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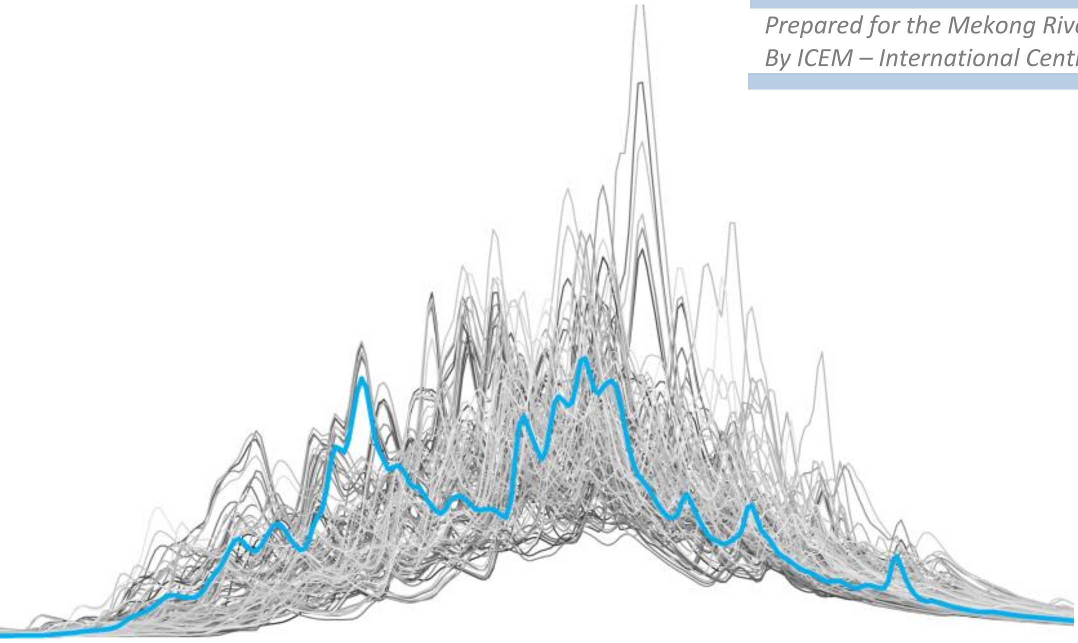
Guidance Manual

RAPID CLIMATE CHANGE ASSESSMENTS FOR WETLAND BIODIVERSITY IN THE LOWER MEKONG BASIN

CLIMATE CHANGE VULNERABILITY ASSESSMENTS FOR MEKONG WETLANDS

Prepared for the Mekong River Commission
By ICEM – International Centre for Environmental Management



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ABOUT THE MRC CLIMATE CHANGE GUIDANCE MANUALS

ICEM implemented the MRC "*Basin-wide Climate Change Impact and Vulnerability Assessment for the Wetlands of the Lower Mekong Basin for Adaptation Planning*" project (hereafter "the Wetlands Study") in 2012. The purpose of the project was to undertake a climate change impact and vulnerability assessment of the wetlands in the Mekong basin and provide recommendations and options for effective adaptation at the regional level. The conduct of eight case studies in the four Lower Mekong Basin countries was central to achieving this goal. Comprehensive climate change downscaling and hydrological modelling led to the assessment of climate change effects on each site. The project has established a solid scientific evidence base for wetlands adaptation and a rapid spatial assessment methodology for climate change vulnerability assessments of natural systems.

The assessment was undertaken at two spatial scales:

1. **Basin-wide:** Vulnerability analysis at this scale used downscaling and modelling techniques to quantify the threat to natural systems posed by climate change in terms of changes to basin hydrology and meteorology and superimpose these changes on best available information of wetland habitats, functions, conditions, communities and provisioning services in order to set priorities for regional and national adaptation.
2. **Case study sites:** The vulnerability of Mekong wetlands to climate change was assessed in detail at case-study sites. Guidelines for case study analysis of vulnerability were developed and distributed for national teams. These guidelines led the user through an analysis of the exposure and sensitivity of the case study wetland to climate threats and implications to the functioning of the wetland habitat, species, and local communities which rely on related ecosystem services.

The MRC wetland project has acted as a pilot and demonstration for the benefit of all MRC member countries. The project has built capacity for climate change vulnerability assessments, principally within the National Mekong Committees (NMCs), national agencies responsible for the natural resource management and those concerned with implementing climate change adaptation planning.

The MRC has recognised the value of the guidelines and methodologies developed during the project and wishes to consolidate the approach and learning in three areas through the development of a set of best-practice manuals and guidelines:

1. Methodology for rapid climate change vulnerability assessments for wetland biodiversity in the Lower Mekong Basin
2. Guidance for conducting case studies for assessing climate change vulnerability and adaptation planning for Mekong wetlands and other natural systems
3. Climate change downscaling and hydrological modelling methods for natural system assessments

This document is the first of these manuals and has been designed to draw on the experience of the Study and provide guidance on climate change downscaling and hydrological modelling techniques and how to analyse and interpret the subsequent results.

This guidance is intended to be a reference resource aimed at teams conducting multi-disciplinary vulnerability assessments for Mekong wetlands and other natural systems. It is not a comprehensive manual which can be applied step-by-step for any climate change vulnerability assessments for natural systems

TABLE OF ABBREVIATIONS

AFWA	Association of Fish and Wildlife Agencies
DOSE	Degree of change of climate parameters
GARP	Genetic Algorithm for Rule-set Production
ICEM	International Centre for Environmental Management
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for the Conservation of Nature and Natural Resources
IWMI	International Water Management Institute
LEK	Local Ecological Knowledge
LMB	Lower Mekong Basin
MRB	Mekong River Basin
MRC	Mekong River Commission
NGO	Non-Government Organisation
NRC	National Research Council
PRA	Participatory Rural Appraisal
SEA START RC	South East Asia START Regional Centre
SPN	Sesan Protection Network
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
WWF	World Wide Fund for Nature

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1 INTRODUCTION

1.1 BACKGROUND

The purpose of this manual is to provide a means to assess climate change vulnerability for habitat and species found in wetlands of the Lower Mekong Basin. The results of the assessment should integrate into existing and future wetland management plans and help wetland managers prioritize habitat and species conservation interventions to maintain wetland ecosystem function. The results of the analysis will also identify gaps in wetland ecological knowledge and contribute to policy development regarding wetland use under future climate scenarios.

This methodology builds on the draft climate change vulnerability assessments methodology prepared and tested through the Basin-wide Climate Change Impact and Vulnerability Assessment for the Wetlands of the Lower Mekong Basin for Adaptation Planning Project implemented for the Mekong River Commission by ICEM in partnership with IUCN, World Fish and SEA START. The methodology draws on lessons learned from the Project's case studies and from a rapid review of the climate change vulnerability assessments literature. It was developed with involvement of technical experts from the region through their hands on experience using it in case studies and participation in technical review workshops.

The target users of this methodology are wetland managers and national and regional agency staff responsible for wetland conservation and wise use. Climate change is causing fundamental shifts in ecological systems and therefore the way natural resources are managed. Natural resources managers can no longer look to the past to guide their conservation and restoration goals. They must now anticipate a different and uncertain climatic future (Milly et al 2008).

The Project case studies confirmed that wetlands provide essential functions for the well being of Lower Mekong Basin communities. The most important function of wetlands and the biodiversity within them is the food and nutrition they provide - food security. Most residents of the Lower Mekong Basin are dependent to some degree on wetland resources for their livelihoods, especially when domestic crops and livestock fail due to drought or flood. Therefore wetland rehabilitation, maintenance and enhancement is an important local, national and regional development strategy. Commitment to wetlands conservation and management is expressed in legislation and regulations within each Lower Mekong Basin country (ICEM et al. 2011).

Already, climate change has had a profound effect on Lower Mekong Basin wetlands – i.e. its rivers, lakes, marshes, flooded forests and all other wet land types. That impact will intensify as the momentum of climate change increases and is expressed through dryer dry seasons, wetter wet seasons, stronger storms and sea-level rise. Wetland management practices that reduce the impacts of climate change on natural and man-made systems and enhances their adaptive capacity is essential if permanent losses are to be avoided. As a first step, the vulnerability of habitats and species that make up wetlands needs to be better understood.

Climate change vulnerability assessment is a new and inexact science. This is because the components to be evaluated (climate, habitats and species ecology) are very complex and the methods we use to model and assess them bring many uncertainties. For that reason, this assessment process needs to be as transparent as possible so that underlying assumptions, value judgments and experiences are well documented and sourced.

The concept of climate change **adaptation** refers to the actions taken in response to climate change, to reduce the adverse impacts or to take advantage of possible opportunities. There are two broad categories of climate change adaptation measures: reactive or anticipatory (Klein 2002).**Reactive adaptation** measures are implemented in response to climate change impacts. Communities have been 'adapting' to environmental (climate) change for centuries. Often this kind of adaptation is gradual over several generations, for example as communities slowly retreat from an expanding desert, but sometimes it has been tragically sudden, for example when a village has to relocate after a landslide. **Anticipatory adaptation** measures are undertaken before impacts are observed, to reduce exposure to future threats – and to enhance the adaptive capacity to them. Anticipatory adaptation can bring about a more orderly change reducing the social and financial costs.

The purpose of the MRC Wetlands and Climate Change Project was to anticipate climate change impact and vulnerability of wetlands in the Mekong Basin and provide recommendations for effective adaptation. Central to achieving this goal was the need to develop a solid scientific evidence base and rapid spatial assessment methodology for climate change vulnerability assessments of natural systems.

The Project has demonstrated the process and benefits of taking a geo-spatial approach to wetland vulnerability assessments, allowing for the transfer of scientific findings from site specific case studies to the sub-basin and basin level to influence planning and management decisions. A key output is a methodology and adaptation guidance for planners to 'up-scale' the climate change assessments and adaptation response in specific cases to other wetlands of the same type.

The assessment was undertaken at two spatial scales:

1. **Basin-wide:** The Mekong Basin comprises a diverse mix of terrestrial and aquatic systems, linking the high-altitude steppes of the Tibetan plateau to the freshwater and tidal floodplains of the Mekong Delta. Analysis at this scale focused on characterizing the wetlands into a discrete number of categories based on their hydro-meteorological, geomorphic, and ecological characteristics together with the socio-economic make-up of surrounding human communities. Then using IPCC SRES scenario A1b and internationally accepted downscaling and modeling techniques, the study quantified the threat posed by climate change in terms of changes to basin hydrology and meteorology.
2. **Case study sites:** the vulnerability of Mekong wetlands to climate change was assessed in greater detail at eight case study sites. For each case study, the team analyzed the exposure and sensitivity of wetland habitat and species to climate threats and its implications for ecosystem function and the communities which rely on them. In this way climate change vulnerability of the case study sites are expressed as biophysical and social phenomena and used to identify trends for wetlands with similar characteristics.

1.2 APPROACH TO REFINING THE VULNERABILITY ASSESSMENT METHOD

The vulnerability assessment methodology presented here is now in its third iteration. The first methodology was developed and tested by ICEM with other projects in the region (ICEM 2011). It was then was refined for wetland habitat and species by this projects earlier case study teams and an ICEM technical analysis (Bezuijen 2011).

This methodology also builds on the work and guidelines produced for the previous case studies (ICEM et al 2011). A rapid review was also made of existing climate change vulnerability assessments methods and guidelines and compared against the outputs of the case studies.

Additions and clarifications were made to this methodology at a workshop in Vientiane Lao in August 2012 with regional wetland species and climate change experts. At the workshop participants critiqued the revised method based on the findings from their case studies. Finally, components from various ICEM project documents produced to date were brought together to make this 'stand-alone' climate change vulnerability assessments manual.

The methodology presented here has two components.

1. The first is a rapid assessment that should be made in the field with wetland managers and community experts. It establishes a site level understanding of climate change, documents past extreme climate events and identifies coping mechanisms community use during and after these extreme climate events.

2. The second component is a more detailed study to anticipate specific wetland habitat and species response to the predicted climate change. The second component can build off of the first rapid assessment, but also can be done as a desk study relying on ecological and experts in different wetland taxa.

In both methods, practitioners will strive to be transparent in the means by which they make an assessment and present an estimate of confidence of their determination. Sections 2 and 3 of this manual describe our underlying assumptions of this methodology and on climate change impacts to wetland biodiversity and ecosystem function. Section 4 presents methodologies for: 1) Wetland village vulnerability assessments, 2) Species vulnerability assessments and 3) Habitat vulnerability assessments.

2 ASSUMPTIONS OF THIS CLIMATE CHANGE VULNERABILITY ASSESSMENT METHODOLOGY

2.1 UNCERTAINTY

Climate change vulnerability assessments draw their origins from other types of risk assessment. Risk assessment involves estimating the probability of an event occurring and the severity of the impacts or consequences of that event. While we can say with high certainty that climate change is occurring, it is difficult to assign a probability to the exact nature and the severity. Doing a robust climate change vulnerability assessment therefore requires an agreement on the underlying **assumptions** to be used and acknowledgement of the **degree of uncertainty** of the component variables (Glick 2009). For this wetland assessment, some of the uncertainties include; the future climate scenario prediction, identifying the levels of exposure the various wetland species and habitats will have to climate change, understanding the level of sensitivities a species or habitat will have to climate change, and understanding the adaptive capacity.

Climate change is not the only factor impacting wetlands in the Lower Mekong Basin. The harvesting of fish, invertebrates, plants, birds, mammals, amphibians and reptiles are increasing to meet local and regional demands. Increasingly invasive species and disease agents have made their way into Lower Mekong Basin wetland systems. Changing wetland hydrology due to irrigation and hydropower are also destabilizing ecosystems. Understanding the complex interrelations between, cultural, economic and biological drivers relays on a complex set of assumptions with varying levels of uncertainly. When putting these issues into context with climate change vulnerability, it is best to start with existing wetland management plans. Unlike rapid assessments, wetland management plans should have had extended expert and community input and should be vetted by peers and supervisory agencies. Through the wetland management plan development process, uncertainties associated with current and future pressures are better understood.

The following is a quick review of the nature of some of the uncertainties associated with climate change vulnerability assessments.

2.1.1 Assumptions about the accuracy of the projects climate model for 2050

The A1B emissions scenario was modeled to 2050 and downscaled for use in our wetland climate change vulnerability assessments. This scenario has been commonly used by other climate change vulnerability assessments. While we do not know all the uncertainty that went into this scenario and model, we can assume that the results have a high level of confidence given the high level of peer review (see Box 1). Obviously, as more data and better understanding become available on climate change, we may have to revisit our various vulnerability assessments used here.

Box 1. The A1B emissions scenario and the climate change model to 2050

The International Panel for Climate Change (IPCC) has identified 40 different scenarios for future greenhouse gas pollution, landuse and other climate change forces. This methodology uses the SRES emission scenario – A1b. This scenario describes a future with very rapid economic growth, increased social interactions, and reduction in regional difference in per capita income. It assumes the global population will peak in the middle of the 21st century and then decline. This scenario also assumes that society will take a middle path in adoption of alternative energy technology. While this scenario is commonly used by other climate change vulnerability assessments, A1b might not best represent the future climate given that current climate change on the planet is currently trending above the high scenario (SC Amer 2007).

There are about 25 IPCC approved computer models for predicting climate change under the various emission scenarios. Before the IPCC allows a model to run into the future, the computer has to first correctly model climate patterns from 1800 to 2000 (Glick and Stein 2011). But not all models work equally across the entire planet. In choosing which emission scenario model to use, it is recommended that: If there is general agreement between models for a given emission scenario - one should use an average of the scenarios. If there is poor agreement- then it is better to make two vulnerability assessments, one using the 'high emission scenarios and one using the low emission scenario. (Tebaldi and Knutti 2001, Glick and Stein 2011)

Six computer models were averaged for LowerMekongBasin 2050 climate (ICEM et al 2012). All are well-established models that have been peer-reviewed. Four of the six models have participated in the Coupled Model Intercomparison Project (http://cmip-pcmdi.llnl.gov/) that adds higher level of peer review.

In comparing the A1FI (fossil fuel intensive emission scenario) and the A1B (balance emission scenario) for the Lower Mekong Basin region- The Climate Wizard computer model available on the WWW shows there is little difference (http://www.climatewizard.org/)

2.1.2 *Assumptions about how climate change affects biodiversity*

A lot has been written about how species or habitats respond to ecological change, in response to both climate and non-climate drivers. However there is still considerable uncertainty around making predictions about how they will respond. This is because these relationships are very complex. Some species and habitats are better studied than others and can offer some insight to the "adaptive capability" of the group; however ecologists warn about extrapolating between species in the same taxa, and that this should be done with great care. In short, there are just too many ecological factors and too many synergistic factors of climate change on existing threats to consider in any one prediction of climate change vulnerability to be entirely certain in our wetlands. Therefore we have to rely on the experience of experts close to the field of study, and to document the assumptions used at the time of the assessment. If more is learned in the future than we will have to modify our predictions. For this study we document our basic assumptions about how climate change affects wetland biodiversity. These assumptions are found in Section 3.2. We have also documented our assumptions about the combined effects of climate change on existing wetland use pressures in Section 3.3.

2.2 GUIDANCE FOR CLIMATE CHANGE VULNERABILITY ASSESSMENTS.

Many good guidelines for methodologies are available in the literature e.g. Glick, P, B.A. Stein, and N.A. Edelson,. 2011; Glick, et al. 2009; Groves, et al. 2010; Heller, and Zavaleta. 2009; Lawler, 2009; Mawdsley,et al. 2009; National Research Council (NRC). 2010; U.S. Climate Change Science Program. 2008; West et al 2009; Williams, et al. 2007; Association of Fish and Wildlife Agencies. 2009. The steps listed in Table 1 are common to many of these guidelines.

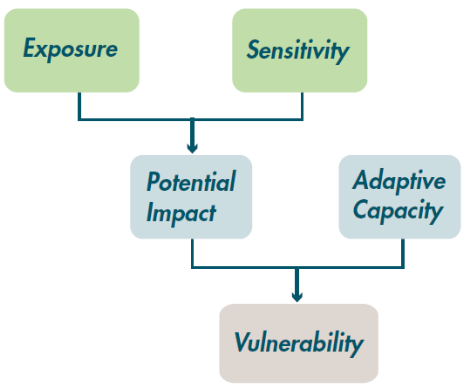
Table 1. Climate change vulnerability assessment implementation steps (from Glick et al 2011)

Steps
1. Determine objectives and scope
Identify the audience, and their requirements
Engage key stakeholders
Establish and agree on goals and objectives
Identify suitable assessment targets (i.e. species or habitats)
Determine appropriate spatial and temporal scales
Select assessment approach based on targets and available resources
2. Gather relevant data and expertise
Review existing literature on assessment targets and their sensitivity to climate impacts
Contact subject experts on target species or habitats
Obtain or develop climatic projections focusing on suitable spatial and temporal scales
Obtain or develop ecological response models
3. Assess components of vulnerability - See Section 4
Evaluate climate sensitivity of assessment targets
Determine likely exposure of targets to climatic/ecological change
Consider adaptive capacity of targets that can moderate potential impact
Estimate overall vulnerability of targets
Document level of confidence or uncertainty in assessments
4. Apply assessment in adaptation planning
Explore why specific targets are vulnerable to inform possible adaptation responses
Consider how targets might fare under various management and climatic scenarios
Share assessment results with stakeholders and decision-makers
Use results to advance development of adaptation strategies and Management Plans

2.3 VULNERABILITY ASSESSMENTS CONCEPTS

The vulnerability framework used here builds off of the general framework promoted by the IPCC 2001, 2007 in which vulnerability is based on an evaluation of *exposure, sensitivity* and *adaptability* to climate change. This is illustrated in Figure 1.

Figure 1. The relationship between Exposure, Sensitivity and Adaptive Capacity. IPCC 2001, 2007



The **exposure** of wetlands to climate change constitutes the degree to which a particular component of a wetland experiences one or more climate driven threats. These threats include changes to: temperature (max, min, average); rainfall (daily, cumulative); evaporation from open water bodies; evapotransipiration from land; runoff; river flow, (water levels and hydrographs); flood depths and duration; and more frequent extreme events (like droughts, typhoons, storm surge, and king tides); and sea-level rise. Exposure is made up of both the frequency and likelihood of experiencing a threat, as well as the directness of that threat.

The **sensitivity** of a species or habitat to climate change reflects the degree to which it is sensitive or likely to be affected by the threat. Sensitivity is innate/ inherent characteristics of a species or habitat.

The **potential impact** is the combined effect of exposure and sensitivity of a wetland component to a specific climate change threat. In this study, wherever possible, Impacts should be expressed as trends indicating the **direction and size of the trend**. The impact can be positive or negative, some habitats or species may benefit from changes in climate. This could be measured as the change in size of a habitat.

The **adaptive capacity** of the wetland species or habitat is its ability to persist or change to the new climatic conditions. A habitat that is constrained by physical barriers or human activities may not have room to "move" to adjacent land, e.g. mangrove habitats may move up the slope of the coast to occupy areas where the tidal range is still favorable, but may not be able to do this if there is a sea wall or aquaculture pond dyke preventing it. Species that have a very specific requirement for food or breeding sites will tend to have a lower adaptive capacity. Some other characteristics that could be considered under adaptive capacity include: breeding season, food source (generalists, or specialists), population size, seasonal migration, habitat preference.

Vulnerability is a measure of the combination of Exposure, Sensitivity and Adaptive Capacity. It is in essence a probability that the species or habitat will survive under the new climate conditions. The significance of vulnerability for wetland adaptation is that it allows for priorities focusing on the more vulnerable wetland components. Vulnerability assessments include not only climate change stresses but also current stresses.

2.4 ECOLOGICAL RESPONSE MODELS

The methodology to assess the sensitivity and adaptability of species, and habitats to climate change is called an ecological response models. Ecological response models are the central part of a vulnerability assessment. There are many kinds of response models. Some involve computer simulations and others just thought experiments. <u>All</u> models however are based on 'expert' opinions and require considerable cooperation between ecologists, resource managers, computer programmers, GIS experts, and climatologists. This cooperation is needed so that the most useful information can be obtained. This cooperation is especially important if the models are to be downscaled from global to regional to individual wetlands for climate change predictions or upscaled from the wetland to the region to a global scale for adaptive response.

