -1</td><td>-25 | -5</td><td>-59 | -24</td></tr>
<tr><td>Snail abundance</td><td>-3 | +6</td><td>-5 | +11</td><td>-5 | +30</td><td>-2 | +37</td><td>-3 | +33</td><td>-9 | +23</td><td>-1 | +39</td><td>-3 | +35</td><td>+2 | +51</td><td>-2 | +35</td><td>-2 | +39</td><td>-2 | +39</td><td>-3 | +35</td><td>-6 | +6</td><td>-1 | +23</td><td>-3 | +25</td></tr>
<tr><td>Diversity of snails</td><td>-5 | +4</td><td>-23 | -15</td><td>-41 | -6</td><td>-40 | -4</td><td>-41 | -5</td><td>-33 | +0</td><td>-40 | -3</td><td>-40 | -3</td><td>-44 | +0</td><td>-39 | -2</td><td>-40 | -2</td><td>-38 | -3</td><td>-37 | -2</td><td>-6 | +6</td><td>-14 | 0</td><td>-44 | -16</td></tr>
<tr><td>Neotricula aperta abundance</td><td>-3 | 0</td><td>+4 | +22</td><td>+6 | +41</td><td>+3 | +46</td><td>+5 | +41</td><td>+7 | +34</td><td>+3 | +46</td><td>+6 | +44</td><td>+2 | +60</td><td>+5 | +43</td><td>+3 | +46</td><td>+2 | +48</td><td>+4 | +44</td><td>-14 | -6</td><td>+6 | +31</td><td>+4 | +33</td></tr>
<tr><td>Bivalves abundance</td><td>-8 | +16</td><td>-66 | -39</td><td>-148| -65</td><td>-155| -65</td><td>-152| -66</td><td>-128| -55</td><td>-153| -62</td><td>-153| -63</td><td>-152| -48</td><td>-152| -63</td><td>-153| -60</td><td>-142| -55</td><td>-131| -49</td><td>-11 | +18</td><td>-52 | -12</td><td>-118| -53</td></tr>
<tr><td>Shrimps and crabs</td><td>-5 | +9</td><td>-10 | +1</td><td>-18 | +29</td><td>-18 | +31</td><td>-17 | +31</td><td>-15 | +30</td><td>-16 | +35</td><td>-18 | +33</td><td>-9 | +56</td><td>-17 | +34</td><td>-17 | +35</td><td>-16 | +33</td><td>-14 | +34</td><td>-6 | +11</td><td>-3 | +19</td><td>-13 | +21</td></tr>
<tr><td>Macrobrachium</td><td>0 | +3</td><td>-1 | +30</td><td>-8 | +54</td><td>-10 | +64</td><td>-9 | +54</td><td>-9 | +41</td><td>-10 | +65</td><td>-9 | +58</td><td>-5 | +98</td><td>-8 | +59</td><td>-10 | +64</td><td>-10 | +69</td><td>-9 | +60</td><td>-19 | -7</td><td>0 | +43</td><td>-10 | +41</td></tr>
<tr><td>Littoral invertebrate diversity</td><td>-3 | -1</td><td>-16 | -11</td><td>-30 | -2</td><td>-30 | -2</td><td>-31 | -2</td><td>-23 | +4</td><td>-29 | -1</td><td>-30 | -2</td><td>-33 | +1</td><td>-29 | -1</td><td>-30 | -2</td><td>-28 | 0</td><td>-28 | 0</td><td>-7 | -1</td><td>-10 | -1</td><td>-33 | -13</td></tr>
<tr><td>Benthic invertebrate diversity</td><td>-2 | +5</td><td>-36 | -25</td><td>-71 | -31</td><td>-71 | -30</td><td>-71 | -30</td><td>-68 | -29</td><td>-70 | -28</td><td>-71 | -29</td><td>-69 | -22</td><td>-71 | -29</td><td>-71 | -28</td><td>-69 | -28</td><td>-67 | -27</td><td>-5 | +5</td><td>-28 | -12</td><td>-65 | -33</td></tr>
<tr><td>Zooplankton abundance</td><td>-7 | +12</td><td>-14 | -4</td><td>-14 | +22</td><td>-13 | +19</td><td>-12 | +24</td><td>-24 | +6</td><td>-9 | +30</td><td>-12 | +26</td><td>-8 | +41</td><td>-11 | +27</td><td>-12 | +23</td><td>-12 | +25</td><td>-11 | +25</td><td>-9 | +15</td><td>-10 | +13</td><td>-11 | +20</td></tr>
<tr><td>Comp: Benthic invertebrate biomass</td><td>-4 | +5</td><td>-18 | -1</td><td>-38 | +8</td><td>-39 | +10</td><td>-38 | +8</td><td>-33 | +9</td><td>-38 | +11</td><td>-38 | +10</td><td>-37 | +23</td><td>-38 | +10</td><td>-38 | +11</td><td>-36 | +13</td><td>-34 | +13</td><td>-8 | +5</td><td>-11 | +13</td><td>-32 | +3</td></tr>
<tr><td>Comp: Dry season insect emergence</td><td>-3 | +1</td><td>-15 | 0</td><td>-33 | +7</td><td>-33 | +7</td><td>-34 | +7</td><td>-28 | +11</td><td>-33 | +7</td><td>-33 | +7</td><td>-34 | +13</td><td>-33 | +7</td><td>-33 | +7</td><td>-31 | +8</td><td>-30 | +9</td><td>-6 | +1</td><td>-10 | +9</td><td>-32 | -2</td></tr>
</table>

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noALU	A2_ALU	I1_noIRR	I2_IRR	F1_noFPI	F2_FPI	F3_FPI	H1a_noHPP	H1b_nomainHPP	H3_HPP
Fish																
Rhithron resident	-6 | +6	-45 | +4	-66 | -3	-63 | -3	-65 | -4	-60 | -1	-64 | -1	-65 | -2	-53 | +34	-63 | -1	-63 | -3	-66 | -2	-66 | -2	-14 | +4	-22 | +49	-62 | -3
Main channel resident (long distance white)	-10 | +6	-86 | -37	-100| -88	-100| -84	-100| -83	-100| -98	-100| -82	-100| -87	-100| -68	-100| -87	-100| -82	-100| -88	-100| -83	-40 | -14	-72 | -27	-100| -76
Main channel spawner (short distance white)	-4 | +5	-46 | -17	-100| -72	-100| -69	-100| -67	-100| -84	-100| -66	-100| -71	-100| -35	-100| -72	-100| -65	-100| -71	-100| -66	-17 | -1	-41 | +6	-100| -60
Floodplain spawner (grey)	-11 | +17	-53 | -12	-68 | -21	-67 | -20	-66 | -19	-75 | -37	-64 | -17	-68 | -20	-42 | +30	-66 | -19	-66 | -18	-67 | -20	-67 | -20	-22 | +16	-32 | +35	-50 | -4
Floodplain resident (black)	-16 | +17	-75 | -25	-87 | -35	-86 | -31	-86 | -29	-86 | -41	-86 | -31	-87 | -33	-79 | +8	-87 | -32	-86 | -30	-87 | -33	-87 | -34	-16 | +25	-56 | +11	-83 | -16
Eurytopic (generalist)	-17 | +22	-55 | +13	-51 | +52	-51 | +52	-52 | +51	-53 | +52	-50 | +55	-49 | +58	-48 | +61	-49 | +58	-50 | +54	-49 | +57	-50 | +53	-10 | +42	-40 | +26	-49 | +50
Anadromous	-11 | +13	-38 | +15	-88 | -23	-85 | -21	-83 | -19	-100| -39	-84 | -20	-88 | -23	-64 | +26	-91 | -26	-85 | -21	-84 | -20	-84 | -20	-25 | -1	-34 | +44	-71 | -7
Catadromous	-2 | +3	-19 | -12	-39 | -26	-33 | -22	-29 | -19	-51 | -36	-33 | -22	-39 | -27	-34 | -23	-43 | -30	-33 | -22	-34 | -23	-33 | -22	-13 | -6	-24 | -16	-30 | -20
Non-native	-1 | +2	+17 | +67	+44 |+136	+42 |+132	+41 |+129	+53 |+155	+38 |+126	+45 |+136	+21 | +81	+43 |+134	+40 |+128	+43 |+135	+41 |+130	+5 | +18	+6 | +24	+33 |+112
Comp: Fish Biomass	-12 | +15	-46 | +7	-59 | +20	-58 | +21	-58 | +21	-62 | +17	-57 | +22	-58 | +23	-52 | +36	-58 | +23	-57 | +22	-58 | +23	-57 | +21	-13 | +24	-34 | +22	-54 | +22
Comp: Sensitive indigenous fish biomass	-8 | +11	-52 | -16	-99 | -49	-96 | -47	-95 | -46	-100| -63	-93 | -44	-98 | -49	-78 | -7	-97 | -48	-93 | -45	-98 | -49	-94 | -46	-21 | +6	-39 | +17	-84 | -36
Herpetofauna																
Ranid	-6 | +3	-15 | -5	-20 | +1	-17 | +3	-17 | +3	-20 | -1	-17 | +2	-23 | -3	-16 | +14	-20 | -2	-17 | +3	-21 | +1	-20 | +1	-13 | -2	-13 | +1	-13 | +1
Aquatic serpents	-5 | +6	-34 | -20	-36 | -17	-37 | -20	-35 | -18	-46 | -31	-28 | -10	-32 | -13	-16 | 0	-30 | -12	-34 | -18	-32 | -13	-33 | -15	-3 | +12	-12 | -1	-23 | -6
Aquatic Turtles	-7 | +14	-71 | -48	-89 | -55	-90 | -57	-90 | -57	-96 | -61	-80 | -46	-88 | -52	-74 | -39	-83 | -48	-87 | -54	-88 | -52	-90 | -55	-8 | +26	-31 | -14	-81 | -53
Semi-aquatic Turtles	-1 | +1	-42 | -27	-64 | -38	-65 | -43	-66 | -42	-62 | -36	-59 | -35	-69 | -42	-77 | -49	-63 | -38	-64 | -42	-68 | -42	-68 | -41	+2 | +5	-22 | -11	-67 | -48
Amphibians-human use	-4 | +2	-11 | -5	-14 | -9	-12 | -6	-11 | -5	-14 | -9	-10 | -6	-18 | -12	-9 | -2	-14 | -10	-12 | -6	-14 | -9	-14 | -9	-10 | -5	-10 | -7	-9 | -5
Aquatic/semi-aqu reptiles-human use	-1 | +8	-37 | -25	-41 | -27	-42 | -29	-42 | -8	-62 | -24	-27 | +4	-34 | -2	-12 | +16	-31 | +0	-38 | -26	-32 | -20	-33 | -21	0 | +16	-9 | -2	-17 | -8
Species richness of riparian/FP amphibians	-3 | +1	-26 | -16	-37 | -23	-28 | -16	-32 | -19	-32 | -19	-33 | -20	-40 | -25	-21 | -8	-37 | -23	-28 | -15	-35 | -21	-34 | -20	-14 | -7	-15 | -7	-36 | -23
Species richness of riparian/FP reptiles	-2 | +5	-63 | -37	-67 | -55	-63 | -37	-63 | -40	-66 | -43	-62 | -44	-66 | -51	-53 | -33	-63 | -48	-61 | -34	-64 | -49	-65 | -49	-9 | 0	-42 | -26	-60 | -47