Ecological response models are simplifications of the real situation, so that means they will never be totally accurate. There is a short sentence that summarizes the situation; "all models are bad, but some may be useful" (Box and Draper 1987). Ecological response models at their best can help identify potential 'tipping points' where ecosystem services might collapse and then cause great harm or disruption to society. Knowing this kind of information can be used by management to prioritize action and make response plans (Bradley and Smith 2004.

In recent years, with increase computing and GIS capabilities, many new ecological response models have been developed. Computer simulation models can produce very powerful visual depictions of change and can be used to test the sensitivity of various inputs to an ecosystem, assuming the models reflect reality.

A rapid review of the literature was made as part of this study and the results are listed in Annex 1. The decision on what model/ models to use depends on the time, money, and technical expertise that is available. It also depends on the species, habitats, and ecosystems of concern, the type of data available, the types of questions being asked, and the particular end-users' needs. As mentioned earlier, for this study six models were averaged for determining the 2050 climate predictions and the Expert system model will be used to determine habitat and species response to climate change.

An important part of model selection is to clearly identify the targets of interest. Targets are measurable parts of the environment where assessments are made. All response modeling should start with a conceptual model. Conceptual models are diagrams and descriptions of key processes (or causal chains) related to the specific species or habitats and identify the conservation goal. They also identify interventions that could be put into place to reduce stresses on the system. Management plans that use the "adaptive management style" use this type of model.

As mentioned earlier, all ecological response models use the Expert model to start with. However some ecological response models only use experts because there is a short time frame, if there is insufficient quantitative data for a computer simulation or as the first model before computer simulations are made. In these cases, the opinions of the taxa experts are used to determine species and habitat response to climate change through literature reviews, workshops and correspondence. But as mentioned earlier, ecosystem response to climate change is very complex and there will be uncertainty. It is therefore important to assess the uncertainly of the results. This assessment is often characterized as probabilities. The IPCC has described Levels of Confidence for uncertainty in the context of climate change (Table 2) (IPCC 2007).

Table 2. Degree of Confidence in Being Correct

Confidence	Probabilityof being correct
Very high confidence	At least 9 out of 10 chance
High confidence	About 8 out of 10 chance
Medium confidence	About 5 out of 10 chance
Low confidence	About 2 out of 10 chance
Very low confidence	Less than 1 out of 10 chance

Chances of being correct, are directly correlated with how many experts have had input on the opinion or have reviewed the findings. Therefore, where ever possible, it is important to include documentation of the evidence and criteria used by the experts to support their decisions. This includes such decisions as the relationships between climate change and species/ habitat response and the cumulative effects of climate change on existing stressors to natural resources.

2.4.1 *Local Ecological Knowledge*

Local Ecological Knowledge (LEK) is a subset of expert method. Much has been written LEK (e.g. Brook and McLachlan 2005, Gilchrist and Mallory 2007). Tapping LEK is an important first step, even when other "expert knowledge is available. This provides an important way to ground-truth the validity of other expert opinions. But LEK also has to be evaluated for its confidence just like any other expert knowledge. Techniques to do this include; triangulation of responses - that is if three people say the same thing it has higher confidence, or the statements can be substantiated by direct observation during the course of the visit (Baird 2006)

Some types of questions are more appropriate for LEK than others. Questions that are normally appropriate for LEK include local species knowledge (i.e. which species are found in what habitat and in what season; local animal food preference, and breeding periods). LEK can help identify which particular climate variables are likely to be the most important for the ecosystem being evaluated (e.g. timing for first rainfall, minimum annual temperatures, etc). LEK is important if there are ethnographic considerations such as cultural and spiritual information. LEK is also essential to understand current land-use and stresses on a species or habitat. This should be used to identify conflicting land uses, local government policy and regulation.

Caution is needed when extrapolating from LEK to the broader ecological picture however. Generally speaking LEK is less familiar with regional knowledge, such as migration routes, off season habitats and locations, and animal behavior when not in the local area. Sometimes quantitative data on abundance and precise dates of certain events are not reliable. Therefore there is the need for greater ecological expertise to be brought in for climate change vulnerability assessments.

2.5 LESSONS LEARNED FROM THE CASE STUDIES

The Basin-wide Climate Change Impact and Vulnerability Assessment for the Wetlands of the Lower Mekong Basin for Adaptation Planning used a draft biodiversity vulnerability assessments methodology for eight case studies in the early part of this Project. The biological and socio-economic outputs from the case studies will no doubt be useful for managers and policy makers in the management of wetlands in the Lower Mekong Basin. The following is a summary of the lessons learned from the previous methodology. A matrix of responses is included in Annex 3

A summary of the lessons learned from four case studies.

- **The Global Circulation Models**: discussing the climate 40 years from now obviously raises a lot of questions about how temperature and precipitation changes were determined. This is true in workshops, with professionals, as well as with local resource managers. Users should know that there is a range of scenarios.
- **Habitat information lacking**-: There is limited information and understanding about climate change and its impacts on the natural environment, wetland ecosystems in particular. Few experts are comfortable extrapolating existing understanding of wetlands into new climate scenarios.
- **More taxa experts**: because of the lack of habitat and species information, a larger team is recommended to address the many aspects of a wetland.
- **This methodology**: because this methodology is so new, an iterative process is needed to teach it, use it, and modify it. The desire is to be able to provide more quantitative outputs.
- **Management issue**: in some cases, the mandate for wetland management is not clear, and some participants in the case study did not feel comfortable discussing biodiversity conservation issues.
- **More comparative data needed**: comparison between case study sites, and other wetlands currently under different climate regimes or different management regimes is not available. This would help bring more understanding to climate change impacts.
- **Species selected**: species selection should also include keystone and economically important species not just endangered species.
- **More time is need**: this was a complicated case study and even rapid assessments need time to study the literature and talk to the appropriate experts.

3 ASSUMPTIONS ABOUT CLIMATE CHANGE AND WETLANDS IN THE LMB

3.1 ANTICIPATED CLIMATE CHANGE IN THE LOWERMEKONG BASIN

Climate change trends in Southeast Asia under various IPCC emissions scenarios in general, show increases in temperature, decreases in rainfall, and sea-level rise. There will be increased frequency, duration and intensity of extreme weather events, such as droughts, storms, floods and typhoons, and heat waves (Cruz et al 2007).

Climate change modeling for the Lower Mekong Basin has been made for the period 2010– 2050 by TKK and SEA START (2009) and Hoanh et al. (2010), and up to 2100 for the Mekong Delta by Carew-Reid (2007) using the A1B emission scenario. Scenario A1b is a rapid economic growth model, where human population reaches 9 billion by 2050 and then gradually declines. It also assumes quick adaptation of new and efficient technologies using many energy sources and the coming together of regional economies. The A1B scenario has medium greenhouse gas emission and therefore produces less climate change than the A1FI scenario that is fossil fuel intensive; but more than the A1T scenario that uses more alternative energy (WMO 2012). The A1B emissions scenario is a commonly used for vulnerability assessments. (see case studies in Glick 2009)

Climate change predictions more specific to the Lower Mekong Basin, include the following (also cited by MRC 2010 for the 'State of Basin' report):

- **Temperature, annual precipitation and runoff will increase** across the basin, whereas dry season precipitation and runoff will vary across the basin. There will be an increase in the frequency, severity and duration of floods and droughts in all Mekong nations.
- A **basin-wide mean annual temperature increase** ranging from 0.4 to 1.2°C, with greater increases for colder catchments in the north of the basin. Not only will the basin become slightly warmer, but the duration of warm periods will extend much longer and cover much wider areas than currently. The number of days over 33°C is predicted to increase by 19-65 days/year in different parts of the basin (compared to a baseline from 1985-2000).
- A 5% (80 mm) **increase in mean annual precipitation**. Large differences will occur across the basin, with changes in wet-season precipitation ranging from +133 mm to -35 mm and changes in dry season precipitation from +54 to -29 mm. An increase in precipitation is predicted in northern and western parts of the basin and a decrease in southern parts including the Mekong Delta and central parts of Laos from Vientiane and southwest towards the border with Vietnam.
- A 30% **increase in dry-season flow** in the upper Mekong River and a 15% increase in wet-season flow in the upper Mekong River down to Phnom Penh (after which the increase is predicted to be smaller due to a lower increase in precipitation). The Mekong Delta will experience higher river flows (even though its rainfall may decrease) due to increased precipitation and flow upstream.
- An **increase in dry season water level** in the floodplains, due both to climate change and hydropower development (TKK and SEA START 2009).
- A **change in monthly mean discharge** of the Mekong River: mean discharges of August, September and October will increase noticeably for the next several decades and discharges of April and May will decrease significantly. Other months show relatively small changes (TKK and SEA START 2009).
- **Increased flow in the Mekong River** will increase water availability in the dry season and increase the risk of flooding in the wet season. Low-lying areas downstream of Kratie to the Mekong Delta, including the Tonle Sap Great Lake area, are particularly at risk of flooding.

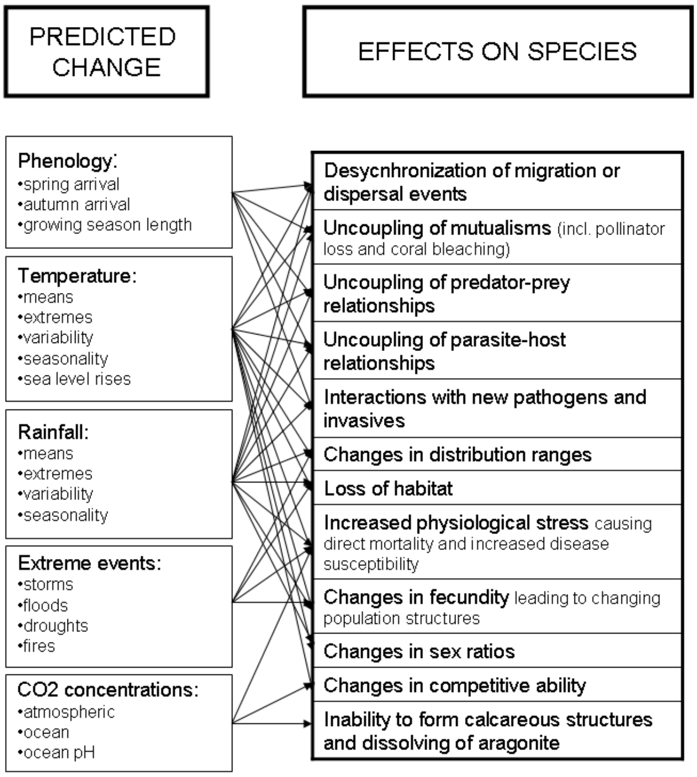
Area of flooding may increase by 9% and area where flooding depth is high (>2 m) may increase by almost 40%, meaning flooding intensity will increase.

- In the Mekong Delta, 30% of the delta may be inundated by 2100 by a sea-level rise of 1 m (Carew-Reid 2007).
- MRC (2009a,b) and MRC and ICEM (2009) provide additional information for each Mekong nation:
  - Cambodia – predicted increase in mean annual temperature of 1.4 - 4.3°C by 2100 and increase in mean annual rainfall, with most increase in wet season;
  - Laos – increase in mean annual temperature, increase in the severity, duration and frequency of floods, especially in plains adjacent to the Mekong River;
  - Thailand – increase in mean annual temperature, decrease in length of cold season, higher rainfall intensity in cold season, water shortages in some river basins;
  - Vietnam – increase in mean annual temperature of 2.5° C by 2070, increases in mean annual minima-maxima temperatures, the highlands become warmer, and there are changes in seasonal rainfall patterns.
- Further climate modeling details for the Lower Mekong Basin are in MRC and ICEM (2009), TKK and SEA START (2009), Hoanh et al. (2010), Kingston et al. (2010) and MRC (2010).
- Additional climate data for the basin is provided by He and Zhang (2005), who analyzed 41 years (1960-2000) of temperature and rainfall data from 19 recording stations along the Mekong River in China (where it is called the Lancang River). This includes three weather stations along the northern borders of Laos and Thailand. At these three stations, over 41 years the ambient temperature and Drought Index increased and precipitation decreased. Overall, the far north of the Lower Mekong Basin experienced more severe temperature increase, precipitation decrease and drought than the upper reaches in Yunan and Tibet.

3.2 ANTICIPATED IMPACTS TO WETLAND BIODIVERSITY IN THE LOWERMEKONG BASIN

In 2008, IUCN Species Programme (Foden et al) produced a paper on species susceptibility to climate change in which the effects on different species could be associated with different predicted changes. A linkage diagram from that report is presented in Figure 2 and demonstrated the complex relationship between climatic factors and biotic response. This section identifies some of the impacts that we can expect to see on wetland biodiversity in the Lower Mekong Basin.

Figure 2. Summary of some of the predicted aspects of climate change and examples of the effects that these are likely to have on species



3.2.1 *Wetland flora and vegetation*

The Lower Mekong Basin supports endemic and restricted-range wetland vegetation communities. These include freshwater swamp forests at Tonle Sap Great Lake and Mekong Delta (Rundel 1999), mangroves in the Mekong Delta (Rundel 1999) and aquatic vegetation zones and riverine forest along the Mekong River mainstream in Cambodia, Laos and Thailand (e.g. Maxwell 2001, 2009). Knowledge of the basin's flora is rudimentary and new species are still being discovered (Maxwell 2009). Potential impacts of climate change include the following.

- **Rising temperatures and reduced air and soil moisture** may cause aquatic and semi-aquatic species to be exposed for longer periods and eventually die. If seeds of such species are short-lived, most will die and little or no recruitment will occur the following wet season. These changes may cause die-back in at least four of six wetland vegetation communities along the Mekong mainstream in northeastern Cambodia and southern Laos: 'aquatic', 'rapids', 'kai kum' and '*Acacia-Anogeissus*' (cf. Maxwell 2009). All have restricted distributions in the basin.
- **Higher wet-season flows and extended inundation** may promote the recruitment of some tree and shrub species of the 'flooded forests' of northeastern Cambodia and southern Laos. Some species may move northward with climate change and in the absence of other disturbance might colonise sections of Mekong mainstream further north in Laos and Thailand. Given the increasing development along the Mekong such opportunities will be limited. Any potential gains may also be balanced by over-inundation, which might result in large-scale die-off. Extended flooding might cause the loss of a newly discovered *Amorphophallus* species known only from a single locality on one island in the Mekong River in northeastern Cambodia (Maxwell 2009). Long-lived tree species in riverine forests along the

Mekong River and lowland tributaries may not show declines for many years, even though recruitment may have stopped. Species with long-lived seeds may have some resilience to altered flood levels, as seeds will lie dormant until suitable flood conditions occur for germination.

- Critically endangered floodplain grassland communities in Cambodia and Vietnam may be reduced and eventually lost due to combined impacts of higher temperatures and elevated levels of carbon dioxide causing drier dry seasons, fires and colonisation by woody shrubs.
- In the Mekong Delta, **sea-level rise** will cause the landward retreat of mangrove communities and displacement of freshwater swamp (Melaleuca) communities. Not all mangroves will have the conditions to retreat and many will be inundated and die. It is unlikely that entire communities will successfully retreat and species composition will change. Reduced sediment deposition from upstream will reduce upstream mangrove colonisation. There will probably be a decline in species diversity and richness and the development of simpler, less species-rich mangrove communities which are most tolerant to saltwater. Freshwater communities will disappear from all areas of the delta which will be permanently inundated by seawater. Upstream retreat for all communities will be restricted by the limited availability of upstream land for colonisation: most land in the delta is already cultivated. As the sea rises and land resources become more scarce, human communities will clear remaining areas. Increasing shortage of arable land will create conflicts with protected areas, as human needs will force government to release protected area lands for food production and resettlement.
- At least two key biodiversity areas in the Mekong Delta will be completely inundated, U Minh Thuong National Park and Bac Lieu Nature Reserve (Carew-Reid 2007). U Minh Thuong protected area is one of the three highest priority sites for wetland conservation in the Mekong Delta. Flooding will result in loss of some of the largest remaining freshwater swamp in the delta and possible local extirpation of some delta flora species.
- **Rising carbon dioxide** levels may lower the pH of inland freshwater and coastal wetlands. In the Songkram River basin and other sub-basins, pH is neutral or slightly alkaline in the dry season (Satrawaha et al. 2009), and the effects of increasing acidity are unknown.
- **Weed invasion**. Some highly invasive plant species such as *Mimosa pigra* are already well-established in parts of the Mekong floodplains (Peh 2010). Climate change could facilitate spread and create large areas of exotic monoculture; this is already occurring in parts of the basin e.g. the Champhone River system in Laos (MRB pers. obs.). Warmer waters will facilitate spread of aquatic invasive plants e.g. *Eichhornia crassipes*, already abundant in the Lower Mekong Basin. Warmer waters may also result in toxic algal blooms.

3.2.2 Aquatic invertebrates

The Mekong River contains the largest living endemic freshwater gastropod fauna in the world, with over 120 endemic species (Hoagland and Davis 1979; Davis 1982; Bogan 1993). Many of these are located in a section of the Mekong mainstream between Khemmarat, Thailand and Kratie, Cambodia (Davis 1982). At least one endemic species is restricted to the Songkram River basin, another species is restricted to the Mun River basin, others are endemic to a few tributaries flowing into the Nam Ngum reservoir in Laos, and others to the Khone Falls (Hoagland and Davis 1979). The basin also supports endemic crabs and prawns (e.g. Kottelat 2009) and probably also endemic dragonflies, mayflies and other invertebrates. Invertebrate richness and diversity in the basin is poorly known and inventories are far from complete. New species are continually being documented. Potential impacts of climate change include the following.

- Small increases in water temperature may result in widespread die-off of eggs, larvae or adults of aquatic invertebrates (in temperate regions of southern Australia an increase of 1-2 ^{o}C is predicted to cause local extinctions of marine invertebrates; Hughes 2003 and references therein). Large-scale declines could cause local extinction given that some mollusc species are specialized and restricted to very small areas. Many invertebrates live in narrow thermal limits and rising temperatures could cause loss of molluscs, dragonflies, mayflies and other aquatic invertebrates.

- One group of clams in the basin, the Order Unionoida, possesses a unique life history trait, an obligate parasitic stage on fish. Larvae attach to the gills of a particular host fish, reside there for a short period, metamorphose and then drop from the gill of the fish to begin life as a juvenile clam (Bogan 1993). These molluscs are especially sensitive to disturbances in wetlands because they are threatened not only by direct impacts to them but also by impacts to their host fish populations. Without the host fish the species is unable to complete its reproductive cycle and faces extinction (Bogan 1993). These molluscs are long-lived (30-130 years) and impacts to a population may not be immediately detectable (Bogan 1993).
- Some endemic molluscs in the basin are opportunistic species which require dynamic and complex microhabitats and periods of flood then exposure to survive (Davis 1982). Increased dry-season flows in the Mekong mainstream may cause the decline or extinction of species which are not adapted to continual inundation.
- Aquatic invertebrates with a dual life stage e.g. dragonflies and mayflies will be impacted by changes in water and on land. Higher wet-season flows may wash away eggs and larvae and drier dry seasons may dessicate eggs. Fires will cause mortality and destroy habitats. It is possible that resilient species may adapt or shift northward or upward and climate change may cause an increase in range and abundance of some species. Whether or not this constitutes a positive impact of climate change is unknown (e.g. the increases may be of invertebrate parasites of fish or pest species which impact aquaculture). It cannot be assumed that most species will respond simply by moving northward or to higher elevations, because many species are closely tied to the microclimate of their habitats and it is unlikely that these habitats will be able to shift completely, due to variable adaptability of plant species and the opportunity they have to colonise new areas. 'Food plants' unable to adapt or retreat will decline, in which case the invertebrates dependent on them will also decline.
- In the Mekong Delta, altered salinity regimes will probably cause large changes in species distribution and productivity. The upstream range and biomass of euryhaline (wide salinity tolerance) species may increase, including those that depend upon brackish water environments to complete their life-cycles e.g. Giant River Prawn *Macrobrachium rosenbergii* (Halls 2009)[1]. Other species (e.g. other prawns, estuarine crabs, benthic worms) may also expand their upstream range. In contrast saltwater intrusion will cause a decline in freshwater species richness in the lower delta. It is unknown whether there are endemic freshwater mollusc species in the delta, although this seems possible on the basis of documented endemism further upstream (Davis 1982). Any endemic freshwater invertebrate species in the delta will be at risk of extinction due to sea-level rise. The potential for upstream retreat by these species is unknown.
- Elevated CO_2 levels may reduce insect fitness and reproduction. The combined effects of elevated CO_2 with rising temperature and altered rainfall could impact many species in the basin.
- Invertebrates form the basis of many food chains, and a decline in biomass and/or change in species composition could reduce seasonal food availability for amphibians, reptiles, fish, birds and mammals. Given the importance of invertebrates as a food source for so many

[1]*Macrobrachium rosenbergii*, recently valid as *M. dacqueti*; as per reference: Wowor & Ng, (2007) The giant freshwater prawn of the *Macrobrachium rosenbergii* species group (Crustacea: Decapoda: Caridea: palaemonidae). Raffles Bull. Zoology 55(2): 321-336

species, even a small decline in invertebrate populations could cause large cascade effects to vertebrates.

3.2.3 Fish

The Lower Mekong Basin supports c.850 freshwater fish species, with a total estimate of c. 1,100 species if possible coastal or marine visitors are included (Hortle 2009). The basin has the most endemic species in the world (Baran et al. 2007 and references therein). The status, distribution and ecology of most species is virtually unknown. Most fish research in the basin has focused on a small number of migratory species of commercial importance; the huge biomass of these lowland species is the principle source of food for millions of people in the lower basin. These assemblages of migratory fish have received preliminary attention for climate change adaptation planning (e.g. Baran et al. 2008; Dugan et al. 2010; Johnston et al. 2010a,b). From a conservation perspective this planning approach is insufficient as it excludes the majority of species in the basin. Potential impacts of climate change include the following.

- Fish productivity and fish catch in the Lower Mekong Basin is strongly dependent on the extent, duration and timing of flooding, and access to productive floodplain and wetland habitats for feeding (MRC 2010 and references therein). Wetter wet seasons may benefit some wet-season migratory species through extended high flows and access to new feeding areas, and higher productivity of some species is predicted (Halls 2009). Conversely, lower and warmer dry season water levels may disrupt migration triggers for dry-season migratory species and may cause greater susceptibility to fishing pressure and disease and competition for limited food resources.
- Higher wet-season flows will scour riverbeds, displacing organic matter, bottom-feeding organisms, small fish fry and fish larvae attached to sand and rocks. Higher flows will also cause increased turbidity, which may disrupt triggers of fish migration or result in eggs and larvae being smothered in sediments. Lower water levels or the complete drying out of floodplain pools, may cause large-scale mortality of 'blackfish' (species which spend the dry season in floodplain water bodies). Floodplain habitats are often disconnected from the mainstream in the dry season and this, combined with overfishing, could cause loss of local populations.
- Warmer waters hold less oxygen and cause increased metabolic rate and food requirements in fish. This will cause metabolic stress to fish, especially in the dry season. This may reduce fish health, growth, reproductive success and survival. Rising temperatures may cause fish species along the Mekong River and lowland tributaries to shift northward or upward along tributaries to cooler waters.
- In the Mekong Delta, increasing upstream salinity will cause stenohaline (narrow salinity tolerance) species to be displaced further upstream, resulting in range contraction and loss of biomass of these fish from the delta. In contrast the upstream range and biomass of euryhaline (wide salinity tolerance) species may increase (Halls 2009). Changes in the salinity regime may impact the life-cycles of anadromous species (requiring access to fresh and marine water during their lifecycle) e.g. the catfish Pangasius krempfi, which conducts annual migrations along the MekongRiver between the South China Sea and southern Laos (Hogan et al. 2007).
- The cool montane headwaters of some Mekong tributaries along the borders between Laos and Vietnam hold endemic, restricted-range species, and new species are still being discovered (e.g. Phu et al. 2006; Kottelat 2009). In 2001, sub-basins of the Mekong River held at least 53 endemic species known only from individual tributaries (Kottelat 2001); since then further endemic species have been discovered. A single tributary in Laos, the Nam Ou River, supports at least five species which are known from no other drainage (Kottelat 2009). Most endemic species are from rapids and montane streams. Such species have little adaptive ability to cope with warmer waters and

cannot shift elsewhere to cooler waters. If physiological tolerance to rising temperatures is exceeded these species will probably become extinct.

- Rapids in the middle reaches of Mekong tributaries hold a specialized fauna of restricted-range fish, molluscs and other invertebrates. The combined impacts of dams or other water-based infrastructure together with climate change may lead to the disappearance of whole assemblages of aquatic species along river stretches.
- The impact of rising CO2 levels on freshwater and marine fish in the basin is unknown.

3.2.4 Amphibians and reptiles

There are no precise figures of species richness, endemism, or number of threatened species for amphibians and reptiles in the Lower Mekong Basin. The entire Indo-Burma Hotspot (including south China and regions of Indochina outside the Lower Mekong Basin) supports over 280 amphibian species (>150 endemic) and over 520 reptile species (>200 endemic) (CEPF 2007 and references therein): many of these species occur in the Lower Mekong Basin. Such figures are constantly outdated because of new species discoveries and ongoing taxonomic research, which is finding many 'new' species within existing species complexes (Stuart et al. 2006). MRC (2010: 81) lists 25 globally threatened amphibian and reptile species for the basin; this list contains significant errors (M.R. Bezuijen pers. obs.). Many frogs, large lizards and snakes are becoming scarce in the basin due to over-hunting. Potential impacts of climate change include the following.

- Predicted impacts of **rising temperatures** on Southeast Asian frog species include drying out of eggs laid in leaf litter and soil, increased stress and mortality of tadpoles from insufficient oxygen, increased susceptibility of eggs, tadpoles and adults to disease, increased competition for food as metabolic rates (and appetite) increase and starvation of weaker individuals (Bickford et al. 2010). Reduced and warmer stream flow in the uplands may impact species which require swift-flowing cool streams to breed in. Drier dry seasons may cause rapid drying of small water bodies causing high mortality of tadpoles and egg masses. Common and widespread lowland species may be highly impacted, because some are prolonged breeders and their life strategy is to breed over long periods of time, and their tadpoles require a longer hydroperiod to develop e.g. *Polypedates leucomystax* and *Microhyla heymonsi* (common lowland species which are widespread in the basin).
- **Heavier rainfall** may lead to greater mortality of frogs that breed in slow-flowing water, because eggs and tadpoles are not adapted to swift flows and will be washed away or damaged by stronger torrents. For amphibians and reptiles that lay their eggs on land, higher rainfall may flood nests and increase the risk of fungal growth on eggs.
- **Wetter wet seasons and drier dry seasons** may change the timing of frog choruses and dates of breeding/egg-laying of frogs, snakes, lizards and turtles. Many species time their breeding to occur with wet season abundance of prey and such changes may already be occurring. Rising air and water temperatures may indirectly affect amphibians and reptiles by changing the abundance of their prey and predators. Drier dry seasons will cause more individuals to stay closer to ponds and streams, which will increase pressures on food and space and increase competition and risk of disease exchange. As streams and pools dry out and become further apart (especially in the late dry season), individuals will be forced to travel further to reach water, making them weaker and more vulnerable to predators and disease. Drier dry seasons may cause species to move into higher elevations, bring with them disease (e.g. Chytrid fungus). Upland migration could also result in new and strong competition with the native species in the uplands and cause native upland species to disappear (T. Chan-Ard pers com).
- For reptiles, body condition, feeding rates, abundance and sex ratio is closely tied to wet- and dry-season levels of rainfall. For some snake species, the wet season is the time of highest fitness

and overall condition (Brown et al. 2002). Wetter wet seasons may benefit some species by providing more food. Drier dry seasons will impact many species due to reduced food and water resources.

- **Rising temperatures** will affect sex ratios and reproductive success of the critically endangered Siamese Crocodile *Crocodylus siamensis* and possibly 10 turtle species which occur in wetland habitats (Asiatic Softshell Turtle *Amyda cartilaginea*, Asian Giant Softshell Turtle *Pelochelys cantorii*, Yellow-headed Temple Turtle *Hieremys annandalii*, Big-headed Turtle *Platysternon megacephalum*, Malayan Box Turtle *Cuora amboinensis*, Stripe-necked Leaf Turtle *Cyclemys tcheponensis*, Giant Asian Pond Turtle *Heosemys grandis*, Malayan Snail-eating Turtle *Malayemys subtrijuga*, Four-eyed Turtle *Sacalia quadriocellata* and Black Marsh Turtle *Siebenrockiella crassicollis*). [Other turtle species occur in the basin but are forest-dwelling and are not included here, although their survival is also dependant on moist microhabitats]. All turtle species in the basin are globally threatened.
- **Temperature ranges** that determine embryo sex in the Siamese Crocodile and these turtles is unknown. For the Saltwater Crocodile *Crocodylus porosus* in Australia, females are produced at egg temperatures of 29-31˚C and 33˚C and males around 31-32˚C (Webb et al. 1987). In the Lower Mekong Basin, temperatures are predicted to rise by 0.4 to 1.2˚C with the number of days over 33˚C predicted to increase by 19-65 days/year. This temperature increase will probably cause some clutches to be of only one sex or another. Higher internal nest temperatures may exceed lethal limits for embryos or cause deformities, both leading to higher mortality and lower recruitment. All of these species are already in decline due to other threats, and this added impact could cause the loss of populations.
- **Warmer temperatures** are also known to cause increased clutch sizes, earlier egg-laying and increased metabolic stress and appetite in crocodiles (e.g. Elsworth et al. 2003; Zhang et al. 2009; Campbell et al. 2010). These will place further stress on the remaining populations of Siamese Crocodile in the basin.
- For two species of sandbar/riverbank nesting turtles in the basin, Asiatic Softshell Turtle and Asian Giant Softshell Turtle, higher wet-season flows may wash away nesting sandbars and affect the rate of formation of new sandbars; similar impacts have been documented for sandbar-nesting turtles elsewhere in Southeast Asia (Kalyar et al. 2007). Such impacts will be magnified by mainstream dam development, which will increase dry-season water levels and may result in permanent inundation of many nesting beaches.
- In the Mekong Delta, **increasing salinity** in wetlands will cause negative impacts for most species. Most amphibians have low tolerance to saltwater and terrestrial reptiles require freshwater to drink. Saltwater intrusion will result in a decline in species richness in affected areas.
- For lowland species dwelling on the Mekong floodplains, there are few options to shift to more suitable habitats. Dispersal to higher elevations or latitudes to reach suitable conditions will involve distances of tens or hundreds of kilometers, which is not feasible for most species, except for individuals nearer such areas. Common and widespread species distributed over large areas may suffer large declines. Species with small ranges in specialized habitats such as in cool montane headwaters are also at risk, because they have little natural resilience to change and nowhere to disperse to. This suggests that once thermal limits are reached, the distribution of many species will contract and populations will decline.
- Many amphibian and reptile species in Southeast Asia are already threatened by other human pressures. The added impacts from climate change could be the tipping point which drives the disappearance of local populations. For frogs in Southeast Asia the impact of climate change and other threats is compounded by the fact that some 'widespread' species actually represent multiple species with small geographic ranges, and consequently, greater vulnerability to extinction (Stuart et al. 2006). This also complicates climate change assessments.

3.2.5 Wetland birds and mammals

At least 206 bird species in the Lower Mekong Basin are wholly or partly dependent on wetland habitats (MRB unpublished data). These include waterfowl, colonial-nesting large resident waterbirds, grassy floodplain-nesting resident birds, sandbar/river channel-nesting birds, non-breeding coastal winter visitors/migrant waterbirds and non-breeding inland visitor/migrant waterbirds. Critical nesting or migratory habitats for many of these species are the Tonle Sap Great Lake (Campbell et al. 2006), the Mekong River mainstream and floodplains in northeastern Cambodia (Timmins 2006, 2008) and parts of Laos and Thailand (Thewlis et al. 1998), and Mekong Delta (Buckton and Safford 2004). A large proportion of these species are globally or regionally threatened by hunting and/or habitat loss.

For mammals, there is no available inventory of wetland-dependant species in the basin. However, at least seven 'large' mammal species (i.e. excluding microchiropteran bats, rodents) are dependant on the Mekong mainstream, floodplain habitats and/or large tributaries (Mekong population of Irrawaddy Dolphin *Orcaella brevirostris*, Hog Deer *Axis porcinus*, Eurasian Otter *Lutra lutra*, Hairy-nosed Otter *L. sumatrana*, Smooth-coated Otter *Lutrogale perspicillata*, Oriental Small-clawed Otter *Aonyx cinerea*, Fishing Cat *Prionailurus viverrinus*) and at least another four species regularly utilise flooded forests, riverbank forest and mangroves (Silvered Leaf Monkey *Semnopithecus cristatus*, Long-tailed Macaque *Macaca fascicularis*, Large Flying-fox *Pteropus vampyrus*, Lyle's Flying-fox *P. lylei*). A wetland Endangered species, the Wild Water Buffalo *Bubalus arnee*, is probably extinct in Vietnam and Lao PDR, but may still exist in Cambodia.[2]Virtually all populations of these species are threatened and in decline. It is likely that a much larger number of small mammals (e.g. bats, rodents) in the basin are also dependant on wetland habitats.

Potential impacts of climate change include the following.

- It is likely that the majority of wetland bird and mammal species will be directly vulnerable to the loss/degradation of wetland habitats and/or changes in prey abundance, caused by **rising temperatures, altered precipitation, wetting and drying regimes and/or sea-level rise**. Wetter wet seasons and drier dry seasons may change the start dates and duration of breeding for some species. If prey species respond differently to climate change, the timing of bird or mammal breeding may be mismatched with their prey, leading to food shortage and potentially, large mortality.
- **Higher water levels** in both the wet and dry seasons would reduce the area of shallow-water feeding habitats required by many waterbird species in the Lower Mekong Basin e.g. at Tonle Sap Great Lake. Some wet-season nesting bird species might benefit from higher wet-season flows, more prolonged flooding and deeper floodplain lakes, which could extend the area of seasonal nesting habitat and abundance of some prey fish species. However any potential benefit could be offset by drier (harsher) dry season conditions, which could cause declines in prey abundance, food shortage and subsequent reduced fitness of individuals. Higher wet-season productivity for some bird species could be offset by higher dry-season mortality.
- Floodplain grasslands in the Lower Mekong Basin are already threatened and support at least four threatened or restricted-range bird species (Sarus Crane *Grus antigone*, Streaked Weaver *Ploceus manyar*, Asian Golden Weaver *Ploceus hypoxanthus*, Black-headed Munia *Lonchura malacca*) as well as the only documented population of Hog Deer in Indochina. Drier dry seasons and elevated carbon dioxide levels may dry out the grasslands, facilitate growth of woody shrubs and weed invasion (e.g. *Mimosa pigra*) and fire. The loss of these grasslands would cause declines in these four bird species. The entire known population of Hog Deer in the Lower Mekong Basin and Indochina is restricted to a single site in northeastern Cambodia and which is highly threatened (Maxwell et al. 2006): climate change impacts could cause the extirpation of this

[2]IUCN Redlist - http://www.iucnredlist.org/details/3129/0 (28/11/12)

population.

- An entire assemblage of sandbar-nesting bird species, most of which are regionally or globally threatened, is at risk of local extinction due to higher dry-season flows. If rises in dry-season water levels are sufficient to cause permanent inundation of sandbars in the Mekong mainstream and its lower tributaries (e.g. the Sesan, Srepok and Sekong River systems) the breeding habitats for this assemblage will disappear. This risk is high because impending hydropower construction along the Mekong mainstream is predicted to cause similar increases in dry season water level. Most species have already declined due to egg collection by local communities and egg predation by domestic dogs (confirmed from studies along Sesan River and Mekong mainstream; Classen 2003, Timmins 2008) and extensive human disturbance of nesting sites (e.g. in 2005, most sandbars along Xe Pian River in Xe Pian National Protected Area in Laos – which were previously documented to support nesting birds - were being used as dry-season fishing camps by local communities; Bezuijen 2006; Bezuijen et al. 2007).
- A possible **increase in the extent of 'flooded forest' vegetation** along the Mekong mainstream and its large tributaries might expand the riverine habitats of some mammal species e.g. Silvered Leaf Monkey, Long-tailed Macaque, flying-foxes and otters. However, given the severe existing pressures on these habitats (which are already highly reduced from clearance and settlement and are continuing to be cleared) and all 'large' mammal species in the Lower Mekong Basin, the likelihood of potential benefit of climate change for such species is low.
- In the Lower Mekong Dry Forests, the **drying out of small waterholes** will force large waterbirds (e.g. ibis, storks) and mammals to travel longer distances to water sources. This may result in reduced fitness and greater mortality. It will also increase the vulnerability of large birds and mammals to hunting, because hunters often focus their efforts at waterholes. The distribution of some waterbird species (e.g. ducks, storks, cranes) in the basin may also change as they respond to localized changes in rainfall and flooding patterns and access new flooded areas or move from dry areas.
- The Mekong Delta supports at least 247 bird species, of which at least 50% (c.123 species) are dependent on wetlands (Buckton and Safford 2004). This includes 21 species for which the delta holds a large proportion of regional or global populations, at least 35 migratory shorebird species and 40% of the eastern race *sharpii* of Sarus Crane (Buckton and Safford 2004). **Sea-level rise** will cause permanent loss of large areas of mudflats and feeding sites for many of these species. Impacts may be particularly severe for migratory shorebirds because one of the nearest alternative feeding areas, the Red River delta in northern Vietnam, is also forecast to lose large areas to sea-level rise (Cruz et al. 2007). Severe rates of inter-tidal habitat loss for shorebirds due to sea-level rise have been modeled in North America (Galbraith et al. 2002). Loss of mudflats as the sea rises will cause crowding and increased competition for food. This may facilitate disease spread e.g. avian influenza, although the effects of climate change on this disease are unclear (Gilbert et al. 2008). Crowding will also increase the vulnerability of birds to hunting.
- It is possible that the arrival and departure dates of migratory bird species to the Mekong Delta is changing. Preliminary analysis elsewhere in the East Asian-Australasian Flyway indicates that some species which utilise the delta are arriving and departing earlier from Australia (Beaumont et al. 2006). This suggests similar changes may be occurring elsewhere in the flyway. Changes in the arrival and departure dates of migratory birds to the Mekong Delta due to climate change could cause birds to miss the period of peak food availability in the delta. Similar concerns have been identified for migratory birds in Indonesia (Noske 2011).
- The **decline of the Mekong Delta** as a key staging site for migratory shorebirds will impact the integrity of the entire East Asian-Australasian Flyway. It will also raise the importance of other sites along the flyway in other nations, and will probably require a reassessment of adaptation priorities in those nations as well as the Mekong Delta.
- Impacts to wetland biodiversity in the delta will be exacerbated by the **complete inundation of**

some protected areas (under a scenario of one-metre rise), including U Minh Thuong National Park and Bac Lieu Nature Reserve (Carew-Reid 2007). This will result in loss of freshwater swamp vegetation, habitats for globally threatened birds and possibly a host of invertebrates whose conservation importance is not yet documented. Climate change will also reduce the integrity of protected areas in the delta which will not be inundated by sea-level rise, such as Tram Chim National Park (Carew-Reid 2007), but which will be subject to more fire, weed invasion, drying and land-use conflicts. This park, which supports floodplain grasslands and over 30% of the dry-season population of Sarus Crane in Southeast Asia (Buckton and Safford 2004), is already threatened by human activities.

3.3 COMBINED IMPACTS OF CLIMATE CHANGE AND EXISTING PRESSURE ON LOWER MEKONG BASIN WETLANDS

Climate change is anticipated to increase existing pressures on biodiversity globally (Opdam and Wascher 2004). In the Lower Mekong Basin, over the short term, climate change is unlikely to replace existing threats which are causing the decline of many species. Instead, climate change will act as an indirect driver to place more pressure on threatened species while also placing new pressures on common species. Examples of possible synergistic impacts with some of the greatest threats currently facing wetland biodiversity in the basin are given below.

3.3.1 Hydropower, overfishing and climate change

Overfishing has caused the near-extinction of at least one species, Mekong Giant Catfish *Pangasianodon gigas* (Hogan 2004) and catches of many other fish species have declined (Allan et al. 2005; Welcomme et al. 2010). There are strong interactions between the effects of fishing and the effects of climate because fishing reduces the age, size, and geographic diversity of populations, making populations more sensitive to additional stresses such as climate change (Brander 2007). Inland fisheries are additionally threatened by changes in precipitation and water management. Higher wet-season flows due to climate change may increase productivity of some wet-season breeding species in the short term, but the combined impacts of mainstream dams, drier dry seasons, warmer waters and higher dry-season water levels may cause declines in species richness and biomass for many other species and over large areas of the Mekong lowlands.

Hydropower development in the Lower Mekong Basin is increasing and there is global concern that proposed dams along the mainstream will cause population declines or extirpation of fish populations (Dugan et al. 2010), Mekong Dolphin (Bezuijen et al. 2007) and other fauna. Some dams along Mekong tributaries in Cambodia, Thailand and Vietnam have caused severe impacts to fish migrations and loss of species richness (e.g. Roberts 2001; Baran et al. 2007; Wyatt and Baird 2007; Trandem 2008).

3.3.2 Overharvesting and climate change

The combined impacts of hunting and climate change are potentially high given the intensity of hunting throughout the Lower Mekong Basin. Virtually all wetland fauna in the basin is subject to hunting or harvesting, which has caused the near-extirpation of most turtles and large mammals and birds, and declines of some large lizards, snakes and frogs. For turtles which use the floodplain wetlands, the drying out of ponds may cause individuals to congregate at fewer pools, making them more vulnerable to hunting. More fires in the Lower Mekong Dry Forests may kill turtles and force surviving turtles to travel longer distances between waterholes. Because wetland use is so intensive, any additional threat such as physiological and habitat stresses caused by climate change, will almost certainly cause the further decline of plant and animal populations.

There is little published information on the synergy between climate change and hunting. Recent modeling studies on the Magpie Goose *Anseranas semipalmata* in the wet-dry tropics of northern

Australia have demonstrated that the combined impacts of saltwater intrusion from sea-level rise, extended periods of inundation due to increased annual rainfall, rising temperatures, elevated CO_2 levels and resulting changes in floodplain vegetation, will reduce the Magpie Goose population to a few thousand individuals within 200-300 years. However, when current hunting levels are added to this, the species will become locally extinct within a century (Traill et al. 2009, 2010). The authors state that hunting will need to be strictly regulated to avoid extinction. In the Lower Mekong Basin, where there is virtually no effective enforcement of wildlife hunting and trade, more rapid declines and losses may be expected.

3.3.3 *Invasive species, disease pathogens and climate change*

Warmer water and air temperatures and altered hydrology will assist the establishment of invasive species and spread of diseases in the Lower Mekong Basin. Climate change enhances the competitive impacts of invasive species on native species and increases the virulence of some diseases (Rahel and Olden 2008), although the synergistic effects of these interactions is little known (Strayer 2010). In general, climate change may make local conditions either better or worse for specific exotic species, but will increase disturbance and stresses in wetland habitats, making them easier to invade (Rahel and Olden 2008). Cool waters in the Mekong headwaters represent 'thermal barriers' for species adapted to warmer temperatures: warmer temperatures may facilitate spread of invasive species from the Mekong lowlands to higher elevations, such as the freshwater invertebrate Golden Apple Snail *Pomacea canaliculata* and weed *Mimosa pigra* (both widespread in the lowlands).