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noALU	A2_ALU	I1_noIRR	I2_IRR	F1_noFPI	F2_FPI	F3_FPI	H1a_noHPP	H1b_nomainHPP	H3_HPP
Birds																
Bank / hole nesting species	+0 | +4	-22 | -16	-36 | -26	-35 | -25	-33 | -24	-49 | -35	-21 | -15	-42 | -30	-23 | -16	-33 | -23	-33 | -24	-34 | -24	-33 | -24	-10 | 0	-18 | -11	-25 | -18
Flocking non-aerial pass of graminoid beds	-1 | +2	-7 | +1	-11 | -2	-10 | -2	-11 | -2	-10 | -2	-10 | -2	-11 | -3	-13 | -1	-11 | -2	-10 | -1	-11 | -2	-11 | -2	-2 | +2	-3 | +6	-10 | -2
Small non-flocking landbird;seasonally flooded veg	0 | +0	+2 | +4	+2 | +3	+2 | +3	+2 | +3	+1 | +2	+2 | +3	+2 | +3	+2 | +6	+2 | +3	+2 | +3	+2 | +4	+2 | +4	-3 | -2	+2 | +7	+2 | +3
Overall bird abundance	0 | +2	-9 | -3	-15 | -9	-15 | -8	-14 | -8	-19 | -12	-10 | -4	-17 | -10	-11 | -3	-14 | -8	-14 | -7	-14 | -8	-14 | -7	-5 | +0	-6 | +1	-11 | -6

Appendix Table 17 BioRA Zone 6: Uncertainty ranges for BioRA indicators

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noALU	A2_ALU	I1_noIRR	I2_IRR	F1_noFPI	F2_FPI	F3_FPI	H1a_noHPP	H1b_nomainHPP	H3_HPP
Geomorphology																
Erosion (bank / bed incision)	-16 | +33	-22 | +29	+6 |+104	+9 |+120	+16 |+121	-14 | +88	+14 |+134	+13 |+129	+8 |+116	+13 |+129	+9 |+120	-1 | +98	+5 |+107	-11 | +59	-18 | +44	+6 |+101
Average bed sediment size in the dry season	-4 | +14	-10 | +4	-10 | +5	-13 | -3	-4 | +13	-13 | -2	-12 | -1	-12 | -1	-14 | -4	-12 | -1	-13 | -3	-17 | -9	-12 | -1	-7 | +9	-13 | -2	-14 | -4
Water clarity	-3 | +5	+4 | +31	+17 | +81	+17 | +80	+17 | +79	+18 | +82	+17 | +79	+17 | +79	+17 | +79	+17 | +79	+17 | +80	+17 | +79	+17 | +78	-6 | +3	+1 | +25	+10 | +60
Vegetation																
C: Biomass algae	-2 | +3	-3 | +11	-5 | +36	-4 | +35	-4 | +35	-1 | +43	-5 | +34	-5 | +34	-2 | +41	-2 | +39	-4 | +35	-6 | +32	-11 | +28	-2 | +11	-3 | +14	-6 | +20
FP: Extent of flooded forest	-2 | -1	-12 | -9	-34 | -25	-23 | -17	-24 | -17	-58 | -42	-16 | -12	-27 | -20	-21 | -15	-23 | -17	-7 | -4	-59 | -43	-12 | -9	-17 | -12	-23 | -17	-23 | -16
FP: Extent of herbaceous marsh	-3 | +0	-21 | -15	-38 | -28	-33 | -24	-33 | -24	-47 | -34	-27 | -18	-37 | -27	-28 | -18	-32 | -23	-20 | -12	-48 | -34	-24 | -15	-17 | -11	-27 | -20	-31 | -22
FP: Extent of grassland	-4 | +3	-24 | -17	-31 | -23	-31 | -23	-30 | -22	-34 | -25	-29 | -21	-33 | -24	-31 | -23	-31 | -22	-32 | -20	-34 | -25	-28 | -21	-7 | +4	-24 | -17	-29 | -21
FP: Biomass algae	-3 | +1	-2 | +2	-11 | -3	-7 | 0	-7 | -1	-10 | +1	-7 | +0	-7 | 0	-4 | +6	-5 | +5	-7 | +1	-12 | -4	-15 | -8	-3 | +12	-1 | +10	-2 | +4
Extent invasive riparian vegetation	-1 | +7	+0 | +47	+1 | +76	+1 | +65	+1 | +65	+2 | +98	+0 | +41	+1 | +83	+1 | +57	+1 | +65	+0 | +46	+1 | +96	+0 | +48	+0 | +40	+1 | +59	+1 | +63
Extent invasive floating/submerged vegetation	-1 | +2	+2 | +20	+2 | +20	0 | +20	+0 | +17	+0 | +21	-3 | +4	+0 | +31	-13 | +7	-1 | +18	0 | +20	-4 | +14	-10 | +8	-4 | +15	-1 | +19	-2 | +19
Comp: Indigenous vegetation biomass	-3 | +1	-21 | -15	-36 | -26	-32 | -23	-32 | -23	-45 | -32	-27 | -18	-35 | -26	-28 | -19	-32 | -23	-22 | -13	-45 | -32	-24 | -16	-14 | -8	-26 | -19	-30 | -22
Comp: Overall vegetation biomass	-3 | +2	-13 | +3	-22 | +2	-20 | +2	-20 | +1	-28 | +2	-17 | -3	-22 | +5	-20 | 0	-20 | +1	-14 | +4	-29 | +0	-17 | +1	-9 | +6	-16 | +3	-19 | +2
Macroinvertebrates																
Snail abundance	-4 | +4	-8 | +2	-15 | +2	-13 | +5	-13 | +3	-16 | +3	-11 | +7	-15 | +3	-11 | +10	-12 | +8	-6 | +15	-18 | +1	-12 | +3	-11 | 0	-12 | +1	-12 | +1
Diversity of snails	-6 | +1	-6 | 0	-40 | -17	-44 | -20	-48 | -22	-28 | -4	-50 | -25	-49 | -24	-40 | -14	-47 | -19	-41 | -14	-36 | -16	-39 | -22	-8 | +1	-8 | -1	-29 | -15
Bivalves abundance	-10 | +8	-12 | +4	-22 | -4	-14 | +14	-21 | -6	-24 | -5	-11 | +19	-16 | +9	-9 | +28	-14 | +11	+1 | +40	-17 | +25	-9 | +23	-19 | -4	-14 | +12	-14 | +12
Shrimps and crabs	-7 | +5	-13 | -1	-21 | -2	-20 | +3	-17 | +1	-24 | -4	-16 | +6	-21 | +1	-17 | +11	-18 | +5	-11 | +19	-25 | +1	-18 | +3	-16 | -4	-18 | 0	-19 | -1
Macrobrachium	+0 | +1	+4 | +5	+5 | +7	+7 | +9	+6 | +8	-9 | -4	+6 | +8	+7 | +9	+18 | +19	+9 | +10	+9 | +10	+13 | +15	+11 | +12	-4 | -1	+8 | +10	+5 | +6

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noALU	A2_ALU	I1_noIRR	I2_IRR	F1_noFPI	F2_FPI	F3_FPI	H1a_noHPP	H1b_nomainHPP	H3_HPP
Littoral invertebrate diversity	-4 | -2	-5 | -1	-31 | -16	-36 | -20	-38 | -21	-20 | -6	-40 | -23	-42 | -24	-34 | -16	-39 | -20	-36 | -20	-26 | -14	-33 | -20	-7 | -1	-6 | -2	-24 | -14
Benthic invertebrate diversity	-2 | +3	-5 | +0	-10 | +1	-8 | +2	-8 | +3	-12 | +1	-6 | +4	-10 | +0	-7 | +3	-8 | +3	-4 | +9	-13 | -1	-8 | +1	-7 | -1	-8 | -3	-8 | -3
Zooplankton abundance	-9 | +10	-16 | -3	-28 | -8	-23 | +1	-25 | -1	-36 | -16	-19 | +6	-25 | -1	-38 | -18	-29 | -12	-10 | +19	-31 | +1	-20 | +8	-20 | +0	-22 | -2	-22 | -2
Comp: Benthic invertebrate biomass	-7 | +6	-11 | +2	-20 | -2	-15 | +7	-17 | -1	-21 | -2	-12 | +10	-17 | +5	-12 | +16	-14 | +8	-5 | +25	-20 | +9	-13 | +9	-15 | -3	-15 | +4	-15 | +4
Fish																
Main channel resident (long distance white)	-3 | +2	-59 | -42	-100| -79	-100| -74	-100| -72	-100| -85	-99 | -71	-100| -76	-100| -75	-100| -77	-97 | -70	-100| -81	-98 | -70	-14 | -3	-47 | -33	-97 | -69
Main channel spawner (short distance white)	-1 | +2	-35 | -25	-82 | -59	-75 | -53	-72 | -52	-93 | -67	-72 | -51	-77 | -55	-77 | -54	-80 | -57	-66 | -42	-82 | -59	-67 | -47	-10 | -6	-34 | -23	-69 | -49
Floodplain spawner (grey)	-7 | +12	-44 | -30	-68 | -48	-63 | -43	-65 | -44	-79 | -62	-60 | -40	-65 | -45	-69 | -49	-70 | -52	-54 | -27	-72 | -49	-53 | -34	-9 | +19	-35 | -22	-54 | -36
Floodplain resident (black)	-15 | +21	-59 | -17	-87 | -38	-86 | -34	-87 | -36	-87 | -48	-85 | -30	-87 | -36	-87 | -41	-87 | -43	-81 | -20	-87 | -36	-82 | -22	-21 | +27	-55 | -10	-80 | -22
Eurytopic (generalist)	-17 | +17	-38 | +28	-57 | +45	-52 | +46	-56 | +42	-57 | +44	-52 | +45	-53 | +47	-52 | +46	-53 | +46	-46 | +53	-59 | +48	-47 | +47	-24 | +21	-39 | +22	-48 | +46
Estuarine resident	-11 | +10	-38 | -23	-70 | -46	-68 | -47	-69 | -46	-69 | -40	-68 | -49	-70 | -48	-60 | -32	-62 | -34	-65 | -40	-69 | -50	-66 | -47	-12 | +19	-33 | -20	-59 | -40
Anadromous	-7 | +7	-18 | -8	-47 | -31	-39 | -23	-39 | -24	-58 | -41	-39 | -22	-42 | -25	-34 | -23	-50 | -35	-39 | -23	-36 | -19	-35 | -18	-17 | +5	-4 | +8	-30 | -15
Catadromous	-5 | +4	-20 | -11	-36 | -23	-31 | -19	-25 | -15	-48 | -34	-29 | -17	-36 | -22	-36 | -25	-42 | -29	-31 | -18	-30 | -16	-29 | -15	-14 | -4	-23 | -11	-28 | -15
Marine visitor																
Non-native	-2 | +5	+15 | +64	+38 |+124	+33 |+112	+32 |+110	+48 |+144	+29 |+105	+36 |+118	+36 |+119	+38 |+124	+24 | +93	+39 |+126	+26 | +96	+2 | +12	+13 | +56	+27 |+100
Comp: Fish Biomass	-8 | +10	-36 | -4	-61 | -11	-57 | -9	-57 | -9	-66 | -15	-55 | -8	-58 | -9	-59 | -10	-60 | -11	-51 | -1	-62 | -10	-51 | -5	-13 | +11	-32 | -3	-52 | -6
Comp: Sensitive indigenous fish biomass	-4 | +6	-42 | -29	-81 | -57	-74 | -52	-73 | -51	-91 | -67	-71 | -50	-76 | -54	-78 | -55	-80 | -58	-66 | -40	-82 | -58	-66 | -45	-10 | +4	-36 | -24	-67 | -47
Herpetofauna																
Ranid	-2 | +4	-12 | -5	-20 | -11	-16 | -6	-16 | -8	-26 | -18	-10 | -1	-20 | -9	-19 | -11	-21 | -13	-14 | -4	-19 | -4	-15 | -1	-8 | +4	-11 | +2	-13 | -3
Aquatic serpents	-5 | +7	-20 | -10	-36 | -20	-31 | -17	-31 | -16	-49 | -32	-23 | -12	-34 | -18	-32 | -16	-34 | -18	-20 | -7	-33 | -13	-17 | +7	-11 | +5	-19 | -9	-23 | -9
Aquatic Turtles	-9 | +8	-41 | -24	-74 | -52	-80 | -53	-75 | -53	-90 | -63	-69 | -43	-89 | -60	-79 | -48	-84 | -54	-57 | -26	-100| -73	-67 | -43	-42 | -21	-64 | -42	-73 | -47
Semi-aquatic Turtles	-6 | -1	-32 | -22	-51 | -36	-70 | -49	-55 | -38	-61 | -42	-64 | -45	-79 | -56	-67 | -47	-70 | -49	-57 | -40	-96 | -72	-71 | -50	-46 | -33	-67 | -48	-73 | -52
Amphibians-human use	-2 | +5	-8 | -3	-12 | -6	-10 | -4	-10 | -5	-18 | -11	-6 | +0	-14 | -7	-15 | -9	-16 | -10	-10 | -4	-9 | -2	-8 | 0	-5 | +0	-6 | -1	-7 | -2

<table>
<tr><th></th><th>Base2007</th><th>2020</th><th>2040</th><th>2040CC</th><th>C2_2040 Wet</th><th>C3_2040 Dry</th><th>A1_noALU</th><th>A2_ALU</th><th>I1_noIRR</th><th>I2_IRR</th><th>F1_noFPI</th><th>F2_FPI</th><th>F3_FPI</th><th>H1a_noHPP</th><th>H1b_nomainHPP</th><th>H3_HPP</th></tr>
<tr><td>Aquatic/semi-aqu reptiles-human use</td><td>-8 | +11</td><td>-25 | -12</td><td>-46 | -25</td><td>-39 | -22</td><td>-37 | -18</td><td>-81 | -54</td><td>-29 | -16</td><td>-42 | -22</td><td>-40 | -20</td><td>-44 | -23</td><td>-24 | -10</td><td>-34 | -9</td><td>-9 | +26</td><td>-11 | +10</td><td>-23 | -8</td><td>-25 | -9</td></tr>
<tr><td>Species richness of riparian/FP amphibians</td><td>-3 | +5</td><td>-23 | -13</td><td>-43 | -30</td><td>-41 | -21</td><td>-40 | -23</td><td>-48 | -42</td><td>-33 | -15</td><td>-44 | -24</td><td>-42 | -33</td><td>-45 | -36</td><td>-36 | -17</td><td>-44 | -19</td><td>-37 | -11</td><td>-7 | +3</td><td>-16 | -3</td><td>-27 | -11</td></tr>
<tr><td>Species richness of riparian/FP reptiles</td><td>-10 | +6</td><td>-59 | -34</td><td>-70 | -65</td><td>-70 | -64</td><td>-70 | -64</td><td>-70 | -68</td><td>-70 | -60</td><td>-70 | -67</td><td>-70 | -63</td><td>-70 | -66</td><td>-69 | -54</td><td>-70 | -68</td><td>-69 | -52</td><td>-29 | -9</td><td>-62 | -34</td><td>-69 | -52</td></tr>
<tr><td colspan="17">Birds</td></tr>
<tr><td>Bank / hole nesting species</td><td>-3 | +5</td><td>-28 | -20</td><td>-53 | -38</td><td>-48 | -34</td><td>-47 | -34</td><td>-66 | -48</td><td>-35 | -25</td><td>-59 | -42</td><td>-52 | -37</td><td>-54 | -39</td><td>-39 | -28</td><td>-54 | -39</td><td>-40 | -28</td><td>-16 | -5</td><td>-28 | -20</td><td>-42 | -30</td></tr>
<tr><td>Flocking non-aerial pass of graminoid beds</td><td>-1 | 0</td><td>-19 | -14</td><td>-27 | -19</td><td>-24 | -18</td><td>-24 | -18</td><td>-31 | -22</td><td>-13 | -9</td><td>-33 | -24</td><td>-21 | -15</td><td>-24 | -18</td><td>-19 | -14</td><td>-30 | -22</td><td>-19 | -14</td><td>-15 | -11</td><td>-22 | -16</td><td>-23 | -17</td></tr>
<tr><td>Small non-flocking landbird;seasonally flooded veg</td><td>0 | +1</td><td>-3 | -1</td><td>-4 | -2</td><td>-3 | +1</td><td>-3 | -2</td><td>-4 | -3</td><td>0 | +4</td><td>-6 | -2</td><td>-3 | +4</td><td>-3 | +1</td><td>-3 | +2</td><td>-3 | +3</td><td>-3 | +2</td><td>-4 | -2</td><td>-3 | +1</td><td>-3 | +1</td></tr>
<tr><td>Overall bird abundance</td><td>-1 | +2</td><td>-17 | -11</td><td>-28 | -20</td><td>-25 | -17</td><td>-25 | -18</td><td>-34 | -24</td><td>-16 | -10</td><td>-33 | -23</td><td>-25 | -16</td><td>-27 | -19</td><td>-20 | -13</td><td>-29 | -19</td><td>-20 | -13</td><td>-12 | -6</td><td>-18 | -12</td><td>-23 | -15</td></tr>
</table>

Appendix Table 18 BioRA Zone 7: Uncertainty ranges for BioRA indicators

<table>
<tr><th></th><th>Base2007</th><th>2020</th><th>2040</th><th>2040CC</th><th>C2_2040 Wet</th><th>C3_2040 Dry</th><th>A1_noALU</th><th>A2_ALU</th><th>I1_noIRR</th><th>I2_IRR</th><th>F1_noFPI</th><th>F2_FPI</th><th>F3_FPI</th><th>H1a_noHPP</th><th>H1b_nomainHPP</th><th>H3_HPP</th></tr>
<tr><td colspan="17">Vegetation</td></tr>
<tr><td>FP: Extent of flooded forest</td><td>-6 | +5</td><td>-17 | -9</td><td>-19 | -11</td><td>-17 | -6</td><td>-14 | -2</td><td>-45 | -33</td><td>-11 | +2</td><td>-19 | -6</td><td>-14 | -2</td><td>-15 | -4</td><td>-16 | -5</td><td>-8 | +7</td><td>-5 | +13</td><td>-8 | +7</td><td>-15 | -3</td><td>-14 | -2</td></tr>
<tr><td>FP: Extent of herbaceous marsh</td><td>-2 | +4</td><td>-14 | -8</td><td>-20 | -13</td><td>-16 | -8</td><td>-16 | -8</td><td>-40 | -25</td><td>-10 | +3</td><td>-19 | -10</td><td>-15 | -6</td><td>-16 | -7</td><td>-16 | -8</td><td>-13 | +0</td><td>-12 | +4</td><td>-4 | +7</td><td>-12 | -5</td><td>-14 | -6</td></tr>
<tr><td>FP: Extent of grassland</td><td>0 | +1</td><td>-8 | -4</td><td>-15 | -10</td><td>-14 | -9</td><td>-14 | -9</td><td>-20 | -13</td><td>-12 | -8</td><td>-15 | -10</td><td>-14 | -9</td><td>-14 | -9</td><td>-14 | -9</td><td>-13 | -9</td><td>-13 | -9</td><td>-1 | +2</td><td>-9 | -6</td><td>-12 | -8</td></tr>
<tr><td>FP: Biomass algae</td><td>-1 | +2</td><td>-2 | +2</td><td>-2 | +6</td><td>-3 | +5</td><td>-1 | +5</td><td>-5 | +7</td><td>-3 | +5</td><td>-3 | +4</td><td>-4 | +4</td><td>-3 | +5</td><td>-3 | +5</td><td>-3 | +5</td><td>-3 | +7</td><td>-3 | +1</td><td>-3 | +2</td><td>-3 | +4</td></tr>
<tr><td>Extent invasive riparian vegetation</td><td>-1 | +3</td><td>+1 | +34</td><td>+1 | +43</td><td>+1 | +37</td><td>+1 | +35</td><td>+2 | +68</td><td>+0 | +11</td><td>+1 | +54</td><td>+1 | +34</td><td>+1 | +36</td><td>+1 | +37</td><td>+1 | +28</td><td>+0 | +26</td><td>0 | +20</td><td>+1 | +32</td><td>+1 | +34</td></tr>
<tr><td>Extent invasive floating/submerged vegetation</td><td>-2 | -1</td><td>-4 | +6</td><td>-3 | +8</td><td>-5 | +6</td><td>-2 | +8</td><td>-17 | -3</td><td>-7 | -5</td><td>-3 | +15</td><td>-3 | +8</td><td>-4 | +7</td><td>-3 | +8</td><td>-1 | +9</td><td>0 | +10</td><td>-1 | +9</td><td>-3 | +7</td><td>-3 | +8</td></tr>
<tr><td>Comp: Indigenous vegetation biomass</td><td>-2 | +3</td><td>-12 | -7</td><td>-18 | -12</td><td>-15 | -8</td><td>-15 | -8</td><td>-33 | -21</td><td>-11 | -1</td><td>-18 | -10</td><td>-14 | -7</td><td>-15 | -8</td><td>-15 | -8</td><td>-13 | -3</td><td>-12 | -1</td><td>-3 | +5</td><td>-11 | -5</td><td>-14 | -6</td></tr>
<tr><td>Comp: Overall vegetation biomass</td><td>-2 | +3</td><td>-9 | +1</td><td>-13 | -1</td><td>-11 | +0</td><td>-11 | +0</td><td>-26 | -5</td><td>-9 | +0</td><td>-13 | +3</td><td>-11 | +1</td><td>-11 | +1</td><td>-11 | +0</td><td>-9 | +3</td><td>-9 | +5</td><td>-2 | +8</td><td>-8 | +2</td><td>-10 | +1</td></tr>
<tr><td colspan="17">Macroinvertebrates</td></tr>
<tr><td>Snail abundance</td><td>-9 | +7</td><td>-15 | 0</td><td>-14 | +4</td><td>-20 | -6</td><td>-12 | +4</td><td>-54 | -39</td><td>-23 | -14</td><td>-17 | +3</td><td>-14 | +5</td><td>-16 | +3</td><td>-15 | +5</td><td>-10 | +13</td><td>-8 | +17</td><td>-10 | +12</td><td>-15 | +3</td><td>-14 | +4</td></tr>
<tr><td>Diversity of snails</td><td>-10 | +9</td><td>-16 | +1</td><td>-15 | +4</td><td>-25 | -9</td><td>-15 | +2</td><td>-57 | -41</td><td>-28 | -17</td><td>-21 | +0</td><td>-19 | +2</td><td>-21 | -1</td><td>-20 | +1</td><td>-16 | +9</td><td>-14 | +13</td><td>-13 | +9</td><td>-20 | -1</td><td>-19 | +1</td></tr>
<tr><td>Bivalves abundance</td><td>-10 | +9</td><td>-16 | +1</td><td>-15 | +4</td><td>-25 | -9</td><td>-15 | +2</td><td>-57 | -41</td><td>-28 | -17</td><td>-21 | +0</td><td>-19 | +2</td><td>-21 | -1</td><td>-19 | +1</td><td>-15 | +9</td><td>-14 | +13</td><td>-13 | +9</td><td>-20 | -1</td><td>-19 | +1</td></tr>
<tr><td>Shrimps and crabs</td><td>-14 | +16</td><td>-23 | +4</td><td>-20 | +12</td><td>-36 | -11</td><td>-22 | +5</td><td>-87 | -63</td><td>-43 | -26</td><td>-26 | +13</td><td>-25 | +11</td><td>-28 | +6</td><td>-26 | +11</td><td>-21 | +20</td><td>-18 | +27</td><td>-20 | +17</td><td>-28 | +5</td><td>-26 | +7</td></tr>
<tr><td>Macrobrachium</td><td>-9 | +9</td><td>-14 | +0</td><td>-13 | +2</td><td>-18 | -8</td><td>-10 | +4</td><td>-47 | -35</td><td>-21 | -14</td><td>-14 | -2</td><td>-12 | +2</td><td>-14 | -1</td><td>-13 | +1</td><td>-7 | +14</td><td>-5 | +20</td><td>-9 | +11</td><td>-14 | -1</td><td>-13 | +1</td></tr>
<tr><td>Benthic invertebrate diversity</td><td>-12 | +14</td><td>-21 | +2</td><td>-19 | +9</td><td>-33 | -11</td><td>-20 | +4</td><td>-76 | -56</td><td>-38 | -22</td><td>-25 | +10</td><td>-24 | +8</td><td>-26 | +3</td><td>-24 | +7</td><td>-19 | +16</td><td>-16 | +23</td><td>-18 | +14</td><td>-26 | +3</td><td>-24 | +5</td></tr>
<tr><td>Zooplankton abundance</td><td>-11 | +15</td><td>-20 | +4</td><td>-17 | +11</td><td>-31 | -8</td><td>-19 | +5</td><td>-70 | -51</td><td>-35 | -20</td><td>-23 | +12</td><td>-21 | +11</td><td>-24 | +7</td><td>-21 | +11</td><td>-17 | +19</td><td>-14 | +26</td><td>-17 | +16</td><td>-23 | +6</td><td>-22 | +8</td></tr>
<tr><td>Zooplankton diversity</td><td>-13 | +14</td><td>-19 | +4</td><td>-16 | +12</td><td>-31 | -9</td><td>-19 | +6</td><td>-77 | -56</td><td>-39 | -23</td><td>-21 | +14</td><td>-21 | +11</td><td>-24 | +6</td><td>-22 | +11</td><td>-17 | +19</td><td>-14 | +26</td><td>-16 | +16</td><td>-24 | +6</td><td>-22 | +8</td></tr>
<tr><td>Benthic invertebrate abundance</td><td>-8 | +6</td><td>-11 | +1</td><td>-11 | +4</td><td>-18 | -6</td><td>-12 | +1</td><td>-41 | -30</td><td>-21 | -12</td><td>-15 | +2</td><td>-14 | +2</td><td>-15 | +0</td><td>-14 | +2</td><td>-13 | +6</td><td>-12 | +8</td><td>-11 | +6</td><td>-15 | +0</td><td>-14 | +1</td></tr>
</table>