For frogs, a key factor in the decline of many global populations is the interaction of climate change with the spread of a fungus which prefers upland environments (Lips et al. 2005; Pounds et al. 1999). The presence of this fungus in the Lower Mekong Basin is unknown (no testing has been conducted) but is predicted (Ron 2005). The fungus has not been recorded on frogs in the Mekong lowlands in Thailand (McLeod et al. 2008). If the fungus is indeed present in montane regions of the basin, rising temperatures might reduce its distribution. This potential benefit might be offset by increasing metabolic stress in montane frogs as temperatures rise.

For birds, a study in Hawaii has shown that climate change will increase the chance of extinction of several bird species due to increased habitat loss, predation and avian malaria (Benning et al. 2002). Currently, cooler temperatures at higher elevations prevent the spread of malaria into remaining populations; increases of 2°C will double the area with malarial infection and cause the extinction of some species (Benning et al. 2002). It is unknown whether similar complex effects are occurring in the Lower Mekong Basin.

4 THE CLIMATE CHANGE VULNERABILITY ASSESSMENT METHODOLOGY

The climate change vulnerability assessments presented here is intended to support decision-making at the wetland level of administration and should be used to strengthen existing wetland management plans. The recommendations from the assessment can also be used to guide wetland management policy and identify further information needs.

The methodology presented here has two components. The Section 4.1 describes a **rapid climate change vulnerability assessment** that can be made in the field with wetland managers and community experts. It establishes a site level understanding of climate change; documents past extreme climate events and their impacts on villages and wetlands; identifies coping mechanisms used in response to these extreme climate events; and then identifies future mechanisms and management interventions to help villages and wetlands adapt to climate change. The Section 4.2 and 4.3 provide an **ecological assessment** relying on ecologists and taxa experts to assess specific wetland habitats and species for their anticipated response to climate change. These sections can build off of Section 4.1 or can be done as a desk study.

In both methods, the practitioner will strive to be transparent in the means by which an assessment is made and present an estimate of certainty in the response.

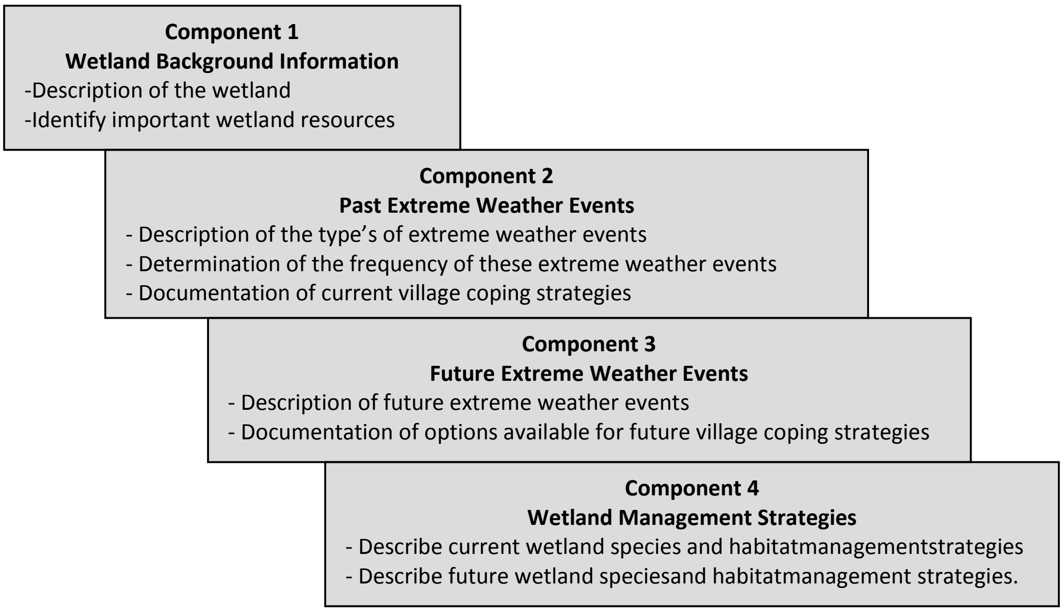
4.1 WETLAND VILLAGE VULNERABILITY ASSESSMENT TOOL

The methodology presented here is a framework for climate change vulnerability assessment for communities that use and manage wetlands. This methodology is not all encompassing and should be modified to meet individual village situations. The methodology has 4 components (See Figure 3). Component 1 provides **background information** on the wetland. This includes a physical description of the wetland, and identification of wetland management authorities, major stakeholders, and important resources used from the wetland for village subsistence. Component 2 compiles a list of **past extreme weather events**. It also identifies the relative frequency of these events and identifies strategies the villagers use to cope with these events. Component 3 describes the nature of **future extreme weather events.** While the first part of this component is mainly informative to stakeholders, it is meant to initiate discussion on the potential strategies villagers can use to cope with extreme weather events that will be more frequent and more severe. The final component 4 focuses the discussion on **wetland management strategies** to improve ecosystem function and resilience to climate change.

To complete the four components, there are five steps in the Wetland Village Vulnerability Assessment for a species and habitat. These are:

1. Understand the purpose of the climate change evaluation
2. Understand the wetland and predict the changes in climate that will occur
3. Agree on the variables to be used for the species assessments
4. Complete the assessment at the wetland site with stakeholders
5. Describe the uncertainty of the assessment and provide recommendations for adaptation management

Figure 3.Assessment components for the climate change vulnerability



4.1.1 Step 1. Understand the purpose of the Wetland Village vulnerability evaluation.

Audience:

The audience for this study are local stakeholders and wetland area managers.

Management Goal:

To increase the resilience and reduce the vulnerability of communities that relay on wetlands to climate change in order to maintain total ecosystem function.

Objectives

1) To increase understanding of the vulnerability of wetlands to climate change. With a focus on species important for village subsistence.
2) To increase the capacity of wetland managers to do transparent and systematic climate change vulnerability assessments.
3) To increase the number of possible measures to reduce the impacts of climate change on wetlands and for managers to provide sound recommendations for effective mitigation.

4.1.2 Step 2. Understand the wetland:

Gather together information

Before you go to the field, gather together the information about the wetland such as old and existing management plans, village development plans, maps, and GIS layers. These can be found at the wetland management office and department offices working in the area. Do not limit your search to just natural resource information. Useful information can be found within other sectors such as agriculture, roads and energy. Also contact UNDP and NGOs that work in the area to see if they have relevant unpublished field surveys.

The Wetland Background Information form (Form 1 in Annex 4) asks questions commonly associated with wetlands. It might not be possible to get exact hectares or kilometers in response to some of the questions if you do not have current maps or satellite imagery. Best estimates for these sizes are adequate for this assessment. Some of these questions may not be appropriate for all wetland types so your team may need to add to or change the nature of the questions to make them more applicable.

Listing the 10 most important wetland resources might be hard to do as there are often more than that. If this is the case, be prepared to group resources that have similar uses and wetland requirements. This can be done as a participatory prioritizing exercise, using PRA techniques.

Predict the future climate.

Before going to the field, be prepared to share with stakeholders predicted changes in climate that are likely to occur at the site. This should include a description of changes in the four key climate change variables, rainfall and hydrology, temperature, and extreme weather events. It should also include seasonal or monthly variations, if these are available. Guidance for predicting the future climate is provided in Section 4.2.3 of this document. Make a brief description of these changes on the **climate change in the wetland area** form (Form 2 in Annex 4).

4.1.3 Step 3 Agree on the variables to be used for the species assessments

Before you can do the vulnerability assessment for the wetland to climate change, your staff needs to agree on the variables to be used. Before meetings with stakeholders in the village, review these data forms to see if the questions are appropriate and that you understand the purpose of each question and questionnaire. Wetland Climate History Form Table 3 (Form 3 in Annex 4) asks stakeholders to think of specific extreme climate events in the past. Examples of extreme weather are listed in Box 2.

Box 2. Examples of extreme weather events
Drought
Extreme heat
Floods
Hailstorms
High winds
Rainstorms
Storm surges
Typhoons
Wild land fires

Determining the 'date' of these events might be difficult. It is acceptable to link the extreme weather with other notable events in the recent history. On the next form you will ask stakeholders if there are any patterns to these extreme weather events.

Table 3. Past extreme weather event form

Extreme weather event	Estimated date or memorable event	Effect on wetland habitats and important species

The wetland climate hazard and impact form (Form 4 in Annex 4), ask stakeholders to describe patterns or frequency of these extreme weather events and to describe the impacts that these events have on the village and wetland use. Examples of impacts are found in Box 3. Determining the frequency of a weather event will be difficult and there will be varying degrees of certainty. Score each question your assessment of confidence in the answers given based on the expertise of the stakeholders present.

The Village Coping Strategies Form (Form 5 in Annex 4) is the place where stakeholders describe how they cope with current extreme climate events. Examples for coping strategies are found in Box 4. Try to limit the number of impacts to three for each extreme weather event.

Box 3. Examples of Climate Impacts:	
Damage to dwellings	Crop damage/loss
Reduced frog stocks	Reduced fish stocks
Disease	Loss of important wetland species
Fuel shortages	Disrupted transport
Personal injury	Income loss
Reduced water quality	Reduced soil fertility
Social conflict/tension	Sick livestock
Water shortage	Unemployment

Ask stakeholders to assess how successful the strategy was, and note in the comment box if they have suggestions on what could have been done better. The form provides response space for three impacts associated with each weather event (i.e. a,b,c). For questions 3 and 4, an open space is provided for weather events that are identified by the participants. Special focus should be made on how they use and manage the wetland.

The **Future Climate Change Coping Strategies form** (Form 6 in Annex 4) asks stakeholders to think how their existing coping strategies will work for future climate change. Again, limit the discussion to the three main impacts for each extreme weather event. Stakeholders are also asked to provide a priority for action. This should be based on the severity of the exposure to the extreme weather event and their current ability to adapt. In the comments section, note how wetlands help in mitigation of these events. For the final question (5), comment on the average priority scores (i.e. Overall preparedness) and identify common themes of vulnerability.

Box 4. Examples of coping strategies:
Water rationing
Pump water from the wetland
Buy more food from town
Gathering of wild food from forest and wetland
Casual labor
Crop shifting
Food rationing
Rainwater harvesting
Reallocation of labor
Selling of personal belongings
Crop replanting

4.1.4 Step 4 Complete the Assessment of the wetlands/ villages in the field

Use the 2050 climate change projections identified in Step 2 and the agreed questions identified in Step 3 to complete the wetland village assessments with wetland stakeholders. It is advised to print forms in Annex 3 to use in the village with stakeholders just in case there insufficient electricity to run a laptop.

4.1.5 Step 5 Provide recommendations for adaptation management and describe the uncertainty of the assessment

The final form (**Future Wetland Management Strategies** – Table 4(Form 7 in Annex 4) looks at how wetland resources are managed now and in the future. For each wetland resource identified on the Wetland Information form, comment on the strengths and weakness of its management. Also identify needs for the future management. At the bottom of the form, provide general comments on how wetland management can help stakeholders cope with future climate change events.

The final question on the form asks you to describe uncertainty and gaps in understanding that should be the focus of more detailed study. These are recommendations that can be given to guide future research or surveys like the study outlined in Section 4.2 of this document.

Table 4. Future Wetland Management strategies form

Wetland Resource		Use	Management during extreme weather events		Comments
			Current management	**Future management**	
0	for	0			
0	for	0			
0	for	0			
0	for	0			
0	for	0			
0	for	0			
0	for	0			
Comment on how wetlands might help to cope with extreme weather					
Describe uncertainty and gaps in understanding that should be followed up with more detailed study.					

4.2 A RAPID VULNERABILITY ASSESSMENT FOR WETLAND HABITATS AND SPECIES

Sections 4.2 and 4.3 outline methodologies for species and habitat vulnerability assessments. While the overall component objectives are the same for species and habitats, the nature of the question (i.e. forms) will have to be different. Because species make up habitats and habitats influence the survival of species, the order that one completes these methods is dependant on the nature of the expert group. Also it is not possible to anticipate relevant questions for every habitat type or species, therefore it is important that the expert groups add questions needed to capture important data for climate change vulnerability. The rapid vulnerability assessment methodology has five main components[3] (see Figure 4)

1. Component 1 is the species or habitat **Narrative**. The Narrative will provide general information about the species or habitat (e.g. its range, its status) and will eventually provide the overall summary of the climate change vulnerability assessment. The Narrative, in essence, will be the final report for the species or the habitat.
2. Component 2 is the **Baseline Conservation Status** assessment. This assessment evaluates current ecological traits and stresses of the species or habitat, before climate change factors are evaluated.
3. Component 3 evaluates the species or habits exposure, sensitivity and adaptability to **Climate change**.

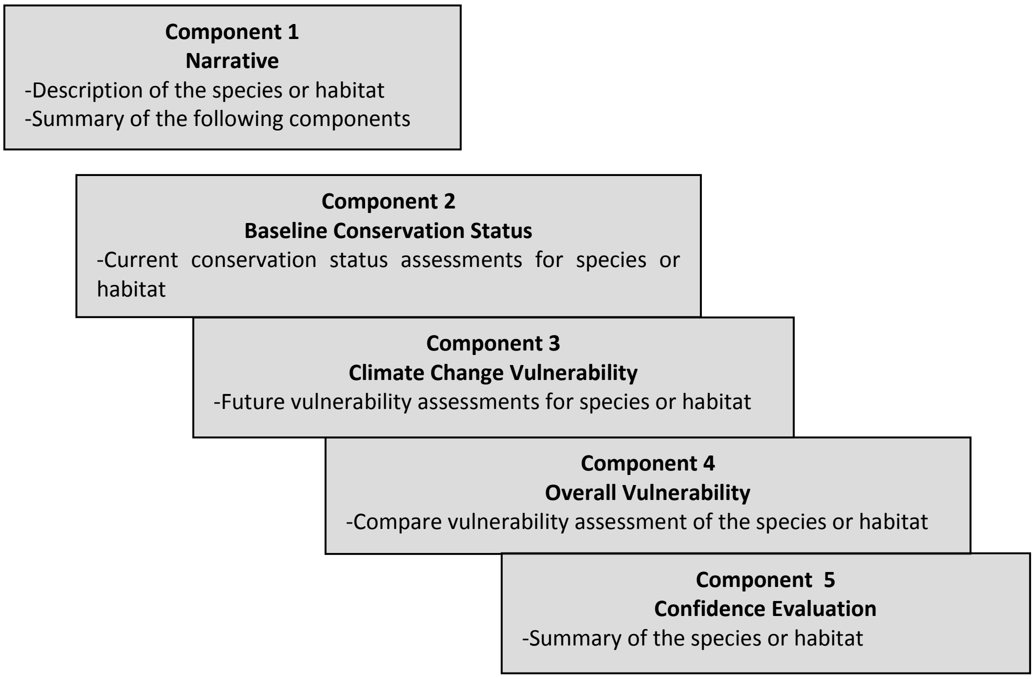
[3]It is an adaptation of the response model using experts and drawing from a approach developed by the United Stated Environmental Protection Agency for assessing climate change vulnerability of threatened and endangered species (USEPA 2009)

4. Component 4 will compare the baseline conservation status with the climate change vulnerability to facilitate management planning.
5. Component 5 will evaluate the uncertainty of Components 2, 3 and 4 and will provide an overall confidence score. Figure 4 illustrates the five components of the methodology.

To complete the five components, there are nine steps in the rapid climate change vulnerability assessment for a species and habitat. These are

1. Understand the purpose of the climate change evaluation
2. Understand the wetland
3. Predict the changes in climate that will occur at the wetland management area
4. Agree on the variables to be used for the assessments
5. Agree on the uncertainty of the assessment
6. Assess species or habitat baseline conservation status
7. Assess the vulnerability of this species or habitat to climate change
8. Assess the overall vulnerability of this species or habitat
9. Provide recommendations for adaptation management

Figure 4. Assessment components for climate change vulnerability (based on the US EPA 2009)



Because there are different questions that need to be asked of a 'species' versus a 'habitat', two sets of data forms were developed to guide the assessment. Section 4.2 outlines questions to be answered for habitat, and Section 4.3 outlines the questions to be answered for species.

Because this is a rapid assessment, the number and details associated with the questions on each form has been intentionally limited. The number and nature of the questions could be expanded, depending on the expertise available and resources available. The number of questions on each form will however bias the overall vulnerability in Component 5. That is because the more questions a form/component has, the more that contribute to the over all total. In some cases it might be that managers will want to 'weigh' the baseline vulnerability assessment higher, as the pressures are direct and immediate and climate change vulnerability assessment lower because these pressures are in the future or indirect. Experts and wetland managers will want to discuss this in the Narrative.

Biological thresholds

As the team works through the habitat and species worksheets, it may become obvious that biological thresholds will be exceeded, e.g. temperature at critical times of year will be higher than the species can survive, **or** that there is no refuge to migrate to, or not enough time to make a migration or adaptation. In these cases the habitat or species will most likely not survive and should be designated as 'Very Vulnerable' regardless of what the worksheet calculations provide.

The methodology presented here for a rapid climate change vulnerability assessments for a species follows the 9 steps outlined in Section 4 above.

4.2.1 Step 1. Understand the purpose of the climate change vulnerability evaluation.

Audience:

The audience for this study is wetland area managers and their department heads.

Management Goal:

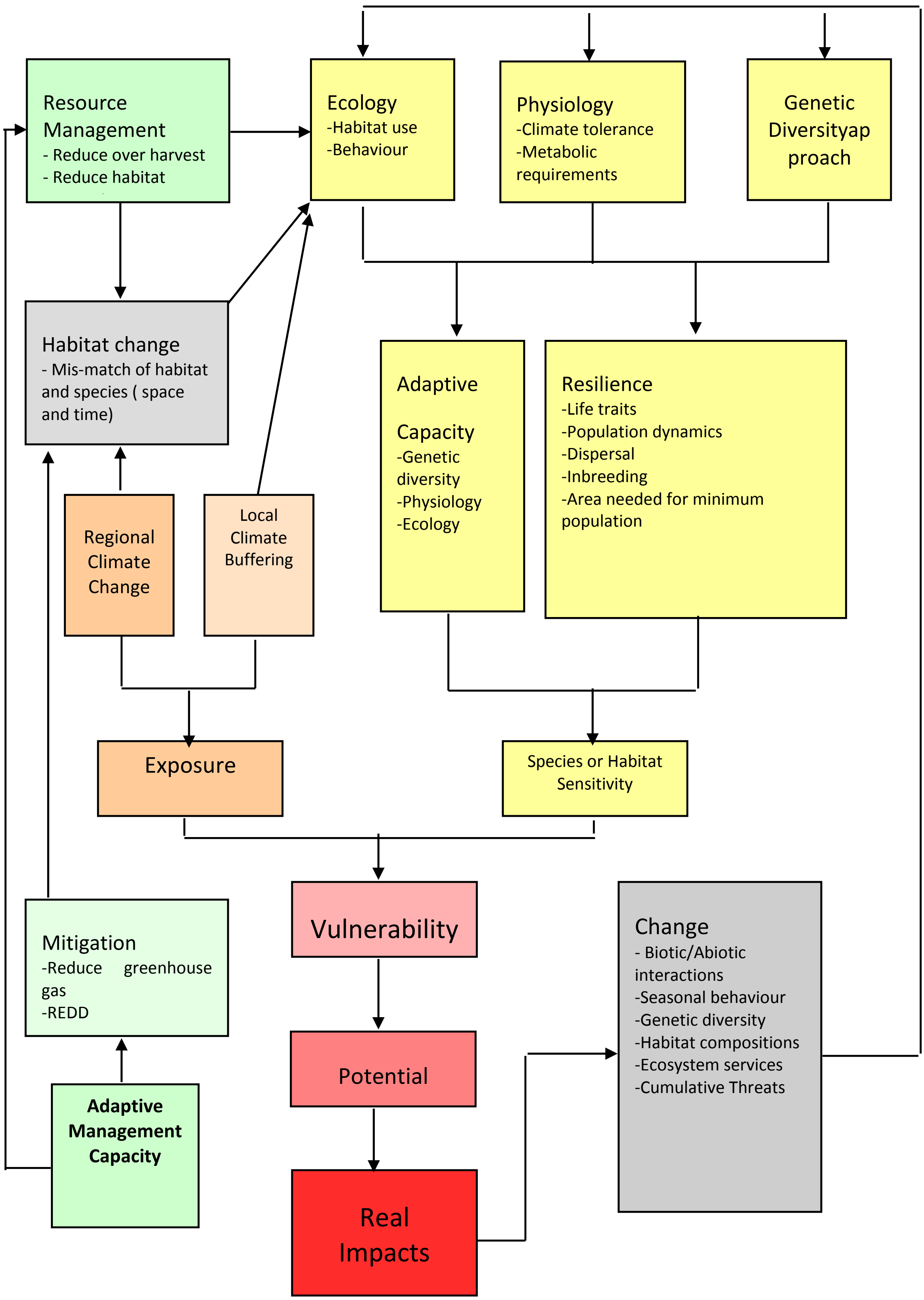
To increase the resilience and reduce the vulnerability of wetlands to climate change in order to maintain total ecosystem function.

Objectives

1) To increase understanding of the vulnerability of wetlands in the Lower Mekong Basin to climate change. With a focus on major habitats, and endangered, commercially important, or key stone species.
2) To increase the capacity of agencies responsible for the natural resource management to do transparent and systematic climate change vulnerability assessments.
3) To increase the number of possible measures to reduce the impacts of climate change on wetlands and for managers to provide feasible recommendations for effective mitigation.

People often have different opinions of the causes of change within ecological systems and the impacts of natural resource management. It is therefore important to agree on the underlying factors and relationships between the natural resource components and then to climate change. A conceptual model can help to get everyone 'on the same page'. There are different formats for illustrating concepts through models. The one in Figure 5 is based on William et al 2008 and is a box diagram showing basic relationships between the environment, management and climate change. Before beginning a climate change vulnerability assessment, the team should agree on the basic causal framework that underlay's the analysis and create a conceptual model for later reference.

Figure 5. An example of a Conceptual Model that includes climate change. (Williams et al 2008)



4.2.2 Step 2.Understand the wetland:

Gather together information

Gather together the information about the wetland such as old and existing management plans, village development plans, maps, and GIS layers. These can found at the wetland management office and department offices working in the area. If the Wetland Village Vulnerability Assessment was completed (Section 4.1 of this document) include this information and key stakeholders. Do not limit your search to just natural resource information. Useful information will be found within other sectors such as agriculture, roads and energy. Also contact the UNDP, and NGO's that work in the area to see if they have relevant unpublished field surveys.

Study the maps and satellite images to understand the current extent of the wetland in the wet and dry seasons. Identify major habitats within the wetland and identify how the wetland fits within the broader landscaped of urban, agriculture or forests.

Prepare an initial inventory of all wetland flora and fauna

Prepare an initial inventory of all wetland flora and fauna based upon existing management plans or earlier surveys. If these reports are not available a list should be prepared with the input of specialists for each group (flora, aquatic invertebrates, fish, amphibians and reptiles, birds, mammals). National assessments are partly complete for some taxa including the following sources: Duckworth et al. (1999a) (for amphibians, reptiles, birds and mammals in Laos), Nabhitabhata and Chan-ard (2005) (amphibians and reptiles in Thailand), Sanguansombat (2005) (birds in Thailand) and (Vidthayanon 2005) (fish in Thailand). Additional information can be obtained from Important Bird Area reports for each Mekong nation as well as a range of other published sources. Identifying the national threat status of a species is important because it will influence relative conservation priorities and planning

Determine the species and habitats you will assess

The number of species that you can assess will depend on the objectives you have set in Step 2 and the knowledge of the species within your team. It is best to use experts for each group of plant or animal if possible. Try to get a good spread between taxa and always include at least two species of higher plant. Also consider species that are currently common and characteristic of the wetland which may be vulnerable to climate change and so may become less common. Choose between 10 - 15 species per site. Make sure that there are at least two species for each of the key habitat types in the wetland.

Find reference material on taxa groups

There are some new multi-volume compilations of taxa information that provide up to date descriptions of the natural history of many animals. For mammals see Wilson, D.E. and Mittermeier R.A. *Handbook of the Mammals of the World* Lynx Edicions, Barcelona and for birds see del Hoyo, J. Elliott & D. Christie edits *Handbook of the Birds of the World*. Lynx Edicions, Barcelona

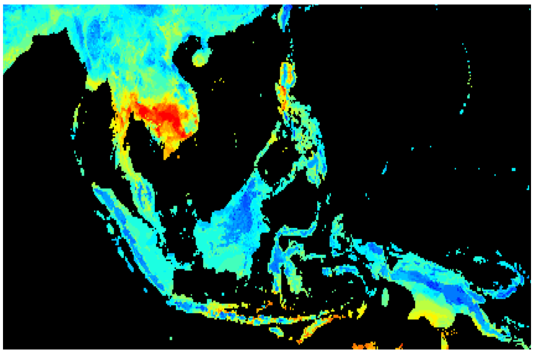
There are many new internet sites with information that describe natural history of plants and animals. For example, the Global biodiversity Information Facility http://data.gbif.org is an online niche modeling software. At this web site you can model species distribution based on climatic characteristics such as those found in Table 5, for known species sightings within a country.

Table 5. Climatic characteristics used to determine species distribution at Global Biodiversity Information Facility

Annual mean temperature	Mean diurnal range
Isothermality	Temperature seasonality
Maximum temperature of warmest month	Minimum temperature of coldest month
Temperature annual range	Mean temperature of wettest quarter
Mean temperature of driest quarter	Mean temperature of warmest quarter
Mean temperature of coldest quarter	Annual precipitation
Precipitation of wettest month	Precipitation of driest month
Precipitation seasonality	Precipitation of wettest quarter
Precipitation of driest quarter	Precipitation of warmest quarter

An example of a niche map for Sarus Crane *Grus antigone* is seen in Figure 6 with red area being where sarus crane is most likely to be found. These models unfortunately do not model future climate conditions.

Figure 6. Sarus crane distribution based on climatic factors.



For basic life history descriptions of species see the *Catalogue of Life* at http://www.catalogueoflife.org and the *Encyclopedia of Life* at http://eol.org/
For conservation status listing see the IUCN Red List http://www.iucnredlist.org
http://www.Fishbase.org

For distribution maps and conservation status of birds see the BirdLife International http://www.birdlife.org/datazone/species/search and International Crane Foundation http://www.savingcranes.org/species-field-guide.html.

With background information collected, begin writing the Habitat or Species Narrative. The Narrative will be the cumulative document for the species and will include background natural history of the species, its anticipated exposure and sensitivity to climate change, its anticipated resilience and adaptive capacity to climate change and management recommendation to mitigate for these changes. The Narrative will also include all the references used in making this assessment and description of the uncertainly and gaps in understanding. A sample Narrative outline is found in the Box5 below and in Annex 5 Form 1.

Box 5Species and Habitat climate change vulnerability assessment – Narrative outline.

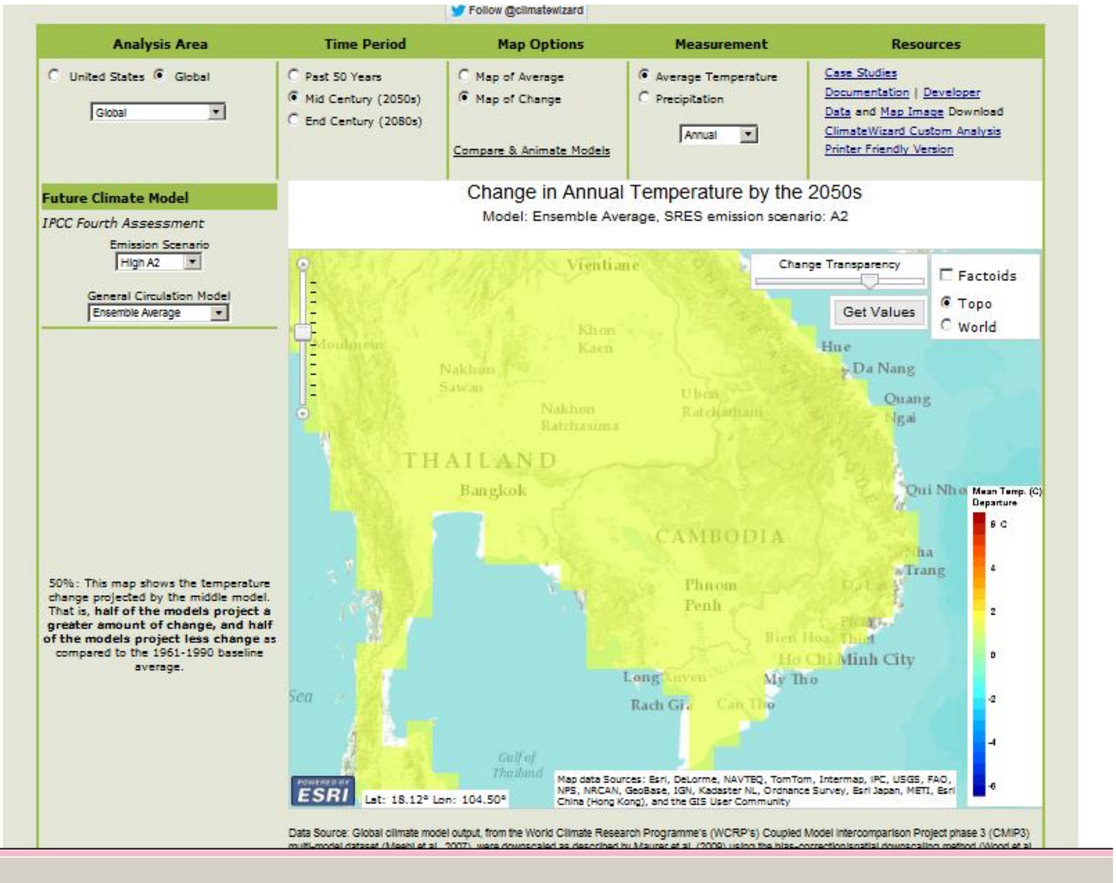
1. **Introduction**
    a. Name and location of the wetland
    b. Who is on the evaluation team
    c. Restate the objectives of the climate change vulnerability assessments
    d. What are the projected climatic changes to this wetland? (add this after Step 3)
2. **Species or Habitats national and international conservation status**
    a. What is the IUCN Red List?
    b. What is the national status or priorities in national actions plans?
3. **Distribution and Population Trends**
    a. Are there estimates of current local and global population's sizes?
    b. Are there estimates of current local and global population's trends?
    c. What is the geographic range of the species or habitat? Where are migration routes and other seasonal habitats?
4. **Habitat description**
    a. Do you have maps of the wetland habitat in the wet and dry season? << include here>>
    b. What are the hydrological factors that affect the wetland habitats?
    c. What species make up this habitat?
    d. What habitats are critical for the species?
    e. Has the habitat increased or decreased in area over time?
5. **Ecological limitations on the distribution and status**
    a. Is the species a specialist within a habitat?
    b. Does this species have a dependant relationship to other species?
    c. Is the habitat or species more abundant in other places?
    d. Is the species affected by invasive species?
6. **Climatic limitations on distribution**
    a. What are the physiological limits to the species or habitat distribution? (e.g. altitude, temperature, precipitation, extreme weather events)
7. **Existing stressors and their effects on distribution and status**- use to complete Form 2 and 4 in Annex 5
    a. Does the species/habitat have commercial value?
    b. Does the species/habitat have subsistence value?
    c. Is the species affected by habitat fragmentation?
    d. Is the wetland/habitat affected by other demands on hydrology? (e.g. irrigation)
8. **Potential Direct (physiological) vulnerability to climate change** - Form 3 and 5 Annex 5
    a. How do you think the species will respond to future temperature and precipitation and hydrological patterns?
    b. Are you aware of related species that have been studied for climate change adaptation? If yes, Can you draw conclusions from them?
9. **Potential Indirect (ecological) vulnerability to climate change** - use this to complete Step 6.
    a. How do you think the species will respond to future ecological change?
    b. How do you think the species will respond to future extraction threats?
10. **Summarize the findings from the Baseline Status** done in Step 5
    a. What is the Baseline status score?
    b. Do you feel confident in the score?
11. **Summarize the findings from the Climate Change Vulnerability Study** done in Step 6.
    a. What is the Climate Change Vulnerability score?
    b. Do you feel confident in the score?
12. **Summarize the findings from Contribution of Climate Change Vulnerability to Species Status** done in Step 7
    a. What is the Combined Vulnerability score?
    b. Do you feel confident in the score?
13. **Summarize the Uncertainty**-
    a. Which factors are you the most uncertain about?
    b. Where is the largest gap in knowledge?
14. **References** -- make a list of all literature and sources used

Step 3. Predict the changes in climate that will occur at the wetland management area

Identify the changes in climate that are predicted to occur at the site. This should include a description of changes in the four key climate change variables, rainfall and hydrology, temperature, sea-level rise and elevated levels of carbon dioxide. Resources for this are available from your various government ministries and should include observations from staff of the management area that have been made over the recent years (use the results from Section 4.1 of this manual if they were completed). In this case study, baseline averages and predicted temperature and rainfall for the period of 2045-2069 were provided by the MRC/ICEM.

Climate change models are also available online at ClimateWizard web site http://www.climatewizard.org/. Here you can select from different Global Circulation Models for different time periods. Figure 7 is an example of temperature change by 2050 using an average of all Global Circulation Models.

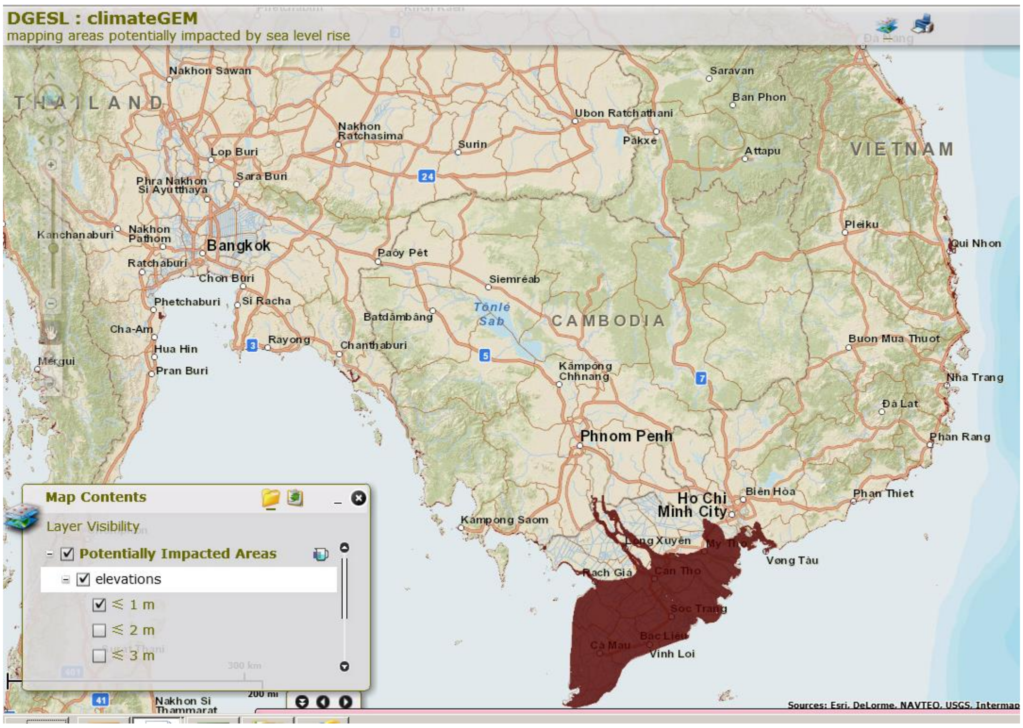
Figure 7. Sample web page from The Climate Wizard



One to three meter sea-level rise projections for the year 2100 are modeled for the entire world at http://climategem.geo.arizona.edu/slr/world/index.html. Although a one meter sea-level rise is not predicted by 2050 (Figure 8), nevertheless the gradual sea-level rise will have significant effects even in 2050. (source DGESL: climate GEM 2012)

A description of the climate change that will occur at the wetland management area should be included as part of the Narrative started in Step 2. The Climate Change in the Wetland Area worksheet developed for the Village Vulnerability Tool (Section 4.1) could be helpful in identifying climate change attributes that pose threats to the habitat or species (see Form 2 in Annex 4)

Figure 8. Illustrating a 1 meter sea level rise for the Lower Mekong Basin



4.2.3 Step 4. Agree on the variables to be used for the habitat assessments.

Before you can do a vulnerability assessment for a habitat (or species) to climate change, your team needs to agree on the variables to be used.

As discussed in Section 3, vulnerability to climate change is determined by **exposure** to climate change, the **sensitivity** of the species, or habitat, to these changes, and the **adaptive capacity** of the species. The vulnerability of a species, is dependent upon the specific threats associated with climate change (temperature shifts, rainfall, change in hydrology etc), but the exposure can be moderated by the capacity of the habitat to provide refuges. The species will have different sensitivities to these changes and the adaptive capacity questions provide insights into the responses that the species will have to these changes. In the Habitat and Species Assessments Forms, a High score means the species has a good chance of adapting to the anticipated climate change, but a low score means that it is more vulnerable.

Habitat and Species Assessments Form 2 (provided in Annex 5) asks questions commonly associated with regular **habitat vulnerability** assessments. These questions may not be appropriate for all habitats so your team may need to add or change the nature of the questions to make them more applicable. Habitat and Species Assessments Form 3 (provided in Annex 5) asks climate change related questions. These questions may not be appropriate for all habitats so your team may need to add or change the nature of the questions to make them more applicable.

On the baseline conservation status and climate change vulnerability forms, an average score is automatically calculated for the scores that were given for each question. Adding extra questions to the form will be incorporated into the average. Responding with an 'NA' (not applicable) does not affect the average. On the Excel spreadsheet, the average score is automatically converted into a vulnerability category (e.g. Very Vulnerable). The justification for the conversion used in the default spreadsheet is done by dividing the average range (1 to 3) by 5 vulnerability categories. This results in a category interval of 0.4. The category break-down is shown in decision matrix in Table 6. The category ranges can be changed by the evaluation team if needed by changing the 'Low' and 'High' break points in the Excel spreadsheet.

Table 6. Vulnerability category decision matrix.

Category interval 0.4	Low	High
Very High Vulnerability to climate change	2.7	3
High Vulnerability to climate change	2.3	2.6
Moderate Vulnerability	1.9	2.2
Low Vulnerability to climate change	1.5	1.8
Very Low Vulnerability to climate change	1	1.4

Also in both the baseline status and climate change vulnerability forms there is a column to indicating the experts' "confidence" in this score. This will be discussed more in the next section.

Biological thresholds

As the team works through the habitat and species worksheets, it may become obvious that biological thresholds will be exceeded or that there is no refuge to migrate to, or not enough time to make a migration or adaptation. In these cases the habitat or species will most likely not survive and should be designated as 'Very High Vulnerability' regardless of what the worksheet calculations provide.

4.2.4 Step 5. Agree on how to describe the uncertainty of the assessment

The intended result of this methodology is to produce an assessment of the relative vulnerabilities of certain species to climate change and other stressors. However the results of this process are subjective and non-quantitative. This can lead to confusion with experts doing the analysis and readers for the report narratives. In short: in the absence of better knowledge, this methodology only provides estimates of a species' relative vulnerabilities. It is not intended that these results be considered precise estimations of a species' survival. Therefore, it is important that the experts agree on the process and that the reasoning for the assessment is well documented and transparent. Well documented and transparent reasoning, will be essential in modifying the species status if new data are gathered that could change our understanding. Ensuring process transparency and documenting important assumptions is as important to the climate change vulnerability assessments as producing the assessment.

During the data gathering portion of the methodology, reference materials should be cited and included in the Narrative. During the evaluation of the questions relating to baseline status and climate change vulnerability (Step 6); expert opinion, sources and caveats should be noted in the comments columns. Associated with each question, a confidence score should be given based on an agreed scale. Confidence and uncertainly have been discussed earlier in this manual (Section 2.4). Table 7 provides guidance on a suggested confidence scoring.

Table 7.Degree of Confidence in Being Correct - a Confidence score for Uncertainty

Confidence Score	Confidence	Probability of being correct	Degree of Confidence in Expert opinion
4	Very high confidence	At least 9 out of 10 chance	Taxa expert opinion and peer review citations available
3	High confidence	About 8 out of 10 chance	Taxa expert opinion only
2	Medium confidence	About 5 out of 10 chance	Non- taxa expert opinion only
1	Low confidence	About 2 out of 10 chance	Best guess
0	Very low confidence	Less than 1 out of 10 chance	No idea

As part of the Narrative for this species, the average the confidence for each step should be discussed and focus should be give to uncertainty across the entire analysis and also in particular for each question. Use the uncertainty score to help identify over generous assumptions or gaps in the current knowledge.

Uncertainty within analysis and in decision making is sometimes meet with skepticism and unease from policy makers. In the case of future climate change this can lead to no action or business as usual. In cases like this, the **precautionary principle** is called upon. The precautionary principle states that if an action has the risk of causing harm to the public or the environment; even in the absence of scientific consensus, that action or policy is harmful. The burden of proof that the action is *not* harmful falls on those taking the action. This principle allows decision makers to make choices in situations where scientific knowledge is lacking on the matter. These protections can be relaxed if further scientific findings provide that no harm will result.

4.2.5 Step 6. Determine the habitat Baseline Conservation Status.

With the information gathered for the Narrative created in Step 2 and the knowledge of taxa experts, use the agreed questions/variables defined in Step 4 to complete the habitat's Baseline Conservation Status for each habitat selected. Use Habitat and Species Assessments Form 2 (provided in Annex 5) or use the accompanying MS Excel spreadsheet - for this baseline status assessment.In addition to answering each of the questions, also provide a confidence score as discussed in Section 4.2.5.

4.2.6 Step 7. Determine the habitat climate change vulnerability

Use the 2050 climate change projections identified in Step 3 and the agreed classifications identified in Step 4 to complete the climate change exposure assessments. Use Habitat and Species Assessments Form 3 (provided in Annex 5) or use the accompanying MS Excel spreadsheet. As you did for the Baseline conservation status assessment, for each of the climate change exposure questions proved a confidence score. On the Narrative form, write the reasons for your answers and especially note any biological thresholds that may be encountered. Step 8. Assess the overall vulnerability of the habitat or species

The method used above is a simplification of complex climate and species interacts. We know that the rankings made are subject to considerable uncertainty. These are, therefore our best estimates at this time given the information available. Table 8 brings together the all the scores and national and international conservation status of the species for evaluation.