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noALU	A2_ALU	I1_noIRR	I2_IRR	F1_noFPI	F2_FPI	F3_FPI	H1a_noHPP	H1b_nomainHPP	H3_HPP
Fish																
Main channel resident (long distance white)	-4 | +7	-38 | -24	-100| -76	-97 | -69	-87 | -61	-100|-100	-90 | -65	-100| -73	-98 | -70	-100| -75	-85 | -61	-100| -78	-81 | -56	-10 | +2	-40 | -28	-82 | -59
Main channel spawner (short distance white)	-7 | +8	-29 | -15	-75 | -51	-75 | -53	-66 | -44	-98 | -82	-74 | -53	-77 | -55	-73 | -51	-77 | -55	-64 | -45	-72 | -50	-59 | -39	-12 | -3	-38 | -26	-65 | -46
Floodplain spawner (grey)	-13 | +20	-39 | -16	-66 | -41	-74 | -52	-66 | -39	-92 | -88	-77 | -53	-74 | -52	-70 | -47	-72 | -50	-69 | -47	-63 | -37	-58 | -30	-20 | +9	-53 | -33	-64 | -42
Floodplain resident (black)	-12 | +18	-37 | -4	-68 | -12	-79 | -23	-68 | -14	-100| -55	-81 | -24	-79 | -22	-73 | -18	-76 | -20	-74 | -21	-63 | -11	-60 | -10	-19 | +9	-53 | -16	-67 | -17
Eurytopic (generalist)	-23 | +26	-34 | +30	-39 | +64	-46 | +53	-43 | +55	-53 | +47	-48 | +51	-44 | +57	-42 | +58	-42 | +58	-46 | +50	-38 | +66	-40 | +58	-25 | +24	-43 | +30	-42 | +51
Estuarine resident	-8 | +8	-29 | -11	-57 | -34	-66 | -44	-61 | -39	-61 | -31	-62 | -42	-73 | -50	-57 | -37	-58 | -37	-66 | -44	-70 | -48	-69 | -48	-20 | -2	-45 | -29	-60 | -40
Anadromous	0 | +1	-7 | -5	-24 | -17	-20 | -14	-19 | -14	-32 | -23	-17 | -13	-22 | -16	-18 | -13	-27 | -20	-20 | -14	-17 | -12	-16 | -12	-7 | -5	+1 | +2	-14 | -10
Catadromous	-3 | +4	-16 | -10	-25 | -17	-24 | -15	-19 | -11	-41 | -29	-19 | -10	-29 | -18	-26 | -16	-30 | -19	-24 | -15	-21 | -11	-20 | -10	-13 | -5	-20 | -12	-23 | -14
Marine visitor																
Non-native	-2 | +5	+15 | +64	+36 | +97	+31 | +97	+30 | +97	+45 | +98	+27 | +95	+34 | +97	+34 | +97	+36 | +97	+24 | +90	+37 | +97	+25 | +92	+2 | +12	+14 | +57	+26 | +94
Comp: Fish Biomass	-12 | +16	-29 | +5	-52 | +0	-58 | -7	-52 | +0	-78 | -28	-59 | -8	-58 | -7	-54 | -3	-56 | -5	-54 | -5	-51 | +1	-47 | +3	-17 | +9	-40 | -4	-51 | -3
Comp: Sensitive indigenous fish biomass	-9 | +13	-34 | -17	-75 | -50	-77 | -55	-69 | -44	-100| -87	-77 | -55	-79 | -56	-75 | -52	-78 | -56	-69 | -48	-73 | -48	-61 | -37	-15 | +2	-44 | -29	-67 | -46
Herpetofauna																
Ranid	-1 | +3	-13 | -5	-17 | -6	-16 | -4	-14 | -3	-31 | -17	-5 | +4	-22 | -7	-14 | -1	-16 | -3	-16 | -4	-11 | +1	-11 | +1	-9 | +1	-15 | -3	-16 | -4
Aquatic serpents	-4 | +5	-16 | -6	-22 | -7	-29 | -16	-19 | -7	-65 | -52	-21 | -11	-32 | -17	-23 | -10	-26 | -12	-27 | -14	-14 | -1	-14 | -2	-10 | 0	-21 | -13	-24 | -12
Aquatic Turtles	-7 | +10	-23 | -9	-30 | -9	-37 | -19	-25 | -8	-90 | -62	-29 | -13	-40 | -20	-29 | -11	-32 | -14	-33 | -17	-18 | +3	-16 | +4	-13 | +3	-28 | -16	-30 | -13
Semi-aquatic Turtles	-1 | +1	-11 | -6	-14 | -9	-7 | -2	-10 | -5	-10 | +15	+7 | +11	-13 | -7	-7 | -3	-6 | -2	-8 | -4	-5 | -2	-5 | -2	-2 | +1	-5 | -1	-5 | -2
Amphibians-human use	+1 | +3	-11 | -8	-14 | -10	-13 | -8	-12 | -8	-30 | -22	-3 | +2	-19 | -13	-11 | -5	-13 | -8	-13 | -8	-9 | -3	-8 | -3	-8 | -3	-12 | -7	-13 | -8
Aquatic/semi-aqu reptiles-human use	-3 | +2	-14 | -9	-20 | -13	-28 | -21	-17 | -11	-96 | -70	-22 | -15	-31 | -23	-21 | -15	-24 | -17	-25 | -18	-11 | -6	-10 | -6	-8 | -4	-20 | -15	-22 | -15
Species richness of riparian/FP amphibians	0 | +3	-15 | -9	-20 | -13	-19 | -5	-16 | -7	-39 | -27	-10 | +3	-22 | -7	-17 | -1	-19 | -5	-19 | -6	-11 | +3	-10 | +4	-7 | +4	-17 | -4	-18 | -5
Species richness of riparian/FP reptiles	-2 | +1	-17 | -11	-22 | -14	-26 | -18	-20 | -13	-51 | -37	-20 | -13	-27 | -19	-22 | -15	-24 | -16	-26 | -18	-14 | -9	-13 | -8	-7 | -4	-23 | -16	-23 | -16

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noALU	A2_ALU	I1_noIRR	I2_IRR	F1_noFPI	F2_FPI	F3_FPI	H1a_noHPP	H1b_nomainHPP	H3_HPP
Birds																
Tree-nesting large waterbirds.	-8 | +15	-43 | -28	-75 | -53	-86 | -61	-65 | -45	-100|-100	-76 | -51	-91 | -66	-71 | -49	-80 | -56	-78 | -55	-55 | -33	-48 | -24	-20 | -2	-59 | -41	-71 | -49
Bank / hole nesting species	-3 | +7	-23 | -15	-42 | -30	-49 | -36	-39 | -28	-100| -76	-40 | -29	-58 | -42	-44 | -32	-47 | -34	-45 | -33	-38 | -27	-35 | -25	-16 | -7	-34 | -24	-42 | -30
Flocking non-aerial pass of graminoid beds	+1 | +1	-6 | -4	-7 | -5	-6 | -4	-5 | -4	-16 | -11	-2 | -1	-7 | -5	-5 | -3	-5 | -4	-6 | -4	-2 | -1	-1 | +0	+0 | +1	-4 | -3	-5 | -3
Large ground-nesting spp: wetland FP	0 | +0	-14 | -10	-17 | -13	-17 | -12	-17 | -12	-19 | -14	-5 | -3	-27 | -19	-17 | -12	-17 | -12	-17 | -12	-17 | -12	-17 | -12	-12 | -8	-15 | -11	-16 | -12
Channel-using large spp: bankside forest	-2 | +3	-10 | -7	-12 | -9	-12 | -8	-9 | -5	-68 | -50	-5 | -1	-16 | -11	-9 | -5	-11 | -7	-10 | -7	-6 | +0	-5 | +4	-6 | +1	-9 | -5	-9 | -5
Dense woody vegetation / water interface	+0 | +1	-14 | -10	-16 | -12	-15 | -11	-14 | -10	-39 | -28	-2 | -1	-24 | -18	-14 | -10	-14 | -10	-15 | -11	-11 | -8	-10 | -7	-10 | -7	-14 | -10	-14 | -10
Small non-flocking landbird;seasonally flooded veg	-1 | +2	-8 | -6	-11 | -8	-8 | -6	-8 | -6	-23 | -17	-2 | -1	-12 | -9	-8 | -6	-8 | -6	-9 | -6	-6 | -4	-5 | -3	-4 | +0	-7 | -5	-8 | -6
Overall bird abundance	-2 | +4	-17 | -11	-26 | -19	-28 | -20	-22 | -16	-52 | -42	-19 | -12	-34 | -24	-24 | -17	-26 | -19	-26 | -18	-19 | -12	-17 | -10	-10 | -3	-20 | -14	-23 | -16
Mammals																
Otters	-3 | +3	-49 | -34	-74 | -53	-85 | -61	-64 | -45	-100|-100	-83 | -60	-89 | -64	-72 | -51	-79 | -57	-76 | -54	-55 | -37	-48 | -30	-27 | -16	-66 | -47	-70 | -50