Table 8. Overall Vulnerability Score

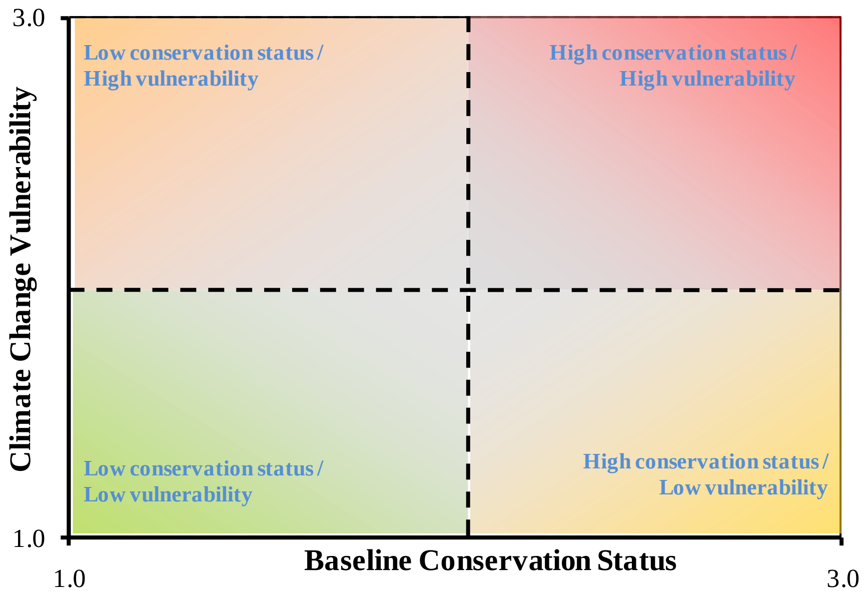
	Scores	Confidence
Habitat/Species Baseline Status		
Habitat/ Species climate change vulnerability		

Overall confidence	
Overall confidence description	

National Conservation Status	
IUCN Global Conservation Status	

In order to understand the likely contribution of climate change vulnerabilities to the baseline status, the score of climate change vulnerability is plotted against the baseline conservation status. The graph in Figure 9 represents four quadrants from this combination, ranging from low conservation status and low climate change vulnerability to high conservation status and high climate change vulnerability. Use the scores obtained from the baseline status worksheet and the climate change vulnerability assessment worksheets and plot the location of the habitat or species. This graphical representation will help planners develop and prioritize management interventions. In general, species in the high conservation status quadrants will require immediate management attention on threats that are not necessarily climate change related. Habitats or species in the high climate change vulnerability quadrants are perhaps less urgent, but will require longer term strategies to maintain populations or habitat quality. Habitat or species in the low conservation status / low climate change vulnerability quadrant, in general, should require less attention.

Figure 9. Baseline conservation status and climate change vulnerability quadrants.



4.3 THE RAPID VULNERABILITY ASSESSMENT FOR SPECIES

The methodology presented here for climate change vulnerability assessments for habitat follows the same 9 steps outlined in Section 4.2. Instructions for the Narrative and describing uncertainty are the same for habitats as they are for species. However the questions related to baseline status and climate change vulnerability are slightly different. Therefore it is important that the evaluation team agree on the variables to be used for the habitat assessment. The next section is a discussion of Step 4 in the habitat variables.

4.3.1 Step 4 Agree on the variables to be used for the species assessments.

Before you can do a climate change vulnerability assessment for a species your team needs to agree on the variables to be used.

As discussed in Section 3, vulnerability to climate change is determined by **exposure** to climate change, the **sensitivity** of the species, or habitat these changes, and the **adaptive capacity** of the species. The vulnerability of a species, is dependent upon the degree of exposure to climate change and its sensitivity to these changes, but can be moderated by the capacity of the habitat, or species to respond to these changes. In the Habitat and Species Assessments Forms, a High score means the species has a good chance of adapting to the anticipated climate change, but a low score means that it is more vulnerable.

Habitat and Species Assessments Form 4 (provided in Annex 5) asks questions commonly associated with **species baseline status**. These questions may not be appropriate for all species so your team may need to add or change the nature of the questions to make them more applicable.

Habitat and Species Assessments Form 5 (see in Annex 5) asks climate change related questions. This includes determining **exposure, sensitivity,** resilience **and adaptation.** These questions may not be appropriate for all species so your team may need to add or change the nature of the questions to make them more applicable.

Baseline status and climate change vulnerability in some species may vary for differing age class. Therefore three age-classes are provided to be scored on each assessment. If a threat factor is uniform across the age-class, it should be scored as an adult. When evaluating the overall vulnerability of the species, use the largest score from the age class. On both forms there is a column for indicating the experts "confidence" in this score. This scoring has been discussed more in Section 4.2.5.

4.4 HABITAT AND SPECIES MANAGEMENT RECOMMENDATIONS

Using the summary information gathered in Step 8 (Section 4.2.8), Step 9 asks the evaluation team to make recommendations for management of both wetland habitats and species. In general species in the high conservation status quadrants will require immediate management attention on threats that are not necessarily climate change related. Habitats or species in the high climate change vulnerability quadrants are perhaps less urgent, but will require longer term strategies to maintain populations or habitat quality. Habitat or species in the low conservation status / low climate change vulnerability quadrant, in general, should require less attention. Species or habitat that are near-to or cross a biological threshold will require special attention / decisions for management. That is to say, they may need to be abandoned, or physically relocated.

The following questions (Table 9) may help guide your recommendations for management planning.

Table 9. Recommendations for management planning

Habitats	Species
Wetland zoning	
• Does this analysis suggest that changes are needed in current zoning for these habitats?	• Can this analysis provide useful information on rezoning the wetland to meet future climate change?
	• Can this analysis provide useful information on identification of future refuges from climate change in the wetland?
Wetland use rules	
• Do you think your overall vulnerability assessments scores are robust enough to prioritize new resource use rules?	• Do you think your overall vulnerability assessments scores are robust enough to prioritize or change wetland resource use rules?
• Can this analysis provide useful information on water management in the wetland?	• Can this analysis provide useful information on water management in the wetland?
Habitat recovery plans	**Species recovery plans**
• Could these habitat vulnerability assessments be used as indicators of the health of the individual species found here?	• Does this analysis suggest that changes are needed in current management plans for these species?
• Can this analysis provide useful information on identification of future refuges from climate change in the wetland?	• Could these species be used as indicators of the health of the broader habitat?
	• If the species is highly vulnerable, what will happen if it disappears from the wetland system?

Habitats	Species
Wetland protection	
• Does this analysis suggest any change in priorities for management interventions?	• Does this analysis suggest any change in priorities for management interventions?
• Can this analysis provide useful information on what stressors to focus on now, to reduce future stress from climate change?	• Can this analysis provide useful information on what stressors to focus on now, to reduce future stress from climate change?
Community outreach	
• Can this analysis provide useful information for community outreach education on wetland conservation?	• Can this analysis provide useful information for community outreach education on wetland conservation?
Cross sector and regional cooperation	
• Can this analysis provide useful information on community development plans regarding the wetland in the face of climate change?	• Do you think your vulnerability assessments scores are robust enough to prioritize mitigation activities between wetland management area?
• Do you think your vulnerability assessments scores are robust enough to prioritize mitigation activities between wetland management areas?	• Are there other sectors (e.g. Agriculture, Forestry, Health) that could benefit from knowing the results of this analysis?
• Are there other sectors (e.g. Agriculture, Forestry, Health) that could benefit from knowing the results of this analysis?	• Can this analysis provide useful information on infrastructure development in and around the wetland?
• Are there other organizations/ agencies (e.g. UNDP, NGO's) that could benefit from knowing the results of this analysis?	• Can this analysis provide useful information on community development plans regarding the wetland in the face of climate change?
• Can this analysis provide useful information on infrastructure development in and around the wetland?	• Are there other organizations/ agencies (e.g. UNDP, NGO's) that could benefit from knowing the results of this analysis?
Wetland funding	
• Can this analysis be used to apply for funding for biodiversity conservation through the climate change funding windows?	• Can this analysis be used to apply for funding for biodiversity conservation through the climate change funding windows?
• Can this analysis be used to apply for funding for more detailed climate change studies through the climate change funding windows?	• Can this analysis be used to apply for funding for more detailed climate change studies through the climate change funding windows?

ANNEXES

ANNEX 1. LITERATURE REVIEW

Aber, J.D., S.V. Ollinger, C.A. Federer, P.B. Reich, M.L. Goulden, D.W. Kicklighter, J.M. Melillo, and R.G. Lathrop Jr. 1995. Predicting the effects of climate change on water yield and forest production in the Northeastern U.S. *Climate Research* 5: 207–222.

Allan, D. R. Abell, Z. Hogan, C. Revenga, B. W. Taylor, R. L.Welcomme and K. Winemiller. 2005. Overfishing of Inland Waters. BioScience 55: 1041-1051.

Allen, C.D., A.K. Macalady, H. Chenchouni, D. Bachelet, N. McDowell, M. Vennetier, T. Kitzberger, A. Rigling, D.D. Breshears, E.H. Hogg, P. Gonzalez, R. Fensham, Z. Zhang, J. Castro, N. Demidova, J.H. Lim, G. Allard, S.W. Running, A. Semerci, and N. Cobb. 2010. A global overview of drought and heatinduced tree mortality reveals emerging climate change risks for forests. *Forest Ecology and Management* 259: 660–684.

Association of Fish and Wildlife Agencies (AFWA). 2009. *Voluntary Guidance for States to Incorporate Climate Change into State Wildlife Action Plans and Other Management Plans.* AFWA, Washington, D.C. http://www.fishwildlife.org/pdfs/ ClimateChangeGuidance%20Document_ Final_reduced%20size.*pdf.*

Baird I.G. 2006.Conducting Rapid Biological Based Assessments using Local Ecological Knowledge. *Nat Hist Bul. Siam Soc. 54(2) 167*-175, 2006

Baird, I. G. 2007. Fishes and forests: the importance of seasonally flooded riverine habitat for Mekong River fish feeding. Natural History Bulletin of the Siam Society 55: 121-148.

Baran, E., N. Schwartz and Y. Kura. 2008. Climate change and fisheries: vulnerability and adaptation in Cambodia. The WorldFishCenter, Penang, Malaysia.

Baran, E., T. Jantunen and C. K. Chong. 2007. Values of inland fisheries in the Mekong River Basin. WorldFishCenter, Phnom Penh, Cambodia.

Beaumont, L. J., I. A. W. Mcallan and L. Hughes. 2006. A matter of timing: changes in the first date of arrival and last date of departure of Australian migratory birds. Global Change Biology 12: 1339-1354.

Benning, T. L., D. LaPointe, C. T. Atkinson and P. M. Vitousek. 2002. Interactions of Climate Change with Biological Invasions and Land-Use in the Hawaiian Islands: Modeling the Fate of Endemic Birds Using a Geographic Information System. Proceedings of the NationalAcademy of Sciences 99: 14246-14249.

Berliner, L.M., R.A. Levine, and D.J. Shea. 2000. Bayesian climate change assessment. *Journal of Climate* 13: 3805–3820.

Bernardo, J., R.J. Ossola, J. Spotila, and K.A. Crandall. 2007. Interspecies physiological variation as a tool for cross-species assessments of global warming-induced endangerment: Validation of an intrinsic determinant of macroecological and phylogeographic structure. *Biology Letters* 3: 695–699.

Bezuijen, M. 2011. Wetland biodiversity & climate change briefing paper: Rapid assessment of the impacts of climate change to wetland biodiversity in the Lower Mekong Basin for the Basin-wide climate change impact and vulnerability assessments for Wetlands of the Lower Mekong Basin for Adaptive Planning. RFP No. 10-240 February 2011 Prepared for the Mekong River Commission.

Bezuijen, M. R. 2006. Incidental wetland bird observations from Attapu and Savannakhet provinces, Lao PDR, March–June 2005. Forktail 22: 49-56.

Bezuijen, M. R., C. Phothitay, S. Chanrya, A. Rasphone and C. D. Hallam. 2007. Wetland resource use in Xe Pian National Protected Area, Lao PDR, in 2005. Natural History Bulletin of the Siam Society 55: 223-234.

Bezuijen, M. R., R. Zanre and M. Goichot. 2007. The Don Sahong Dam and the Irrawaddy Dolphin. Unpublished report. WWF-Greater Mekong Programme, Vientiane, Laos.

Bickford, D., S. D. Howard, D. J. J. Ng and J. A. Sheridan. 2010. Impacts of climate change on the amphibians and reptiles of Southeast Asia. Biodiversity and Conservation 19: 1043–1062.

Bogan, A. E. Freshwater Bivalve Extinctions (Mollusca: Unionoida): A Search for Causes. American Zoologist 33: 599-609.

Box, G.E.P., and N.R. Draper. 1987. *Empirical Model-building and Response Surfaces.* Wiley Series in Probability and Statistics, Boyd, J. 2007. The endpoint problem. *Resources* 165: 25–28. New York.

Bradley, M.P., and E.R. Smith. 2004. Using science to assess environmental vulnerabilities. *Environmental Monitoring and Assessment* 94: 1–7.

Brander, K. M. 2007. Global Fish Production and Climate Change. Proceedings of the National Academy of Sciences 104: 19709-19714.

Brook, R.K., and S.M. McLachlan. 2005. On using expert-based science to "test" local ecological knowledge. *Ecology and Society***10**(2):

Brown, G. P., R. Shine and T. Madsen. 2002. Source Responses of Three Sympatric Snake Species to Tropical Seasonality in Northern Australia. Journal of Tropical Ecology 18: 549-568.

Buckton, S. T. and R. J. Safford. 2004. The avifauna of the Vietnamese Mekong Delta. Bird Conservation International 14: 279-322.

Campbell, H. A., R. G. Dwyer, M. Gordos and Craig E. Franklin. 2010. Diving through the thermal window: implications for a warming world. Proceedings of the Royal Society B. doi:10.1098/rspb.2010.0902. 8 pages.

Campbell, I. C., C. M. Poole, W. Giesen and J. Valbo-Jorgensen. 2006. Species diversity and ecology of Tonle Sap Great Lake, Cambodia. Aquatic Sciences 68: 1-19.

Carew-Reid, J. 2007. Rapid Assessment of the Extent and Impact of Sea-Level Rise in Viet Nam. Climate Change Discussion Paper 1. ICEM – International Centre for Environmental Management, Brisbane, Australia.

Christensen, L., C.L. Tague, and J.S. Baron. 2008. Spatial patterns of simulated transpiration response to climate variability in a snow dominated mountain ecosystem. *Hydrological Processes* 22: 3576–3588.

Claassen, A. H. 2003. Abundance, Distribution, and Reproductive Success of Sandbar Nesting Birds Below the Yali Falls Hydropower Dam on the Sesan River, northeastern Cambodia. WWF-Cambodia Program/DANIDA/Wildlife Conservation Society-Cambodia/BirdLife International-Vietnam/Sesan Protection Network (SPN) Project Ratanakiri Province, Phom Penh, Cambodia.

Clough, J.S., R.A.Park, and R. Fuller. 2010. SLAMM 6 beta technical documentation. Warren Pinnacle Consulting, Inc., Warren, VT.

Cruz, R.V., H. Harasawa, M. Lal, S. Wu, Y. Anokhin, B. Punsalmaa, Y. Honda, M. Jafari, C. Li and N. Huu Ninh. 2007. Asia. Pages 496-506 in M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, eds. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K.

Davis, G. M. 1982. Historical and Ecological Factors in the Evolution, Adaptive Radiation, and Biogeography of Freshwater Mollusks. American Zoologist 22: 375-395.

Duckworth, J. W., R. E. Salter, and K. Khounboline. (compilers.) 1999a. Wildlife in Lao PDR: 1999 status report. IUCN-The World Conservation Union / Wildlife Conservation Society / Centre for Protected Areas and Watershed Management, Vientiane, Laos.

Dugan, P., A. Delaporte, N. Andrew, M. O'Keefe and R. Welcomme. 2010. Blue Harvest: Inland Fisheries as an Ecosystem Service. WorldFishCenter, Penang, Malaysia.

Foden, W., Mace, G., Vié, J.-C., Angulo, A., Butchart, S., DeVantier, L., Dublin, H., Gutsche, A., Stuart, S. and Turak, E. 2008. Species susceptibility to climate change impacts. In: J.-C. Vié, C. Hilton-Taylor and S.N. Stuart (eds). The 2008 Review of The IUCN Red List of Threatened Species. IUCN Gland, Switzerland.Elsworth, P. G., F. Seebacher and C. E. Franklin. 2003. Sustained Swimming Performance in Crocodiles (Crocodylus porosus): Effects of Body Size and Temperature. Journal of Herpetology 37: 363-368.

Galbraith, H., R. Jones, R. Park, J. Clough, S. Herrod-Julius, B. Harrington and G. Page. 2002. Global Climate Change and Sea-Level Rise: Potential Losses of Inter-tidal Habitat for Shorebirds. Waterbirds: The International Journal of Waterbird Biology 25: 173-183.

Garzón, M.B., R. Blazek, M. Neteler, R. Sánchez de Dios, H.S. Ollero, and C. Furlanello. 2006. Predicting habitat suitability with machine learning models: The potential area of *Pinus sylvestris* L. in the Iberian Peninsula. *Ecological Modelling* 197: 383–393.

Gilbert, M., J. Slingenbergh and X. Xiao. 2008. Climate change and avian influenza. Rev. Sci. Tech. 27: 459-466.

Gilchrist G. and M. Mallory, 2007. Comparing Expert Based Science with Local Ecological Knowledge: What are We Afraid of? Ecology and Society 12 (1) 2007

Gitay, H., A. Suaréz, R. Watson, O. Ansimov, F. S. Chapin, R. V. Cruz, M. Finlayson et al. 2002. Climate change and biodiversity. IPCC Technical Paper V. Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Gitay, H., Finlayson, C.M.&Davidson, N.C. 2011. *A Framework for assessing the vulnerability of wetlands to climate change*. Ramsar Technical Report No. 5/CBD Technical Series No. 57. Ramsar Convention Secretariat, Gland, Switzerland& Secretariat of the Convention on Biological Diversity, Montreal, Canada. ISBN 92-9225-361-1 (print); 92-9225-362-X (web).

Glick, P., A. Staudt, and B. Stein. 2009. *A New Era for Conservation: Review of Climate Change Adaptation Literature.* National Wildlife Federation, Washington, D.C. http://www.nwf.org/ News-and-Magazines/Media-Center/ Reports/Archive/2009/~/media/ PDFs/Global Warming/Reports/ CimateChangeAdaptationLiterature Review.ashx.

Glick, P., B.A. Stein, and N.A. Edelson, editors. 2011. *Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment.* National Wildlife Federation, Washington, D.C..

Groves, C., M. Anderson, C. Enquist, E. Girvetz, T. Sandwith, L. Schwarz, and R. Shaw. 2010. *Climate Change and Conservation: A Primer for Assessing Impacts and Advancing Ecosystem-based Adaptation in The Nature Conservancy.* The Nature Conservancy, Arlington, VA. http://conserveonline.org/workspaces/ climateadaptation/documents/a-primerfor- assessing-impacts/view.html.

Halls, A. 2009. Climate change and Mekong fisheries. Catch and Culture 15: 12-16.

Harrison, P.A., P.M. Berry, N. Butt, and M. New. 2006. Modeling climate change impacts on species' distributions at the European scale: Implications for conservation policy. *Environmental Science & Policy* 9: 116–128.

Hartman, M.D., J.S. Baron, and D.S. Ojima. 2007. Application of a coupled ecosystem chemical equilibrium model, DayCent- Chem, to stream and soil chemistry in an alpine watershed. *Ecological Modelling* 200: 493–510.

Heller, N.E. and E. S. Zavaleta. 2009. Biodiversity management in the face of climate change: A review of 22 years of recommendations. Biological Conservation 142: 14-32.

Hoagland, K. E. and G. M. Davis. 1979. The Stenothyrid Radiation of the Mekong River 1. The *Stenothyra mcmulleni* Complex (Gastropoda: Prosobranchia). Proceedings of the Academy of Natural Sciences of Philadelphia 131: 191-230.

Hoanh, C. T., K. Jirayoot, G. Lacombe and V. Srinetr. 2010. Impacts of climate change and development on Mekong flow regime. First assessment – 2009. MRC Technical Paper No. 29. Mekong River Commission, Vientiane, Lao PDR.

Hogan, Z. 2004. Threatened fishes of the world: *Pangasianodon gigas* Chevey, 1931 (Pangasiidae). Environmental Biology of Fishes 70: 210.

Hogan, Z., I. G. Baird, R. Radtke and M. J. Vander Zanden. 2007. Long distance migration and marine habitation in the tropical Asian catfish, *Pangasius krempfi*. Journal of Fish Biology 71: 818-832.

Hortle K. G. 2009. Fishes of the Mekong - how many species are there? Catch and Culture 15: 4-12. http://www.mrcmekong.org/download/Reports/CCI_Forum_Notes_Final_Revised24Jun09_2.pdf#search=%22ccai)

http://www.thailand.panda.org/en/publications/publications/?156861/Assessing-the-implications-of-climate-change-at-the-provincial-level-in-Ca-Mau-and-Krabi

Hughes, L. 2003. Climate change and Australia: Trends, projections and impacts. Austral Ecology 28: 423-443.

Hunter, M.L. 2007. Climate change and moving species: Furthering the debate on assisted colonisation. *Conservation Biology* 21: 1356–1358.

ICEM, IUCN, World Fish, SEA START et al 2011. Case Study Guidance: Basin-wide climate change impact and vulnerability assessments for Wetlands of the Lower Mekong Basin for Adaptive Planning RFP No. 10-240 April 2011 Prepared for the Mekong River Commission.

ICEM, IUCN, World Fish, SEA START et al 2012. Basin-Wide Vulnerability Assessment: Basin-wide climate change impact and vulnerability assessments for Wetlands of the Lower Mekong Basinfor Adaptive Planning RFP No. 10-240 April 2011 Prepared for the Mekong River Commission.

ICEM. 2010. Saline Intrusion in the Mekong Delta, Vietnam – Trends, Impacts and Adaptation. Unpublished report. International Centre for Environmental Management, Hanoi, Vietnam.

Intergovernmental Panel on Climate Change (IPCC). 2001b. *Climate Change 2001: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. CambridgeUniversity Press, Cambridge, UK

Intergovernmental Panel on Climate Change (IPCC). 2007a. *Climate Change 2007: Synthesis Report.* Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team, R.K. Pachauri, and A. Reisinger (eds.) Intergovernmental Panel on Climate Change, Geneva, Switzerland

Johnson, W. C., B. V. Millett, T. Gilmanov, R. A. Voldseth, G. R. Guntenspergen and D. E. Naugle. 2005. Vulnerability of Northern Prairie Wetlands to Climate Change. BioScience 55: 863-872.

Johnston, R. M., C. T. Hoanh, G. Lacombe, A. N. Noble, V. Smakhtin, D. Suhardiman, S. P. Kam and P. S. Choo. 2010a. Rethinking agriculture in the Greater Mekong Subregion: how to sustainably meet food needs, enhance ecosystem services and cope with climate change. International Water Management Institute, Colombo, Sri Lanka.

Johnston, R., G. Lacombe, C. T. Hoanh, A. Noble, P. Pavelic, V. Smakhtin, D. Suhardiman, K. S. Pheng and C. P. Sze. 2010b. Climate change, water and agriculture in the Greater Mekong Subregion. IWMIResearch Report 136. International Water Management Institute/WorldFishCenter, Colombo, Sri Lanka.

Kalyar, J. Thorbjarnarson and K. Thirakhupt. 2007. An Overview of the Current Population and Conservation Status of the Critically Endangered River Terrapin, *Batagur baska* (Gray, 1831) in Myanmar, Thailand and Malaysia. The Natural History Journal of Chulalongkorn University 7: 51-65.

KleinR., "Adaptation to Climate Variability and Change: What is Optimal and Appropriate", in C. Biuponni and M. Schecter (eds), *Climate Change and the Mediterranean Region: Socio-economic Impacts, Vulnerability and Adaptation* (Cheltenham: Edward Elgar, 2002),

Kottelat, M. 2001. Conservation Priorities for Fish. Pages 183-195 in M. C. Baltzer, N.T. Dao and R. Shore, compilers. Towards a Vision for Biodiversity in the Forests of the Lower Mekong Ecoregion Complex. Technical Annex. WWF Indochina / WWF US, Hanoi, Vietnam and Washington, D.C., USA.

Kottelat, M. 2009. Fishes of the upper Nam Ou drainage in Laos. Community Fisheries: supporting food security and aquatic biodiversity (ComFish Project). Unpublished report. WWF Laos, Vientiane, Laos.

Lavorel, S., S. McIntire, J. Landsberg, and T.D.A. Forbes. 1997. Plant functional classifications: From general groups to specific groups based on response to disturbance. *Trends in Ecology & Evolution* 12: 474–478.

Lawler, J.J. 2009. Climate change adaptation strategies for resource management and conservation planning. *Annals of the New YorkAcademy of Sciences* 1162: 79–98. http://training.fws.gov/branchsites/lkm/ climate_change/june_09/cc-adaptreview.pdf.

Lips, K. R., P. A. Burrowes, J. R. Mendelson III and G. Parra-Olea. 2005. Amphibian Declines in Latin America: Widespread Population Declines, Extinctions, and Impacts. Biotropica 37: 163-165.

Lunetta, K.L., L.B. Hayward, J. Segal, and P. Van Eerdewegh. 2004. Screening large-scale association study data: Exploiting interactions using random forests. *BMC Genetics* 5: Article 32. doi:10.1186/1471-2156-5-32.

Martin, T.E. 2001. Abiotic vs. biotic influences on habitat selection of coexisting species, with implications for climate change. *Ecology* 82: 175–188.

Mawdsley, J.R., R. O'Malley, and D.S. Ojima. 2009. A review of climate change adaptation strategies for wildlife management and biodiversity conservation. *Conservation Biology* 23: 1080-1089. http://cses.washington.edu/cig/outreach/ seminarfiles/2009seminars/Mawdsleyetal- 2009.pdf.

Maxwell, A., C. Nareth, D. Kong, R. J. Timmins and J. W. Duckworth. 2006. Hog Deer (*Axis porcinus*) confirmed in the wild in eastern Cambodia. Natural History Bulletin of the Siam Society 54: 227-237.

Maxwell, J. F. 2001. Vegetation. Pages 47-54 in G. Daconto, ed. Siphandone Wetlands. CESVI, Bergamo, Italy.

Maxwell, J. F. 2009. Vegetation and vascular flora of the Mekong River, Kratie and Steung Treng Provinces, Cambodia. Maejo International Journal of Science and Technology 3: 143-211.

McLeod, D. S., J. A. Sheridan, W. Jiraungkoorskul and W. Khonsue. 2008. A survey for chytrid fungus in Thai amphibians. The Raffles Bulletin of Zoology 56: 199-204.

Milly, P.C.D., J. Betancourt, M. Falkenmark, R.M. Hirsch, Z.W. Kundzewicz, D.P. Lettenmaier, and R.J. Stouffer. 2008. Stationarity is dead: Whither water management? *Science* 319: 573–574.MRC 2010 'State of Basin' report

MRC and ICEM. 2009. Climate Change Adaptation in the Lower Mekong Basin Countries. Regional Synthesis Report. CCAI – Climate Change and Adaptation Initiative. Unpublished report. ICEM – International Centre for Environmental Management, Hanoi, Vietnam.

MRC. 2009a. Adaptation to climate change in the countries of the Lower Mekong Basin. MRC Management Information Booklet Series No.1. Mekong River Commission Secretariat, Vientiane, Laos.

MRC. 2009b. Adaptation to climate change in the countries of the Lower Mekong Basin: Regional Synthesis Report. MRC Technical Paper No. 24. Mekong River Commission Secretariat, Vientiane, Laos.

MRC. 2009c. Report on The Regional Forum on the Mekong River Commission Climate Change and Adaptation Initiative 2-3 February Bangkok, Thailand. Mekong River Commission Secretariat, Vientiane, Laos. (Downloaded:

MRC. 2010.State of the Basin Report 2010. Mekong River Commission Secretariat, Vientiane, Laos.

Nabhitabhata, J. and T. Chan-ard. 2005. Thailand Red Data: Mammals, Reptiles and Amphibians. Office of Natural Resources and Environmental Policy and Planning, Bangkok, Thailand.

National Research Council (NRC). 2010. *Adapting to the Impacts of Climate Change.* America's Climate Choices: Panel on Adapting to the Impacts of Climate Change. National Academies Press, Washington, D.C. http://americasclimatechoices.org/ paneladaptation.shtml.

Noske, R.A. 2011. The potential impacts of climate change on the birds of Indonesia. In: Impact of Climate Change on Biodiversity; does Nature Conservation need New Strategies? Proceedings of German Alumni Summer School, Manado, Indonesia. Cuvillier Verlag, Göttingen, Germany.

O'Connor, R.J., M.T. Jones, D. White, C. Honsaker, T. Loveland, B. Jones, and E. Preston. 1996. Spatial partitioning of environmental correlates of avian biodiversity in the conterminous United States. *Biodiversity Letters* 3: 97–110.

Ojima, D.S., W.J. Parton, M.B. Coughenour, J.M.O. Scurlock, T.B. Kirchner, T.G.F. Kittel, D.O. Hall, D.S. Schimel, E. Garcia Moya, T.G. Gilmanov, T.R. Seastedt, A. Kamnalrut, J.I. Kinyamario, S.P. Long, J.-C. Menaut, O.E. Sala, R.J. Scholes, and J.A. van Veen. 1996. Impact of climate and atmospheric carbon dioxide changes on grasslands of the world. p. 271–311. In: *Global Change: Effects on Coniferous Forests and Grasslands.* A.I. Breymeyer, D.O. Hall, J.M. Melillo, and G.I. Agren (eds.) SCOPE Volume 56. John Wiley & Sons, Chichester, UK.

Opdam, P. and D. Wascher. 2004. Climate change meets habitat fragmentation: linking landscape and biogeographical scale levels in research and conservation. Biological Conservation 117: 285-297.

Parmesan, C., and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421: 37–42.

Pearson, R. G. and T. P. Dawson. 2003. Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? Global Ecology & Biogeography 12: 361-371.

Peh, K. S-H. 2007. Potential Effects of Climate Change on Elevational Distributions of Tropical Birds in Southeast Asia. The Condor 109: 437-441.

Phillips, S.J., R.P. Anderson, and R.E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modelling* 190: 231–259.

Phu, V. V., T. T. C. Ha and H. T. Hong. 2006. An Assessment of the Fish Fauna of the Green Corridor Forest Landscape, Thua Thien Hue Province, Vietnam. Report No 5: Green Corridor Project. WWF Greater Mekong Programme / FPD Thua Thien Hue Province, Vietnam.

Pounds, J. A., M. P. L. Fogden and J. H. Campbell. 1999. Biological response to climate change on a tropical mountain. Nature 398: 611-614.

Rahel F.J. and J.D. Olden J.D. 2008. Assessing the effects of climate change on aquatic invasive species. Conservation Biology 22: 521-533.

Reist, J.D., F.J. Wrona, T.D. Prowse, M. Power, J.B. Dempson, J.R. King, and R.J. Beamish. 2006. An overview of effects of climate change on selected arctic freshwater and anadromous fishes. *Ambio* 35: 381–387.

Roberts, T. R. 2001. On the river of no returns: Thailand's Pak Mun dam and its fish ladder. Natural History Bulletin of the Siam Society 49: 189-230.

Ron, S. 2005. Predicting the Distribution of the Amphibian Pathogen Batrachochytrium dendrobatidis in the New World. Biotropica 37: 209-221.

Root, T.L. 1988b. Environmental factors associated with avian distributional boundaries. *Journal of Biogeography* 15: 489–505.

Rundel, P. W. 1999. Conservation Priorities In Indochina - WWF Desk Study. Forest habitats and flora in Lao PDR, Cambodia and Vietnam. World Wide Fund for Nature - Indochina Programme Office, Hanoi, Vietnam.

Sanguansombat, W. 2005. Thailand Red Data: Birds. Office of Natural Resources and Environmental Policy and Planning, Bangkok, Thailand.

Satrawaha, R., P. Prathepha, R. Andrews and T. Petney. 2009. Fundamental hydrochemical parameters of the Songkhram River in Northeast Thailand: foundation data for the study of an endangered tropical wetland ecosystem. Limnology 10: 7-15.

Stolton S, Hockings, M, Dudley, N, MacKinnon, K, Whitten, T and Leverington, F (2007) 'Reporting Progress in Protected Areas A Site Level Management Effectiveness Tracking Tool: second edition.' World Bank/WWF Forest Alliance published by WWF, Gland, Switzerland.

Stockwell, D.R., and D. Peters. 1999. The GARP modeling system: Problems and solutions to automated spatial prediction. *International Journal of Geographical Information Science* 32: 143–158.

Strayer, D. L. 2010. Alien species in fresh waters: ecological effects, interactions with other stressors, and prospects for the future. Freshwater Biology 55: 152-174.

Stuart, B. L., R. F. Inger and H. K. Voris. 2006. High level of cryptic species diversity revealed by sympatric lineages of Southeast Asian forest frogs. Biology Letters 2: 470-474.

Tebaldi, C., and R. Knutti. 2007. The use of the multi-model ensemble in probabilistic climate projections. *Philosophical Transactions of the Royal Society* A 365: 2053–2075.

Thewlis, R. M., R. J. Timmins, T. D. Evans and J. W. Duckworth. 1998. The conservation status of birds in Laos: a review of key species. Bird Conservation International 8 (Supplement): 1-159.

Timmins, R. J. 2006. An assessment of the biodiversity conservation significance of the Mekong Ramsar site, Stung Treng, Cambodia. Mekong Wetlands Biodiversity Conservation and Sustainable Use Programme, Vientiane, Laos.

Timmins, R.J. 2008. Pages 53-80 in M. R. Bezuijen, R. J. Timmins and T. Seng, eds. Biological surveys of the Mekong River between Kratie and StungTrengTowns, northeast Cambodia, 2006-2007. WWF Greater Mekong - Cambodia Country Programme / Cambodia Fisheries Administration / Cambodia Forestry Administration, Phnom Penh, Cambodia.

TKK and SEA START RC. 2009. Water and Climate Change in the Lower Mekong Basin: Diagnosis & recommendations for adaptation, Water and Development Research Group. Helsinki University of Technology (TKK) / Southeast Asia START Regional Center (SEA START RC) / Chulalongkorn University. Water & Development Publications, Helsinki University of Technology, Espoo, Finland.

Traill, L.W., C.J.A. Bradshaw, S. Delean, B.W. Brook. 2010. Wetland conservation and sustainable use under global change: a tropical Australian case study using magpie geese. Ecography 33: 818-825.

Traill, L.W., Whitehead, P.J. and B.W. Brook. 2009. How will climate change affect plant–herbivore interactions? A tropical waterbird case study. Emu 109: 126-34.

Trandem, A. 2008. A Vietnamese/Cambodian Transboundary Dialogue: Impacts of dams on the Se San River. Development 51: 108-113.

U.S. Climate Change Science Program (U.S. CCSP). 2008. *Preliminary Review of Adaptation Options for Climate-sensitive Ecosystems and Resources.* A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. S.H. Julius and J.M. West (eds.); J.S. Baron et al. (authors). U.S. EPA, Washington, D.C. http://downloads. climatescience.gov/sap/sap4-4/sap4-4- final-report-all.pdf.

U.S. Environmental Protection Agency(EPA). 2009. *A Framework for Categorizing the Relative Vulnerability of Threatened and Endangered Species to Climate Change*.EPA/600/R-09/011. National Center for Environmental Assessment, Washington, D.C. http://www.epa.gov/ncea.

United Nations Framework Convention on Climate Change (UNFCCC).2008. *Compendium on Methods and Tools to Evaluate Impacts of, Vulnerability and Adaptation to, Climate Change.* UNFCC, Bonn, Germany. http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/2674.php.

Vidthayanon, C. 2005. Thailand Red Data: Fishes. Office of Natural Resources and Environmental Policy and Planning, Bangkok, Thailand.

Webb, G. J. W., A. M. Beal, S. C. Manolis and K. E. Dempsey. 1987. The Effects of Incubation Temperature on Sex Determination and Embryonic Development Rate in Crocodylus johnstoni and C. porosus. Pages 507-531 in G. J. W. Webb, S. C. Manolis and P. J. Whitehead, eds. Wildlife Management: Crocodiles and Alligators. Surrey Beatty and Sons Pty Limited/Conservation Commission of the Northern Territory, Chipping Norton and Darwin, Australia.

Welcomme, R. L., I. G. Cowx, D. Coates, C. Béné, S. Funge-Smith, A. Halls and K. Lorenzen. 2010. Inland capture fisheries. Phil. Trans. R. Soc. B 365: 2881-2896.

West, J.M., S.H. Julius, P. Kareiva, C. Enquist, J.J. Lawler, B. Petersen, A.E. Johnson, and M.R. Shaw. 2009. U.S. natural resources and climate change: Concepts and approaches for management adaptation. *Environmental Management* 44: 1001–1021. http://www. ncbi.nlm.nih.gov/pmc/articles/PMC2791483/ pdf/267_2009_Article_9345.pdf.

Williams, B.K., R.C. Szaro, and C.D. Shapiro. 2007. Adaptive Management: The *U.S. Department of the Interior Technical Guide.* Adaptive Management Working Group, U.S. Department of the Interior, Washington, D.C. http://www.doi.gov/initiatives/ AdaptiveManagement/TechGuide.pdf.

Williams, S.E., L.P. Shoo, J.L. Isaac, A.A. Hoffmann, and G. Langham. 2008. Towards an integrated framework for assessing the vulnerability of species to climate change. *PloS Biology* 6: 2621–2626.

WMO 2012 The World Meteorological Organization http://www.wmo.int/pages/themes/climate/emission_scenarios.php

Wyatt, A. B. and I. G. Baird. 2007. Transboundary Impact Assessment in the Sesan River Basin: The Case of the YaliFalls Dam. International Journal of Water Resources Development 23: 427-442.

Zhang, F., Y. Li, Z. Guo and B.R. Murray. 2009. Climate warming and reproduction in Chinese alligators. Animal Conservation 12: 128-137.

ANNEX 2. EXAMPLES OF OTHER RESPONSE MODELS

Model Type	Characteristic Qualitative or Quantitative		Source
Conceptual model	Model identifies key processes related to the conservation goal qualitative		Open standards
General Character-ization Models	Model uses generalized traits to identify how groups of species might respond to climate or habitat change.- Qualitative		Lavorel et al. 1997 Parmesan and Yohe 2003; Allen et al. 2010.
	Nature Serve Climate Change Vulnerability Index		http://www.natureserve.org/prodServices/climatechange/ClimateChange.jsp
Expert Opinion Models	Models are constructed from the opinions of experts on a species, habitat, or ecosystem. It is often used when qualitative data are insufficient to develop a different model- Qualitative		
	Bayesian Analysis Toolkit	Bayesian statistics are used to combine data from different sources to estimates of uncertainty	http://www.mppmu.mpg.de/bat/ Berliner et al. 2000; Prato 2009
	TreeAge Pro software		http://www.treeage.com/products/index.html
	Delphi Decision Aid site		http://armstrong.wharton.upenn.edu/delphi2/
Habitat and Occupancy Models	Model determines habitat suitability over an area based on the agreed habitat criteria. Quantitative		
	Climate Envelope models	ranges of biophysical attributes, e.g., climate, soils, vegetation or land cover, elevation, etc. are requirements that a species will occupy (e.g., “suitable” habitat)	Harrison et al. 2006; Pearson and Dawson 2003 http://software.informer.com/getfree-bioclim-download-software/
	Bioclim		http://software.informer.com/getfree-bioclim-downloadsoftware/
	Open Modeller	openModeller is an ecological niche modelling library, providing a uniform method to model species distribution patterns with a variety of algorithms	http://sourceforge.net/projects/openmodeller/files/
	WETSIM	Simulates wetland habitat change in the prairie pothole region of North America	Johnson, et al. 2005. http://proceedings.esri.com/library/userconf/proc06/papers/papers/pap_1916.pdf
	Sea-Level Affecting Marshes Model (SLAMM),.	Model uses a decision tree incorporating geometric and qualitative relationships to represent transfers among coastal habitat under various scenarios of sea-level rise	Clough et al. 2010

Model Type	Characteristic Qualitative or Quantitative		Source
	GAP Program models:		http://www.nbii.gov/portal/server.pt/community/maps_and_data/1850/species_modeling/7000
	NOAA Coastal Climate Adaptation:		http://collaborate.csc.noaa.gov/climateadaptation/default.aspx
	Genetic Algorithm for Rule-set Production (GARP) and Maximum Entropy (Maxent)	Niche-based model to estimate species distributions and habitat suitability. involves quantitative estimates of the probability of occurrence of a species	GARP Stockwell and Peters 1999 http://www.nhm.ku.edu/desktopgarp Maxent Phillips et al. 2006 http://www.cs.princeton.edu/~schapire/maxent
	Regression Tree and Random Forests	use habitat suitability for species, and are able to assess how biophysical attributes change among different geographies	http://rattle.togaware.com/rattle-download.html O'Connor et al. 1996; Lunetta et al. 2004; Garzón et al. 2006
Physiologically Based Models	Models incorporate sensitive aspects of individual species physiologies that influence foraging, nesting/reproduction, thermoregulation, and migration		Root 1988a and 1988b; Martin 2001; Reist et al. 2006; Bernardo et al. 2007; Hunter 2007
Ecological Models	models used to assess sensitivity and vulnerability of important ecological processes to climate change.		
	CENTURY	a general model of plant–soil nutrient cycling	http://www.nrel.colostate.edu/projects/century5/ Ojima et al. 1996.
	DayCent-Chem	predicts carbon and nitrogen dynamics within forests and leaching of nitrogen from forests to streams	Hartman et al. 2007
	Regional Hydro-Ecologic Simulation System (RHESSys)	GIS–based hydro-ecological modeling framework, which simulates how water, carbon, and nutrients fluctuate through the environment on a watershed scale	http://fiesta.bren.ucsb.edu/~rhessys/setup/downloads/downloads.html Christensen et al. 2008
	PnET	is a suite of three nested models, which simulate carbon, water, and nitrogen dynamics of forest ecosystems	http://www.pnet.sr.unh.edu/ Aber et al. 1995
	Regional Drought models		
	Variable Infiltration Capacity (VIC)	These models track the movement of water through the landscape	http://www.hydro.washington.edu/Lettenmaier/Models/VIC/
	Compendium of conceptual ecological response models:		http://www.fileheap.com/software/conceptual_data_model.html

Model Type	Characteristic Qualitative or Quantitative		Source
	USDAForestServiceClimateChange ResourceCenter:		***http://www.fs.fed.us/ccrc/***
	PATCH Landscape model:		http://www.epa.gov/wed/pages/ news/03June/schumaker.htm
Bioclimatic metrics	WorldClim		http://www.worldclim.org/.
	Climate Adaptation Knowledge Environment (CAKE):		http://www.cakex.org/
	ClimateWizard:		http://www.climatewizard.org.

ANNEX 3. LESSONS LEARNED FROM THE CASE STUDIES

	Xe Champhone	Lower Songkhram River	Stung Treng and Lower Stung Sen	Tram Chim
SRES Model	Inaccurate prediction of the ways in which climate may change leads to incorrect prediction of the vulnerability of ecological and species vulnerability.	Exact trends and degree of change should be discussed and agreed BEFORE the vulnerability assessment. Multiple climate projections were lumped into a single scenario rather than working with range of future climate or various extreme conditions from different climate projections, which would make the assessment more robust	Huge gaps remain on even how local climate change would be and how it would be different from global or regional average.	Could not open this file
Habitat information lacking	more days of direct field observation, and would have benefited from field visits in both wet and dry seasons. We also need to examine both seasonal or cross-section changes.	Major limitation is the understanding of how species or habitat is sensitive to climate variability and extreme weather event. More scientific evidence is needed, especially about "DOSE (degree of change of climate parameters) – RESPONSE (biological response of biota & ecosystems to be analyzed) curve /relationship"	There is limited information and understanding about climate change and its impacts on the natural environment, wetland ecosystems in particular.	
More taxa experts	The technical team should have members from different backgrounds especially biology, hydrology, wildlife, fisheries, botany and sociology.	Team working could be more intensive and more productive To extend expert opinion collection to cover more experts in the process, so that it would have been the expert group judgment, not just that of a single expert	Our expert judgment tends to be less participatory. More engagement from people with experiences should be involved. With the process dragged for too long, we lost our concentration and not quite sure of what we had agreed to in earlier discussions.	