Appendix Table 19 BioRA Zone 8 (8a, 8b and 8c combined): Uncertainty ranges for BioRA indicators

<table>
<tr><th></th><th>Base2007</th><th>2020</th><th>2040</th><th>2040CC</th><th>C2_2040 Wet</th><th>C3_2040 Dry</th><th>A1_noALU</th><th>A2_ALU</th><th>I1_noIRR</th><th>I2_IRR</th><th>F1_noFPI</th><th>F2_FPI</th><th>F3_FPI</th><th>H1a_noHPP</th><th>H1b_nomainHPP</th><th>H3_HPP</th></tr>
<tr><td colspan="17">Vegetation</td></tr>
<tr><td>FP: Extent of flooded forest</td><td>-9 | +5</td><td>-51 | -32</td><td>-62 | -42</td><td>-20 | +18</td><td>-16 | +22</td><td>-64 | -31</td><td>-18 | +21</td><td>-22 | +16</td><td>-20 | +23</td><td>-21 | +18</td><td>-26 | +18</td><td>-29 | +10</td><td>-29 | +11</td><td>-29 | +12</td><td>-26 | +15</td><td>-22 | +12</td></tr>
<tr><td>FP: Extent of herbaceous marsh</td><td>-3 | +3</td><td>-22 | -9</td><td>-37 | -21</td><td>-22 | +6</td><td>-15 | +9</td><td>-29 | -2</td><td>-27 | +2</td><td>-30 | +0</td><td>-25 | +5</td><td>-28 | +2</td><td>-27 | +2</td><td>-35 | -6</td><td>-32 | -3</td><td>-6 | +23</td><td>-15 | +9</td><td>-26 | -2</td></tr>
<tr><td>FP: Extent of grassland</td><td>-3 | +4</td><td>-33 | -19</td><td>-41 | -24</td><td>-34 | -14</td><td>-27 | -10</td><td>-46 | -31</td><td>-33 | -11</td><td>-35 | -19</td><td>-36 | -15</td><td>-34 | -16</td><td>-36 | -12</td><td>-35 | -9</td><td>-35 | -11</td><td>-20 | +6</td><td>-25 | -3</td><td>-30 | -11</td></tr>
<tr><td>FP: Biomass algae</td><td>-2 | +5</td><td>-8 | +1</td><td>-18 | -6</td><td>-11 | +4</td><td>-10 | +4</td><td>-12 | +1</td><td>-11 | +4</td><td>-11 | +4</td><td>-10 | +6</td><td>-11 | +4</td><td>-11 | +4</td><td>-8 | +9</td><td>-11 | +5</td><td>-8 | +22</td><td>-8 | +20</td><td>-9 | +10</td></tr>
<tr><td>Biomass of marine algae</td><td>-2 | +1</td><td>-4 | +0</td><td>-6 | 0</td><td>-10 | -7</td><td>-10 | -7</td><td>-10 | -7</td><td>-11 | -8</td><td>-11 | -8</td><td>-10 | -8</td><td>-11 | -8</td><td>-10 | -6</td><td>-10 | -6</td><td>-10 | -6</td><td>-7 | +4</td><td>-7 | +2</td><td>-7 | -3</td></tr>
<tr><td>Extent invasive riparian vegetation</td><td>-3 | +4</td><td>+2 | +97</td><td>-1 |+108</td><td>-39 | +9</td><td>-6 | +28</td><td>-18 |+117</td><td>-39 | -7</td><td>-34 | +32</td><td>-40 | +8</td><td>-37 | +16</td><td>-45 | +12</td><td>-49 | +15</td><td>-49 | +17</td><td>-37 | +15</td><td>-44 | +9</td><td>-34 | +18</td></tr>
<tr><td>Extent invasive floating/submerged vegetation</td><td>+0 | +3</td><td>-3 | +8</td><td>-3 | +8</td><td>0 | +10</td><td>+1 | +11</td><td>-6 | +5</td><td>-3 | +0</td><td>-3 | +17</td><td>-2 | +11</td><td>-3 | +9</td><td>-1 | +17</td><td>-5 | +13</td><td>-9 | +11</td><td>+1 | +18</td><td>-2 | +16</td><td>-2 | +14</td></tr>
<tr><td>Mangroves</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td><td>0 | 0</td></tr>
<tr><td>Comp: Indigenous vegetation biomass</td><td>-6 | +4</td><td>-42 | -25</td><td>-53 | -35</td><td>-23 | +9</td><td>-18 | +13</td><td>-53 | -26</td><td>-22 | +11</td><td>-25 | +5</td><td>-24 | +12</td><td>-24 | +8</td><td>-28 | +8</td><td>-30 | +3</td><td>-30 | +4</td><td>-23 | +12</td><td>-24 | +9</td><td>-24 | +4</td></tr>
<tr><td>Comp: Overall vegetation biomass</td><td>-4 | +4</td><td>-22 | +15</td><td>-28 | +11</td><td>-22 | +7</td><td>-12 | +11</td><td>-36 | +11</td><td>-23 | +2</td><td>-23 | +12</td><td>-24 | +9</td><td>-23 | +8</td><td>-26 | +10</td><td>-30 | +4</td><td>-29 | +8</td><td>-21 | +12</td><td>-24 | +9</td><td>-21 | +9</td></tr>
<tr><td colspan="17">Macroinvertebrates</td></tr>
<tr><td>Snail abundance</td><td>-1 | +2</td><td>-4 | -2</td><td>-9 | -6</td><td>-3 | +5</td><td>-3 | +5</td><td>-4 | +2</td><td>-2 | +6</td><td>-5 | +4</td><td>-3 | +6</td><td>-4 | +5</td><td>-3 | +5</td><td>-3 | +4</td><td>-4 | +4</td><td>-2 | +11</td><td>-2 | +11</td><td>-3 | +7</td></tr>
<tr><td>Diversity of snails</td><td>-1 | +2</td><td>-3 | -1</td><td>-8 | -6</td><td>-2 | +5</td><td>-2 | +5</td><td>-3 | +3</td><td>-2 | +6</td><td>-3 | +5</td><td>-2 | +6</td><td>-3 | +5</td><td>-3 | +6</td><td>-2 | +4</td><td>-3 | +5</td><td>-1 | +12</td><td>-1 | +12</td><td>-2 | +7</td></tr>
<tr><td>Bivalves abundance</td><td>-1 | +2</td><td>-3 | -1</td><td>-8 | -6</td><td>-3 | +6</td><td>-2 | +6</td><td>-3 | +3</td><td>-2 | +6</td><td>-3 | +6</td><td>-3 | +7</td><td>-3 | +6</td><td>-3 | +6</td><td>-2 | +5</td><td>-3 | +5</td><td>-1 | +13</td><td>-1 | +13</td><td>-2 | +8</td></tr>
<tr><td>Polychaete worms</td><td>-1 | +2</td><td>-3 | +8</td><td>-8 | +3</td><td>-3 | +17</td><td>-3 | +14</td><td>-4 | +14</td><td>-3 | +17</td><td>-3 | +17</td><td>-3 | +17</td><td>-3 | +17</td><td>-3 | +15</td><td>-2 | +14</td><td>-3 | +15</td><td>0 | +23</td><td>-1 | +23</td><td>-3 | +10</td></tr>
<tr><td>Shrimps and crabs</td><td>-1 | +2</td><td>-4 | -2</td><td>-9 | -6</td><td>-3 | +5</td><td>-3 | +5</td><td>-4 | +2</td><td>-2 | +6</td><td>-5 | +4</td><td>-3 | +5</td><td>-4 | +5</td><td>-4 | +5</td><td>-3 | +3</td><td>-4 | +4</td><td>-2 | +11</td><td>-2 | +11</td><td>-3 | +7</td></tr>
<tr><td>Littoral invertebrate diversity</td><td>-1 | +2</td><td>-4 | -2</td><td>-9 | -6</td><td>-3 | +5</td><td>-3 | +5</td><td>-4 | +2</td><td>-2 | +6</td><td>-5 | +4</td><td>-3 | +5</td><td>-4 | +5</td><td>-3 | +5</td><td>-3 | +3</td><td>-4 | +4</td><td>-2 | +11</td><td>-2 | +11</td><td>-3 | +7</td></tr>
<tr><td>Benthic invertebrate diversity</td><td>-1 | +2</td><td>-4 | -2</td><td>-9 | -7</td><td>-3 | +5</td><td>-3 | +5</td><td>-4 | +2</td><td>-2 | +6</td><td>-5 | +4</td><td>-3 | +5</td><td>-4 | +5</td><td>-3 | +5</td><td>-2 | +4</td><td>-4 | +4</td><td>-2 | +11</td><td>-2 | +11</td><td>-3 | +7</td></tr>
<tr><td>Zooplankton abundance</td><td>-1 | +3</td><td>-5 | -2</td><td>-10 | -7</td><td>-3 | +8</td><td>-3 | +9</td><td>-5 | +3</td><td>-2 | +9</td><td>-5 | +7</td><td>-3 | +9</td><td>-4 | +8</td><td>-3 | +11</td><td>-6 | +3</td><td>-5 | +6</td><td>-3 | +13</td><td>-3 | +12</td><td>-4 | +8</td></tr>
</table>

<table>
<tr><th></th><th>Base2007</th><th>2020</th><th>2040</th><th>2040CC</th><th>C2_2040 Wet</th><th>C3_2040 Dry</th><th>A1_noALU</th><th>A2_ALU</th><th>I1_noIRR</th><th>I2_IRR</th><th>F1_noFPI</th><th>F2_FPI</th><th>F3_FPI</th><th>H1a_noHPP</th><th>H1b_nomainHPP</th><th>H3_HPP</th></tr>
<tr><td>Comp: Benthic invertebrate biomass</td><td>-1 | +2</td><td>-3 | +1</td><td>-8 | -4</td><td>-3 | +8</td><td>-3 | +7</td><td>-4 | +5</td><td>-3 | +9</td><td>-4 | +7</td><td>-3 | +9</td><td>-3 | +8</td><td>-3 | +8</td><td>-2 | +6</td><td>-3 | +7</td><td>-1 | +14</td><td>-2 | +14</td><td>-3 | +8</td></tr>
<tr><td colspan="17">Fish</td></tr>
<tr><td>Rhithron resident</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Main channel resident (long distance white)</td><td>-5 | +2</td><td>-67 | -43</td><td>-100| -87</td><td>-92 | -60</td><td>-80 | -44</td><td>-93 | -82</td><td>-92 | -58</td><td>-93 | -63</td><td>-92 | -60</td><td>-92 | -64</td><td>-94 | -58</td><td>-96 | -82</td><td>-94 | -67</td><td>-12 | +20</td><td>-44 | -10</td><td>-92 | -57</td></tr>
<tr><td>Main channel spawner (short distance white)</td><td>-7 | +4</td><td>-67 | -42</td><td>-100| -87</td><td>-93 | -56</td><td>-80 | -42</td><td>-95 | -76</td><td>-92 | -55</td><td>-94 | -59</td><td>-93 | -56</td><td>-94 | -59</td><td>-95 | -53</td><td>-98 | -76</td><td>-95 | -63</td><td>-14 | +17</td><td>-48 | -13</td><td>-93 | -54</td></tr>
<tr><td>Floodplain spawner (grey)</td><td>-9 | +14</td><td>-59 | -37</td><td>-96 | -69</td><td>-70 | -12</td><td>-49 | +5</td><td>-81 | -33</td><td>-71 | -12</td><td>-71 | -14</td><td>-70 | -11</td><td>-72 | -12</td><td>-73 | -7</td><td>-85 | -33</td><td>-81 | -23</td><td>-17 | +64</td><td>-36 | +22</td><td>-68 | -15</td></tr>
<tr><td>Floodplain resident (black)</td><td>-9 | +13</td><td>-67 | -14</td><td>-98 | -37</td><td>-78 | +20</td><td>-55 | +31</td><td>-90 | +2</td><td>-80 | +21</td><td>-80 | +19</td><td>-78 | +22</td><td>-81 | +22</td><td>-82 | +24</td><td>-89 | -1</td><td>-91 | +9</td><td>-18 | +61</td><td>-40 | +33</td><td>-76 | +14</td></tr>
<tr><td>Eurytopic (generalist)</td><td>-12 | +15</td><td>-46 | +47</td><td>-52 | +79</td><td>-36 | +90</td><td>-29 | +84</td><td>-35 | +94</td><td>-39 | +89</td><td>-36 | +90</td><td>-37 | +90</td><td>-36 | +92</td><td>-42 | +89</td><td>-38 | +88</td><td>-41 | +90</td><td>-19 | +57</td><td>-29 | +63</td><td>-38 | +85</td></tr>
<tr><td>Estuarine resident</td><td>-10 | +9</td><td>-50 | -18</td><td>-77 | -36</td><td>-66 | -15</td><td>-68 | -22</td><td>-71 | -20</td><td>-62 | -12</td><td>-74 | -22</td><td>-68 | -17</td><td>-69 | -18</td><td>-71 | -21</td><td>-72 | -18</td><td>-70 | -21</td><td>-21 | +45</td><td>-34 | +14</td><td>-64 | -24</td></tr>
<tr><td>Anadromous</td><td>-4 | +3</td><td>-21 | -14</td><td>-43 | -31</td><td>-31 | -16</td><td>-28 | -14</td><td>-44 | -27</td><td>-29 | -15</td><td>-35 | -20</td><td>-30 | -16</td><td>-38 | -22</td><td>-30 | -15</td><td>-33 | -17</td><td>-28 | -14</td><td>-8 | +21</td><td>-4 | +11</td><td>-27 | -15</td></tr>
<tr><td>Catadromous</td><td>-4 | +7</td><td>-27 | -17</td><td>-46 | -32</td><td>-34 | -10</td><td>-27 | -5</td><td>-52 | -26</td><td>-31 | -7</td><td>-40 | -14</td><td>-41 | -14</td><td>-46 | -18</td><td>-34 | -9</td><td>-37 | -15</td><td>-30 | -8</td><td>-13 | +6</td><td>-24 | -3</td><td>-31 | -8</td></tr>
<tr><td>Marine visitor</td><td>0 | +0</td><td>-1 | +0</td><td>-2 | -1</td><td>+1 | +2</td><td>+1 | +1</td><td>+1 | +1</td><td>+1 | +2</td><td>+1 | +2</td><td>+1 | +2</td><td>+1 | +2</td><td>+0 | +3</td><td>+0 | +3</td><td>+0 | +4</td><td>0 | +6</td><td>0 | +6</td><td>-1 | +1</td></tr>
<tr><td>Non-native</td><td>-1 | +5</td><td>+21 | +78</td><td>+52 | +98</td><td>+34 | +93</td><td>+21 | +83</td><td>+45 | +96</td><td>+32 | +92</td><td>+36 | +94</td><td>+34 | +93</td><td>+36 | +94</td><td>+32 | +95</td><td>+44 | +97</td><td>+39 | +96</td><td>-2 | +1</td><td>+8 | +41</td><td>+31 | +96</td></tr>
<tr><td>Comp: Fish Biomass</td><td>-7 | +8</td><td>-42 | +6</td><td>-63 | -3</td><td>-51 | +22</td><td>-42 | +23</td><td>-55 | +13</td><td>-51 | +22</td><td>-52 | +20</td><td>-51 | +22</td><td>-52 | +21</td><td>-53 | +23</td><td>-62 | +10</td><td>-56 | +17</td><td>-15 | +36</td><td>-31 | +26</td><td>-51 | +16</td></tr>
<tr><td>Comp: Sensitive indigenous fish biomass</td><td>-7 | +5</td><td>-66 | -41</td><td>-100| -85</td><td>-92 | -52</td><td>-77 | -37</td><td>-94 | -71</td><td>-92 | -51</td><td>-93 | -54</td><td>-92 | -51</td><td>-93 | -54</td><td>-93 | -49</td><td>-96 | -72</td><td>-94 | -59</td><td>-14 | +21</td><td>-47 | -10</td><td>-91 | -50</td></tr>
<tr><td colspan="17">Herpetofauna</td></tr>
<tr><td>Ranid</td><td>-2 | +4</td><td>-23 | -13</td><td>-31 | -20</td><td>-19 | -2</td><td>-12 | +3</td><td>-33 | -12</td><td>-14 | +1</td><td>-23 | -4</td><td>-19 | -2</td><td>-19 | -2</td><td>-19 | -1</td><td>-21 | -5</td><td>-19 | -2</td><td>-7 | +8</td><td>-12 | +4</td><td>-17 | -2</td></tr>
<tr><td>Aquatic serpents</td><td>-2 | +5</td><td>-19 | -10</td><td>-33 | -17</td><td>-12 | +8</td><td>-7 | +15</td><td>-25 | -2</td><td>-9 | +9</td><td>-18 | +5</td><td>-12 | +8</td><td>-14 | +8</td><td>-10 | +8</td><td>-27 | -8</td><td>-15 | +3</td><td>-4 | +17</td><td>-7 | +7</td><td>-14 | +4</td></tr>
<tr><td>Aquatic Turtles</td><td>-7 | +7</td><td>-46 | -29</td><td>-71 | -42</td><td>-17 | +18</td><td>-12 | +26</td><td>-52 | -12</td><td>-15 | +19</td><td>-23 | +13</td><td>-17 | +19</td><td>-19 | +18</td><td>-19 | +14</td><td>-40 | -2</td><td>-26 | +7</td><td>-9 | +29</td><td>-13 | +15</td><td>-22 | +11</td></tr>
<tr><td>Semi-aquatic Turtles</td><td>-7 | +6</td><td>-52 | -30</td><td>-59 | -19</td><td>-55 | -35</td><td>-50 | -20</td><td>-84 | -69</td><td>-47 | -30</td><td>-63 | -42</td><td>-54 | -35</td><td>-57 | -37</td><td>-58 | -38</td><td>-49 | -26</td><td>-59 | -39</td><td>-51 | -32</td><td>-54 | -35</td><td>-56 | -35</td></tr>
<tr><td>Amphibians-human use</td><td>-3 | +3</td><td>-18 | -12</td><td>-29 | -20</td><td>-16 | -2</td><td>-8 | +7</td><td>-22 | -8</td><td>-10 | +3</td><td>-18 | -4</td><td>-13 | 0</td><td>-15 | -1</td><td>-13 | +1</td><td>-30 | -12</td><td>-18 | -4</td><td>-10 | +8</td><td>-15 | -1</td><td>-17 | -2</td></tr>
<tr><td>Aquatic/semi-aqu reptiles-human use</td><td>-2 | +7</td><td>-17 | -10</td><td>-33 | -23</td><td>-11 | +0</td><td>-7 | +16</td><td>-30 | -20</td><td>-8 | +5</td><td>-14 | -4</td><td>-10 | +2</td><td>-11 | 0</td><td>-9 | +3</td><td>-33 | -16</td><td>-14 | -3</td><td>-4 | +18</td><td>-8 | +5</td><td>-11 | 0</td></tr>
<tr><td>Species richness of riparian/FP amphibians</td><td>0 | +2</td><td>-35 | -23</td><td>-57 | -41</td><td>-6 | +3</td><td>+1 | +8</td><td>-42 | -21</td><td>-3 | +6</td><td>-9 | +3</td><td>-3 | +6</td><td>-6 | +4</td><td>-5 | +6</td><td>-15 | -3</td><td>-9 | +3</td><td>+5 | +12</td><td>+3 | +10</td><td>-8 | +4</td></tr>
</table>

	Base2007	2020	2040	2040CC	C2_2040 Wet	C3_2040 Dry	A1_noALU	A2_ALU	I1_noIRR	I2_IRR	F1_noFPI	F2_FPI	F3_FPI	H1a_noHPP	H1b_nomainHPP	H3_HPP
Species richness of riparian/FP reptiles	-1 | +1	-48 | -35	-57 | -47	-14 | -6	-1 | +4	-47 | -39	-11 | -4	-16 | -8	-11 | -4	-14 | -6	-14 | -7	-33 | -27	-25 | -15	-3 | +1	-14 | -8	-18 | -10
Birds																
Bank / hole nesting species	-4 | +4	-32 | -12	-65 | -35	-28 | -9	-17 | -1	-41 | -16	-29 | -20	-29 | +0	-28 | -8	-29 | -8	-27 | -8	-52 | -26	-35 | -14	-1 | +37	-12 | +11	-31 | -10
Flocking non-aerial pass of graminoid beds	+0 | +0	-8 | -6	-14 | -10	-6 | -4	-2 | -2	-15 | -11	-5 | -3	-7 | -5	-5 | -4	-6 | -4	-7 | -5	-11 | -8	-9 | -6	-3 | -1	-5 | -3	-7 | -5
Large ground-nesting spp: wetland FP	-1 | -1	-6 | -4	-7 | -5	-13 | -9	-6 | -4	-11 | -8	-7 | -5	-16 | -12	-13 | -9	-12 | -9	-12 | -9	-13 | -10	-13 | -9	-10 | -7	-12 | -9	-12 | -9
Overall bird abundance	-2 | +1	-15 | -7	-28 | -17	-16 | -7	-9 | -2	-22 | -11	-14 | -9	-18 | -6	-16 | -7	-16 | -7	-16 | -7	-25 | -14	-19 | -10	-5 | +10	-10 | 0	-17 | -8
Mammals																
Otters	-7 | +6	-49 | -34	-81 | -62	-30 | -9	-22 | 0	-60 | -43	-24 | -2	-40 | -19	-29 | -8	-33 | -11	-31 | -9	-55 | -33	-41 | -18	-11 | +30	-20 | +10	-35 | -12

Appendix D Inputs to the social and economic assessments

A set of BioRA composite indicators was computed for use in the social and economic assessments. These indicators included in each composite indicator were identified through discussion with the lead consultants for the social and economic components of the Council Study and are listed in Appendix Table 20. The significance of changes in these composite indicators for people living in the LMB and for the national economies of the four LMB countries is the subject of the Social Assessment Report and the Economic Assessment Report, respectively.

Appendix Table 20 BioRA composite indicators for social and economic assessments

<table>
<tr><th>Information required</th><th colspan="2">BioRA indicators used</th></tr>
<tr><td rowspan="22">Biomass of capture fisheries and OAAs</td><td rowspan="5">White fish</td><td>FISH: Main channel resident (long distant white) species</td></tr>
<tr><td>FISH: Main channel spawner (short distant white) species</td></tr>
<tr><td>FISH: Anadromous</td></tr>
<tr><td>FISH: Catadromous</td></tr>
<tr><td>FISH: Rhithron resident</td></tr>
<tr><td>Black fish</td><td>FISH: Floodplain resident</td></tr>
<tr><td>Grey fish</td><td>FISH: Floodplain spawners</td></tr>
<tr><td>Generalist fish</td><td>FISH: Eurytopic (generalist)</td></tr>
<tr><td rowspan="2">Marine fish</td><td>FISH: Estuarine resident species</td></tr>
<tr><td>FISH: Marine visitors</td></tr>
<tr><td>Non-native</td><td>FISH: Non-native</td></tr>
<tr><td>Overall fish biomass</td><td>FISH: Biomass</td></tr>
<tr><td rowspan="5">Aquatic invertebrates</td><td>MACROINVERTEBRATES: Shrimps and crabs</td></tr>
<tr><td>MACROINVERTEBRATES: Aquatic snails</td></tr>
<tr><td>MACROINVERTEBRATES: Bivalve abundances</td></tr>
<tr><td>MACROINVERTEBRATES: Polychaete worms</td></tr>
<tr><td>MACROINVERTEBRATES: Macrobranchion prawns</td></tr>
<tr><td>Amphibians</td><td>HERPETOFAUNA: Amphibians for human use.</td></tr>
<tr><td>Reptiles</td><td>HERPETOFAUNA: Aquatic/semi-aquatic reptiles for human use</td></tr>
<tr><td>Overall OAA biomass</td><td>Calculated</td></tr>
<tr><td rowspan="3">Persistence of iconic species</td><td>Mekong catfish</td><td>FISH: Main channel resident (long distant white) species</td></tr>
<tr><td>Irrawaddy dolphin</td><td>MAMMALS: Irrawaddy dolphin</td></tr>
<tr><td>Hog Deer</td><td>MAMMALS: Wetland ungulates</td></tr>
</table>

Information required	BioRA indicators used	
	Sarus crane and Bengal florican	BIRDS: Large ground-nesting species of floodplain wetlands
Aquatic biodiversity	INTEGRITY: Biodiversity	
Viability of river bank gardens	GEOMORPHOLOGY: Erosion (bank / bed incision)	
	VEGETATION: Extent of lower bank vegetation cover	
Extent of inundated forest	VEGETATION: Area of flooded forest	
Extent of marshes and inundated grasslands	Floodplain habitats	VEGETATION: Extent of herbaceous marsh vegetation
		VEGETATION: Extent of flooded grassland vegetation
Extent of channel erosion	GEOMORPHOLOGY: Erosion (bank / bed incision)	
Risk of river-related diseases	MACROINVERTEBRATES: *Neotricula aperta*[149]	
River channel condition	Integrity of habitats	GEOMORPHOLOGY INTEGRITY

The predicted changes in the capture fishery and OAA composite indicators computed for use in the social and economic assessments are presented in Appendix Table 21, and those for the aquatic biodiversity, viability of river bank gardens, river bank condition, risk of river-related disease, extent of indigenous wetland vegetation and bank erosion are presented in Appendix Table 22.

These are presented per BioRA zone for impounded and non-impounded sections of the river combined, and are relative to the 2007 Baseline.

[149] *Neotricula aperta* are the host snails for schistosomiasis (bilharzia), which in recent times has increased in the middle reaches of lower Mekong River (FA 4). Note: Malaria is not linked with the mainstream Mekong River (*BIORA TECHNICAL REPORT SERIES*. Volume 1: Specialists' Report).

Appendix Table 21 Combined predicted change in biomass of capture fisheries and OAAs for the main development scenarios and sub-scenarios per BioRA zone relative to 2007

Focus area	Biomass of capture fisheries						Biomass of OAAs			
	White fish	Grey and generalist fish	Black fish	Marine and other fish	Non-native	Overall fish biomass	Aquatic inver-tebrates	Amphi-bians	Reptiles	Overall OAA biomass
Scenario I1_noIRR										
Zone 1	-86	-6			81	-34	-25			-25
Zone 2	-70	-4			58	-41	-2			3
Zone 3	-63	9	-31	-11	30	-41	-12	-6	-26	-14
Zone 4	-31	-13	-40	-4	26	-17	-14	-6	-30	-15
Zone 5	-36	-26	-53	0	42	-21	-12	-7	-35	-15
Zone 6	-35	-18	-42	-23	38	-21	-3	-7	-20	-6
Zone 7	-24	-14	-22	-14	38	-14	-8	-11	-11	-9
Zone 8	-55	-17	-47	-11	50	-18	-2	-16	-16	-7
Scenario 2040										
Zone 1	-100	-23			87	-54	-8			2
Zone 2	-100	-26			57	-71	13			33
Zone 3	-90	33	-16	-27	82	-61	-16	-8	-8	-13
Zone 4	-100	-13	-10	-12	90	-41	-12	-5	-9	0
Zone 5	-99	26	-59	0	95	4	-2	-5	-24	5
Zone 6	-77	-28	-71	-45	79	-38	-13	-10	-37	-12
Zone 7	-69	-20	-42	-33	76	-27	-5	-14	-16	-9
Zone 8	-96	-22	-85	-23	94	-31	-7	-25	-30	-14
Scenario 2040CC										
Zone 1	-100	-23			89	-56	-9			1
Zone 2	-100	-26			58	-75	13			34
Zone 3	-92	24	-29	-27	97	-66	-16	-9	-9	-13
Zone 4	-100	-13	-10	-12	90	-40	-12	-6	-6	0
Zone 5	-97	26	-58	0	93	5	-1	-4	-24	6
Zone 6	-70	-25	-67	-44	71	-34	-9	-9	-32	-7
Zone 7	-68	-29	-54	-40	68	-35	-18	-12	-24	-17
Zone 8	-79	9	-33	-14	70	-13	2	-9	-8	-2
Scenario A1_noALU										
Zone 1	-100	-22			88	-56	-9			1
Zone 2	-100	-26			57	-73	13			34
Zone 3	-91	25	-23	-27	85	-63	-15	-7	1	-10
Zone 4	-100	-12	-9	-12	88	-40	-12	-4	-2	1
Zone 5	-96	27	-58	0	91	6	0	-3	-12	9
Zone 6	-67	-23	-64	-45	65	-33	-8	-4	-24	-4
Zone 7	-67	-30	-55	-38	63	-36	-25	-2	-18	-19
Zone 8	-78	8	-35	-11	68	-13	2	-4	-4	0
Scenario A2_ALU										
Zone 1	-100	-23			89	-56	-9			1
Zone 2	-100	-26			58	-75	13			34

Focus area	Biomass of capture fisheries						Biomass of OAAs			
	White fish	Grey and generalist fish	Black fish	Marine and other fish	Non-native	Overall fish biomass	Aquatic inver-tebrates	Amphi-bians	Reptiles	Overall OAA biomass
Zone 3	-92	25	-28	-27	98	-65	-15	-11	-11	-13
Zone 4	-100	-14	-11	-12	93	-41	-12	-8	-9	0
Zone 5	-98	28	-59	0	95	5	-1	-7	-16	7
Zone 6	-72	-26	-69	-45	75	-36	-12	-12	-33	-9
Zone 7	-71	-27	-53	-45	72	-34	-8	-18	-27	-13
Zone 8	-79	8	-30	-26	73	-14	1	-12	-12	-4
Scenario C2_2040Wet										
Zone 1	-100	-24			86	-53	-7			2
Zone 2	-100	-26			57	-74	13			34
Zone 3	-92	27	-20	-27	94	-64	-12	-6	-2	-9
Zone 4	-100	-14	-9	-12	89	-40	-12	-4	-10	0
Zone 5	-96	25	-57	0	92	5	-1	-4	-19	7
Zone 6	-67	-27	-69	-44	69	-35	-13	-9	-29	-9
Zone 7	-59	-22	-43	-36	67	-27	-6	-11	-14	-8
Zone 8	-60	13	-12	-25	50	-9	1	-1	4	1
Scenario C3_2040Dry										
Zone 1	-100	-22			89	-57	-10			-1
Zone 2	-100	-26			58	-79	13			34
Zone 3	-95	12	-56	-27	105	-70	-31	-11	-68	-35
Zone 4	-100	-14	-11	-12	94	-42	-12	-4	-9	0
Zone 5	-100	24	-60	0	102	0	-2	-5	-28	4
Zone 6	-85	-34	-76	-42	94	-43	-11	-16	-69	-21
Zone 7	-96	-45	-98	-34	89	-55	-57	-28	-82	-54
Zone 8	-90	2	-47	-25	85	-19	0	-16	-28	-7
Scenario I1_noIRR										
Zone 1	-100	-23			89	-56	-9			1
Zone 2	-100	-26			57	-73	13			34
Zone 3	-91	23	-26	-27	92	-64	-15	-8	-7	-12
Zone 4	-99	-13	-9	-12	89	-39	-13	-5	-4	0
Zone 5	-87	34	-44	0	75	12	5	-2	-6	14
Zone 6	-71	-28	-71	-35	76	-36	-4	-13	-31	-3
Zone 7	-67	-24	-48	-34	73	-30	-7	-10	-18	-9
Zone 8	-77	8	-28	-23	70	-13	2	-7	-6	-1
Scenario I2_IRR										
Zone 1	-100	-23			89	-56	-9			1
Zone 2	-100	-26			58	-75	13			34
Zone 3	-92	26	-26	-27	95	-65	-15	-10	-7	-12
Zone 4	-100	-13	-10	-12	91	-41	-12	-6	-5	0
Zone 5	-98	28	-58	0	94	5	-1	-6	-14	8
Zone 6	-74	-29	-72	-37	80	-37	-9	-14	-35	-8
Zone 7	-71	-26	-50	-35	76	-32	-9	-12	-20	-12
Zone 8	-80	9	-29	-24	73	-13	1	-8	-8	-2

Focus area	Biomass of capture fisheries						Biomass of OAAs			
	White fish	Grey and generalist fish	Black fish	Marine and other fish	Non-native	Overall fish biomass	Aquatic inver-tebrates	Amphi-bians	Reptiles	Overall OAA biomass
Scenario F1_noFPI										
Zone 1	-100	-23			89	-56	-9			1
Zone 2	-100	-26			58	-75	13			34
Zone 3	-92	28	-19	-27	96	-65	-11	-8	-1	-9
Zone 4	-100	-13	-10	-12	90	-41	-12	-6	-5	0
Zone 5	-95	26	-58	0	92	6	0	-4	-23	7
Zone 6	-61	-16	-56	-40	57	-27	1	-8	-18	2
Zone 7	-59	-27	-50	-40	56	-32	-7	-12	-21	-10
Zone 8	-74	6	-28	-25	69	-13	1	-6	-5	-1
Scenario F2_FPI										
Zone 1	-100	-23			89	-56	-9			1
Zone 2	-100	-26			58	-75	13			34
Zone 3	-92	24	-29	-27	97	-66	-16	-9	-9	-13
Zone 4	-100	-13	-10	-12	90	-41	-12	-6	-5	0
Zone 5	-98	27	-59	0	94	5	0	-5	-20	7
Zone 6	-77	-29	-72	-45	81	-38	-8	-7	-23	-5
Zone 7	-68	-16	-39	-43	77	-25	0	-8	-8	-3
Zone 8	-89	-2	-53	-24	87	-23	1	-21	-27	-7
Scenario F3_FPI										
Zone 1	-100	-23			89	-56	-9			1
Zone 2	-100	-26			58	-75	13			34
Zone 3	-92	23	-30	-27	97	-66	-16	-9	-11	-13
Zone 4	-100	-13	-10	-12	90	-41	-12	-6	-5	0
Zone 5	-96	26	-59	0	93	5	0	-5	-20	7
Zone 6	-63	-19	-58	-43	59	-29	-7	-6	7	2
Zone 7	-53	-16	-37	-42	58	-23	3	-7	-8	0
Zone 8	-83	1	-42	-25	78	-17	1	-11	-11	-3
Scenario H1a_noHPP										
Zone 1	-14	-2			13	-5	-2			-2
Zone 2	-17	3			19	-9	-2			-1
Zone 3	-21	3	-6	-1	11	-13	-3	-6	-5	-4
Zone 4	-15	-4	-5	-1	15	-3	-5	-8	5	-4
Zone 5	-12	10	4	0	11	4	-4	-7	5	-3
Zone 6	-8	1	1	3	5	-2	-7	-4	-2	-6
Zone 7	-8	-5	-8	-8	5	-6	-1	-8	-5	-3
Zone 8	3	20	22	8	-3	10	6	-1	5	4
Scenario H1b_nomainHPP										
Zone 1	-39	-5			36	-16	-23			-23
Zone 2	-47	5			46	-25	0			0
Zone 3	-56	6	-31	-9	25	-37	-10	-9	-23	-12
Zone 4	-32	-11	-39	-4	27	-16	-14	-10	-26	-15
Zone 5	-22	-6	-22	0	14	-7	0	-8	-9	-3
Zone 6	-31	-16	-35	-20	33	-18	-4	-5	-17	-4

Focus area	Biomass of capture fisheries						Biomass of OAAs			
	White fish	Grey and generalist fish	Black fish	Marine and other fish	Non-native	Overall fish biomass	Aquatic inver-tebrates	Amphi-bians	Reptiles	Overall OAA biomass
Zone 7	-33	-23	-37	-26	33	-24	-9	-12	-17	-11
Zone 8	-29	8	-3	-4	22	-2	5	-8	-4	1
Scenario H3_HPP										
Zone 1	-100	-23			89	-56	-9			1
Zone 2	-100	-26			57	-72	13			34
Zone 3	-91	24	-24	-27	92	-64	-15	-8	-5	-12
Zone 4	-98	-10	-3	-12	85	-38	-12	-4	-4	1
Zone 5	-94	29	-51	0	86	8	-2	-3	-13	8
Zone 6	-65	-20	-57	-38	62	-30	-8	-6	-19	-6
Zone 7	-59	-24	-44	-36	61	-29	-8	-12	-18	-10
Zone 8	-73	4	-31	-25	68	-16	2	-9	-8	-2

Appendix Table 22 Combined predicted change in aquatic biodiversity, viability of river bank gardens, river bank condition, risk of river-related disease, extent of indigenous wetland vegetation and bank erosion for the main development scenarios and sub-scenarios relative to 2007

Focus area	Aquatic biodiversity	Viability of river bank gardens	Extent of inundated forest	Extent of indigenous wetland vegetation	Extent of bank erosion (Extent sedimentation at FA7, FA8)	Risk of river-related diseases	River channel condition
Scenario 2020							
Zone 1	-36	-100			116		-26
Zone 2	-48	-62			43		-12
Zone 3	-28	-28	-19	-12	26	-3	-9
Zone 4	-40	-48			37	-1	-15
Zone 5	-37	-59	-6	-18	59	15	-18
Zone 6	-13	6	-9	-18	-6		-6
Zone 7	-11	-24	-12	-9	-24		-2
Zone 8	-20		-39	-21			-8
Scenario 2040							
Zone 1	-57	-100			117		-26
Zone 2	-85	-100			70		-19
Zone 3	-34	-30	-23	-14	28	-4	-10
Zone 4	-78	-73			37	-44	-16
Zone 5	-73	-80	-29	-54	80	-37	-28
Zone 6	-23	-46	-28	-29	46		-17
Zone 7	-20	-56	-14	-15	-56		-3
Zone 8	-35		-50	-31			-8

Focus area	Aquatic biodiversity	Viability of river bank gardens	Extent of inundated forest	Extent of indigenous wetland vegetation	Extent of bank erosion (Extent sedimentation at FA7, FA8)	Risk of river-related diseases	River channel condition
Scenario 2040CC							
Zone 1	-58	-100			117		-26
Zone 2	-85	-100			64		-19
Zone 3	-34	-24	-25	-12	21	-5	-9
Zone 4	-78	-77			40	-44	-16
Zone 5	-73	-82	-27	-53	82	-37	-28
Zone 6	-22	-56	-19	-27	56		-16
Zone 7	-21	-54	-11	-12	-54		-2
Zone 8	-19		2	-16			3
Scenario A1_noALU							
Zone 1	-57	-100			114		-25
Zone 2	-84	-100			62		-18
Zone 3	-32	-10	-23	-8	6	-5	-6
Zone 4	-77	-76			40	-45	-15
Zone 5	-71	-82	-26	-51	82	-37	-27
Zone 6	-19	-65	-13	-23	65		-15
Zone 7	-19	-58	-4	-8	-58		-1
Zone 8	-17		4	-17			4
Scenario A2_ALU							
Zone 1	-59	-100			119		-27
Zone 2	-85	-100			66		-20
Zone 3	-36	-21	-31	-17	19	-4	-10
Zone 4	-79	-77			41	-43	-17
Zone 5	-73	-82	-27	-54	82	-37	-29
Zone 6	-24	-62	-22	-29	62		-17
Zone 7	-23	-56	-12	-15	-56		-3
Zone 8	-21		0	-21			0
Scenario C2_2040Wet							
Zone 1	-58	-100			117		-26
Zone 2	-85	-100			78		-21
Zone 3	-35	-30	-31	-12	26	-4	-10
Zone 4	-79	-73			36	-44	-16
Zone 5	-73	-80	-27	-53	80	-38	-28
Zone 6	-21	-59	-19	-26	59		-17
Zone 7	-18	-56	-7	-12	-56		-2
Zone 8	-15		6	-11			-1
Scenario C3_2040Dry							
Zone 1	-59	-100			114		-21
Zone 2	-85	-100			58		-16
Zone 3	-52	-27	-82	-38	25	-4	-14
Zone 4	-77	-70			34	-43	-15
Zone 5	-75	-71	-33	-57	71	-39	-27
Zone 6	-28	-28	-49	-34	28		-17
Zone 7	-38	-72	-38	-25	-72		-5
Zone 8	-29		-48	-27			-7
Scenario I1_noIRR							
Zone 1	-58	-100			117		-26
Zone 2	-85	-100			67		-20

Focus area	Aquatic biodiversity	Viability of river bank gardens	Extent of inundated forest	Extent of indigenous wetland vegetation	Extent of bank erosion (Extent sedimentation at FA7, FA8)	Risk of river-related diseases	River channel condition
Zone 3	-39	-26	-45	-18	20	-5	-11
Zone 4	-78	-79			41	-45	-16
Zone 5	-70	-89	-26	-53	89	-34	-31
Zone 6	-23	-53	-17	-24	53		-15
Zone 7	-19	-55	-7	-12	-55		-2
Zone 8	-19		5	-18			3
Scenario I2_IRR							
Zone 1	-58	-100			117		-26
Zone 2	-84	-100			63		-19
Zone 3	-38	-21	-46	-18	19	-4	-10
Zone 4	-79	-77			40	-44	-16
Zone 5	-72	-81	-27	-53	81	-37	-27
Zone 6	-24	-62	-19	-26	62		-17
Zone 7	-21	-56	-9	-12	-56		-2
Zone 8	-20		2	-19			2
Scenario F1_noFPI							
Zone 1	-58	-100			117		-26
Zone 2	-85	-100			64		-19
Zone 3	-30	-24	-12	-5	21	-5	-8
Zone 4	-78	-77			40	-44	-16
Zone 5	-72	-82	-27	-52	82	-37	-28
Zone 6	-17	-56	-4	-20	56		-15
Zone 7	-19	-55	-10	-13	-55		-2
Zone 8	-19		-1	-18			2
Scenario F2_FPI							
Zone 1	-58	-100			117		-26
Zone 2	-85	-100			64		-19
Zone 3	-34	-24	-25	-12	21	-5	-9
Zone 4	-78	-77			40	-44	-16
Zone 5	-72	-79	-27	-53	79	-37	-28
Zone 6	-26	-40	-49	-35	40		-16
Zone 7	-17	-55	0	-9	-55		-1
Zone 8	-26		-7	-21			2
Scenario F3_FPI							
Zone 1	-58	-100			117		-26
Zone 2	-85	-100			64		-19
Zone 3	-39	-24	-46	-18	21	-5	-11
Zone 4	-78	-77			40	-44	-16
Zone 5	-72	-79	-27	-53	79	-37	-28
Zone 6	-18	-47	-9	-21	47		-14
Zone 7	-14	-54	5	-8	-54		-1
Zone 8	-22		-6	-20			3
Scenario H1a_noHPP							
Zone 1	-9	1			-3		-1
Zone 2	-15	-1			-1		-1
Zone 3	-16	-2	-34	-14	1	-1	-3
Zone 4	-22	2			3	1	-2
Zone 5	-9	-7	-1	2	7	-8	0

Focus area	Aquatic biodiversity	Viability of river bank gardens	Extent of inundated forest	Extent of indigenous wetland vegetation	Extent of bank erosion (Extent sedimentation at FA7, FA8)	Risk of river-related diseases	River channel condition
Zone 6	-6	-15	-13	-7	15		-4
Zone 7	-4	9	0	0	9		-1
Zone 8	3		-6	1			1
Scenario H1b_nomainHPP							
Zone 1	-30	-63			63		-19
Zone 2	-34	-39			28		-10
Zone 3	-31	-19	-47	-18	15	-3	-10
Zone 4	-47	-46			36	0	-16
Zone 5	-23	-47	-3	0	47	20	-18
Zone 6	-14	-4	-19	-21	4		-7
Zone 7	-14	-31	-8	-9	-31		-2
Zone 8	-6		-2	-9			2
Scenario H3_HPP							
Zone 1	-58	-100			116		-26
Zone 2	-85	-100			68		-20
Zone 3	-39	-26	-43	-23	21	-5	-10
Zone 4	-78	-83			46	-44	-16
Zone 5	-70	-84	-27	-50	84	-40	-26
Zone 6	-20	-44	-18	-25	44		-14
Zone 7	-18	-51	-7	-11	-51		-2
Zone 8	-19		-2	-18			0

Appendix E Ecosystem integrity for all scenarios per BioRA zone