	Xe Champhone	Lower Songkhram River	Stung Treng and Lower Stung Sen	Tram Chim
This methodology	More team training in the case study approach and method may also be needed	To have a workshop to clearly agree on methodology and to thoroughly review data for the assessment prior to and also mid-way through the assessment. Approaches & methods developed worked well; case studies methods are considered useful It's possible to further develop to a so-called quantitative meta-study and/or systematic review research.	• In the calculation matrix, M+M+L = H, does not look right.	
Management issues	difficult to have open conversations about the management or future of the site		With the process dragged for too long, we lost our concentration and not quite sure of what we had agreed to in earlier discussions.	
More comparative data needed	Also, the data is very patchy across wetlands sites, even within countries, making it hard to develop a comprehensive baseline and to draw comparisons between sites	not practical to separate effect of climate change from other human-induced threats in vulnerability assessment.		
Species selected	should not only consider vulnerable and endangered species but also keystone species		Clear identification of species groups and parameters for assessment and should be made before hands and this should be the basis for talking with community.	
More time need	More time needed	Time is a big constraint, and is always limited.	There should be enough time for literature review before one should proceed to field assessment.	

ANNEX 4. WETLAND VILLAGE CLIMATE CHANGE VULNERABILITY ASSESSMENTS FORMS

Wetland Village Climate Change Vulnerability Assessment Form 1. Wetland description

Wetland Description
Provided in Wetland Village VA Tool spreadsheet, 1. Wetland Info

A methodology for rapid climate change vulnerability assessments for wetlands biodiversity in the Lower Mekong Basin

This worksheet is be used by wetland managers to discuss climate change issues with villagers. This worksheet should be used in conjunction with the methodology report titled "A methodology for rapid climate change vulnerability assessments for wetlands biodiversity in the Lower Mekong Basin"

1	**Wetland name**

2	**Wetland location**
	Village
	District
	Province

3	**Team Members (villager, manager, expert)**

4	**Brief description of the wetland**	
	Who has management authority for the wetland?	
	Who are the major stakeholders in the wetland use?	
	Total Hectares?	
	What are the major habitats?	
	What are the key species?	
	Hectares open water in the dry season?	
	Hectares of marsh?	
	Kilometers of rapids and riffles?	
	Hectares of wet forest?	

5 List the 10 most important wetland resources used in the village.

Rank	Item	Use
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Wetland Village Climate Change Vulnerability Assessment Form 2. Climate change in the wetland area

Climate Change in the Wetland Area

Provided in Wetland Village VA Tool spreadsheet,, 2. Future climate

To find the projected 2050 climate change please go to the climate change vulnerability assessment manual.

	Future weather	
1	Rainfall	
2	Temperature	
3	Hydrology	
4	Extreme weather events	
5	How will the wetland change as a result of climate change	
6	Seasonal changes	
7	Soil water availability	

Wetland Village Climate Change Vulnerability Assessment Form 3. Wetland climate history

Wetland Climate History

Provided in Wetland Village VA Tool spreadsheet, 3. C History

Village name	
Team members	
Wetland name	

Make a list of extreme weather events over the last 10 years. What effect has extreme weather had on the wetland habitats and important species?

Extreme weather event	Estimated date or memorable event	Effect on wetland habitats and important species

Examples of extreme weather events

Drought
Extreme heat
Floods
Hailstorms
High Winds
Rainstorms
Storm surges
Typhoons
Wild fires

Wetland Village Climate Change Vulnerability Assessment Form 4. Wetland climate hazards and impacts

Wetland Climate Hazard and Impact (Exposure)

Provided in Wetland Village VA Tool spreadsheet, 4. Frequency-Impacts

Use the list you made on the climate history form to complete this questions. In the 'Comments' column, note what impact this has had on the village.

Village name	**0**
Team members	**0**
Wetland name	**0**

Variable	Score	Definitions		Confidence	Impacts
1. Does your village experience drought?		**1**	· 1 in 10 years		What impacts were felt by the village?
		2	· 1 in 5 years		
		3	· 1 in 3 years		
2. Does your village experience flood?		**1**	· 1 in 10 years		
		2	· 1 in 5 years		
		3	· 1 in 3 years		
3. Does your village experience strong winds?		**1**	· 1 in 10 years		
		2	· 1 in 5 years		
		3	· 1 in 3 years		
4. Does your village experience extreme heat?		**1**	· 1 in 10 years		
		2	· 1 in 5 years		
		3	· 1 in 3 years		
5. Does your village experience typhoon?		**1**	· 1 in 10 years		
		2	· 1 in 5 years		
		3	· 1 in 3 years		
6. Does your village experience hailstorm?		**1**	· 1 in 10 years		
		2	· 1 in 5 years		
		3	· 1 in 3 years		
7. Does your village experience dust storm?		**1**	· 1 in 10 years		
		2	· 1 in 5 years		
		3	· 1 in 3 years		

Variable	Score	Definitions		Confidence	Impacts
8. Does your village experience wild fire?		**1** **2** **3**	· 1 in 10 years · 1 in 5 years · 1 in 3 years		
9. Does your village experience storm surge		**1** **2** **3**	· 1 in 10 years · 1 in 5 years · 1 in 3 years		
Average extreme weather event.			**Average confidence**		

Example impacts:

- Crop damage/loss
- Damage to dwellings
- Depletion of grain stores
- Disease
- Disrupted transport
- Fuel shortages
- Household food insecurity
- Income loss
- Loss of life
- Loss of savings
- Loss of trees
- Personal injury
- Reduced fish stocks
- Reduced soil fertility
- Reduced water quality
- Sick or weak livestock
- Social conflict/tension
- Unemployment
- Water shortage

Examples of hazards:

- Drought
- Extreme cold
- Extreme heat
- Floods
- Hailstorms
- High Winds
- Rainstorms
- Sand/Dust storms
- Storm surges
- Typhoons
- Wild land fires

Wetland Village Climate Change Vulnerability Assessment Form 5. Village coping strategies

Village coping strategies worksheet (Resilience/Adaptation)
Provided in Wetland Village VA Tool spreadsheet, 5. Current coping

Using your list made for climate hazard frequency, list impacts and coping strategies used by the village. Space is provided for 3 impacts for each extreme weather event. How does the wetland help villages to cope with extreme weather?

Village name	
Team members	
Wetland name	

Variable	Coping with the impacts		Score	Definitions		Comments
	Impact	Coping strategy				
1a. When your village experiences **drought,** what do you do?	Impact 1			**1** **2** **3**	· Mostly successful · OK but not the best · Not very successful	
1b. When your village experiences **drought,** what do you do?	Impact 2			**1** **2** **3**	· Mostly successful · OK but not the best · Not very successful	
1c. When your village experiences **drought,** what do you do?	Impact 3			**1** **2** **3**	· Mostly successful · OK but not the best · Not very successful	
2a. When your village experiences **flood** what do you do?	Impact 1			**1** **2** **3**	· Mostly successful · OK but not the best · Not very successful	
2b. When your village experiences **flood** what do you do?	Impact 2			**1** **2** **3**	· Mostly successful · OK but not the best · Not very successful	

Variable	Coping with the impacts		Score	Definitions		Comments
2c. When your village experiences **flood** what do you do?	Impact 3			1 2 3	· Mostly successful · OK but not the best · Not very successful	
3a. When your village experiences what do you do?	Impact 1			1 2 3	· Mostly successful · OK but not the best · Not very successful	
3b. When your village experiences what do you do?	Impact 2			1 2 3	· Mostly successful · OK but not the best · Not very successful	
3c. When your village experiences what do you do?	Impact 3			1 2 3	· Mostly successful · OK but not the best · Not very successful	
4a. When your village experiences what do you do?	Impact 1			1 2 3	· Mostly successful · OK but not the best · Not very successful	
4b. When your village experiences what do you do?	Impact 2			1 2 3	· Mostly successful · OK but not the best · Not very successful	
4c. When your village experiences what do you do?	Impact 3			1 2 3	· Mostly successful · OK but not the best · Not very successful	
	Average score					
5. Comment on the average coping score and how wetlands help to cope with extreme weather						

Example impacts:

Crop damage/loss
Damage to dwellings
Depletion of grain stores
Disease
Disrupted transport
Fuel shortages
Household food insecurity
Income loss
Loss of life
Loss of savings
Loss of trees
Personal injury
Reduced fish stocks
Reduced soil fertility
Reduced water quality
Sick or weak livestock
Social conflict/tension
Unemployment
Water shortage

Examples of coping strategies:

Casual labor
Common property systems
Crop shifting
Food rationing
Food storage
Gathering of wild food
Income diversification
Rainwater harvesting
Reallocation of labor
Selling of personal belongings
Tree/Crop replanting
Water rationing
Pumping more water for rice
Some people move to the city

Wetland Village Climate Change Vulnerability Assessment Form 6. Future coping strategies

Future Coping Strategies Worksheet
Provided in Wetland Village VA Tool spreadsheet, 6. Future coping

Using the list made for current weather impacts and coping, and using prediction of future climate, complete this form for how the village will cope with future climate events. Space is provided for 3 impacts for each extreme weather event. Prioritize each impact as importance on the village livelihoods.

Village name	
Team members	
Wetland name	

Variable	Coping with future impacts		Score	Definitions		Comments
	Impact	Management strategy				
1a. When your village experiences future **droughts,** what will you do?	Impact 1			1 2 3	· Low priority · Medium priority · High priority	
1b. When your village experiences future **droughts,** what will you do?	Impact 2			1 2 3	· Low priority · Medium priority · High priority	
1c. When your village experiences future **droughts,** what will you do?	Impact 3			1 2 3	· Low priority · Medium priority · High priority	
2a. When your village experiences future **floods** what will you do?	Impact 1			1 2 3	· Low priority · Medium priority · High priority	
2b. When your village experiences future **floods** what will you do?	Impact 2			1 2 3	· Low priority · Medium priority · High priority	
2c. When your village experiences future **floods** what will you do?	Impact 3			1 2 3	· Low priority · Medium priority · High priority	
3a. When your village experiences what will you do?	Impact 1			1 2 3	· Low priority · Medium priority · High priority	
3b. When your village experiences what will you do?	Impact 2			1 2 3	· Low priority · Medium priority · High priority	

Variable	Coping with future impacts		Score	Definitions		Comments
3c. When your village experiences what will you do?	Impact 3			**1** **2** **3**	· Low priority · Medium priority · High priority	
4a. When your village experiences what will you do?	Impact 1			**1** **2** **3**	· Low priority · Medium priority · High priority	
4b. When your village experiences what will you do?	Impact 2			**1** **2** **3**	· Low priority · Medium priority · High priority	
4c. When your village experiences what will you do?	Impact 3			**1** **2** **3**	· Low priority · Medium priority · High priority	
	Average score					
5. Comment on the average priority score and identify common themes of vulnerability.						

Example impacts:
Crop damage/loss
Damage to dwellings
Reduced fish stocks
Reduced frog stocks
Loss of wetland species
Depletion of grain stores
Disease
Disrupted transport
Fuel shortages
Loss of fish
Personal injury
Reduced soil fertility
Reduced water quality
Sick or weak livestock
Social conflict/tension
Unemployment
Water shortage

Examples of coping strategies:
Casual labor
Pumping more water for rice
Crop shifting
Food rationing
Food storage
Gathering of wild food
Rainwater harvesting
Reallocation of labor
Selling of personal belongings
Crop replanting
Water rationing
Some people move to the city

Wetland Village Climate Change Vulnerability Assessment Form 7. Future wetland strategies

Future Wetland Strategies Worksheet
Provided in Wetland Village VA Tool spreadsheet, 7. Future wetland

Using the habitat and species list made in the Wetland Information tab Box 5, Please advise on future wetland management during extreme weather events.

Village name	
Team members	
Wetland name	

Wetland Resource		Use	Management during extreme weather events		Comments
			Current management	**Future management**	
0	for	0			
0	for	0			
0	for	0			
0	for	0			
0	for	0			
0	for	0			
0	for	0			
Comment on how wetlands might help to cope with extreme weather					
Describe uncertainty and gaps in understanding that should be followed up with more detailed study					

ANNEX 5. HABITAT AND SPECIES CLIMATE CHANGE VULNERABILITY ASSESSMENTS FORMS

Habitat and Species CC VA Form 1. Climate Change Vulnerability Narrative

Species name		
Expert team		
Wetland name and location		

Description of the habitat or species

Give a brief description of:

1. Introduction
    a. Name and location of the wetland
    b. Who is on the evaluation team
    c. Restate the objectives of the climate change vulnerability assessments
    d. What are the projected climatic changes to this wetland? (add this after you complete Step 3)
2. Species or Habitats national and international conservation status
    a. What is the IUCN Red List?
    b. What is the national status or priorities in national actions plans?
3. Distribution and Population Trends
    a. Are there estimates of current local and global population's sizes?
    b. Are there estimates of current local and global population's trends?
    c. What is the geographic range of the species or habitat? Where are migration routes and other seasonal habitats?
4. Habitat description
    a. Do you have maps of the wetland habitat in the wet and dry season? << include here>>
    b. What are the hydrological factors that affect the wetland habitats?
    c. What species make up this habitat?
    d. What habitats are critical for the species?
    e. Has the habitat increased or decreased in area over time?
5. Ecological limitations on the distribution and status
    a. Is the species a specialist within a habitat?
    b. Does this species have a dependant relationship to other species?
    c. Is the habitat or species more abundant in other places?
    d. Is the species affected by invasive species?
6. Climatic limitations on distribution
    a. What are the physiological limits to the species or habitat distribution? (e.g. altitude, temperature, precipitation, extreme weather events)
7. Existing stressors and their effects on distribution and status- Does the species/habitat have commercial value?
    a. Does the species/habitat have subsistence value?
    b. Is the species affected by habitat fragmentation?
    c. Is the wetland/habitat affected by other demands on hydrology? (e.g. irrigation)
8. Potential Direct (physiological) vulnerability to climate change
    a. How do you think the species will respond to future temperature and precipitation and hydrological patterns?
    b. Are you aware of related species that have been studied for climate change adaptation? If yes, Can you draw conclusions from them?
9. Potential Indirect (ecological) vulnerability to climate change - use this to complete form z.
    a. How do you think the species will respond to future ecological change?
    b. How do you think the species will respond to future extraction threats?

10. Summarize the findings from the Baseline Conservation Status Study done in Step 5
    a. What is the Baseline Status score?
    b. Do you feel confident in the score?
11. Summarize the findings from the Climate Change Vulnerability Study done in Step 6.
    a. What is the Climate Change Vulnerability score?
    b. Do you feel confident in the score?
12. Summarize the findings from Combined Vulnerability done in Step 7
    a. What is the Combined Vulnerability score?
    b. Do you feel confident in the score?
    c. Speculate what you think will happen to the species or habitat given the current management conditions?
13. Summarize the Uncertainty-
    a. Which factors are you the most uncertain about?
    b. Where is the largest gap in knowledge?

Baseline conservation status average confidence	
Climate change vulnerability average confidence	

14. References make a list of all literature and sources used

Habitat and Species CC VA Form 2. Baseline Habitat Status Variables and Definitions

Baseline Habitat Variables and Definitions

Provided in Habitat VA Tool spreadsheet, 2. H baseline

Habitat name	
Expert team	
Wetland name and location	

Variable	Score		Characteristics of the Species	Confidence	Comment.
1. How much of this habitat type is found in the wetland?		**1**	· The habitat covers large proportion of the wetland area		
		2	· The habitat covers medium proportion of the wetland area		
		3	· The habitat covers small proportion of the wetland area		
2. What is the habitat size trend in the last 50 years in this wetland?		**1**	· The habitat is increasing		
		2	· The habitat is staying the same		
		3	· The habitat is decreasing		
3. What is the total geographic representation of the habitat within the region?		**1**	· The habitat common throughout the region		
		2	· The habitat found in few places throughout the region		
		3	· The habitat only found in this wetland		
4. What is the habitat size trend in the region in the last 50 years?		**1**	· This habitat type is increasing in the LMB		
		2	· This habitat type is the same in the LMB		
		3	· This habitat type is decreasing in the LMB		
5. What is the relative vegetation diversity for this type of habitat?		**1**	· There are large number of plant species making up habitat		
		2	· There is an intermediate number of plant species between large and small		
		3	· There is a single species or few species predominate the habitat		
6. Does the habitat normally require flood for regeneration?		**1**	· Flood is needed		
		2	· Some flood is needed		
		3	· Flood is not tolerated		
7. Does the habitat normally require fire for regeneration?		**1**	· Fire is needed		
		2	· Some fire is needed		
		3	· Fire is not tolerated		
8. What is the degree of disturbance needed to maintain this habitat?		**1**	· High disturbance is needed		
		2	· Modified		
		3	· Undisturbed is needed		

Variable	Score		Characteristics of the Species	Confidence	Comments
9. Are there keystone species needed to maintain this the habitat?		1 2 3	· No · A few · Many		
10. Are there important economic species in this wetland?		1 2 3	· No · A few · Many		
11. Are exotic species a problem in this habitat?		1 2 3	· No · A little · Very serious problem		
12. Are there threats to conversion of this habitat?		1 2 3	· No · Maybe · Yes		
13. How does the habitat recover from recent extreme weather events?		1 2 3	· recovers fast · recovers slowly · does not recover		
14. Is the wetland currently protected?		1 2 3	· Yes · Protection status is being considered · No		
15. Additional question specific to this habitat?		1 2 3	· less vulnerable · more vulnerable		
Total score			**Average Confidence**		

National Conservation Status

National Conservation Status Descriptions

A	National Park
B	National Protected area
C	Provincial protected area
D	Community protected area, Fish Conservation Zone, Community Forest
E	No protection

Global Conservation Status

Global Conservation Status Descriptions

F	Ramsar site
G	UNESCO Biosphere Reserve
H	World Heritage Site
I	No designation

Habitat and Species CC VA Form 3. Habitat Climate Change Variables and Definitions

Climate Change Threats

Provided in Habitat VA Tool spreadsheet, 3. H threat

Describe the main threats to the habitat at this location from climate change

Climate Change in the Wetland Area

1	**Rainfall**	
2	**Temperature**	
3	**Hydrology**	
4	**Extreme weather events**	
5	**How will the wetland change as a result of climate change**	
6	**Seasonal changes**	
7	**Soil water availability**	

Habitat Climate Change Exposure and Definitions

Provided in Habitat VA Tool spreadsheet, 4. H climate

Habitat name	
Expert team	
Wetland name and location	

Variable	Score		Definitions	Confidence	Comment
Threats from climate change					
1. Is temperature change considered to be an issue		1 2 3	· Temperature change is not an issue. **· Temperature change is a moderate** · Temperature change is a serious issue		
2. Is exposure to drought an issue?		1 2 3	· Precipitation changes is not an issue. **· Moderate exposure to drought** **· major drought issues**		
3. Is exposure to flood an issue?		1 2 3	· Flooding is not an issue. **Moderate exposure to flood** **Major flood issues**		
4. Is exposure to hydrological change an issue?		1 2 3	· Hydrological change is not an issue **· Moderate hydrological exposure** · Major hydrological exposure		
5. extreme weather events - typhoons and high winds?		1 2 3	· Extreme weather is not an issue **· Moderate exposure to extreme events** · major exposure to extreme events		
6. additional questions specific to the species		1 2 3	· less exposure Moderate exposure to fire · more exposure		
Exposure					
7. How much of this habitat type will be exposed to **changing hydrology** and hydraulics (i.e. flows)?		1 2 3	· <75% · >25% and <75% · >25%		
8. How much of this habitat type will be exposed to changes in extent, depth and duration of **inundation** from rainfall?		1 2 3	· <75% · >25% and <75% · >25%		
9. How much of this habitat type will be exposed to changes in **sediment** washed down from the watershed, resulting from soil erosion changes?		1 2 3	· <75% · >25% and <75% · >25%		

Variable	Score		Definitions	Confidence	Comment
10. How much of this habitat type will be exposed to **sea level rise** and changes in the tidal rainstorm events and storm surge?		**1** **2** **3**	· <75% · >25% and <75% · >25%		
11. Will baseline stress be increased by the new climate in the LMB?		**1** **2** **3**	· pretty sure they will not · 50/50 chance · pretty sure they will		
12. additional question specific to this species ??		**1** **2** **3**	· less vulnerable · more vulnerable		
Sensitivity					
13. Is the habitat generally **Heat** tolerant?		**1** **2** **3**	· The habitat has tolerance to a broad thermal range · Intermediate · The habitat has narrow thermal range		
14. Is the habitat generally tolerant to flooding?		**1** **2** **3**	· The habitat has tolerance to flooding · Intermediate · The habitat has narrow tolerance to flooding		
15. Is the habitat generally tolerant to drought?		**1** **2** **3**	· The habitat has tolerance to drought · Intermediate · The habitat has narrow tolerance to drought		
16. Are keystone species likely to be affected by climate change?		**1** **2** **3**	· The keystone species are tolerant to climate change · Intermediate · The keystone species are not tolerant to climate change		
17. Are important economic species likely to be affected by climate change?		**1** **2** **3**	· The economic species are tolerant to climate change · Intermediate · The economic species are not tolerant to climate change		

Variable	Score		Definitions	Confidence	Comment
18. Is the habitat generally tolerant to sediment increase?		**1** **2** **3**	· The habitat has tolerance to a broad sediment range · Intermediate · The habitat has narrow sediment range		
19. Is the habitat generally tolerant to soil erosion?		**1** **2** **3**	· The habitat has tolerance to soil erosion · Intermediate · The habitat has narrow tolerance to soil erosion		
20. Is the habitat generally tolerant to sea level rise and changes in the tidal range, storm events and storm surge?		**1** **2** **3**	· The habitat is tolerant to sea level rise · Intermediate · The habitat has narrow tolerance sea level rise		
21. additional question specific to this species ??		**1** **2** **3**	· less vulnerable · more vulnerable		
Adaptive capacity					
22. Does the habitat have resilient vegetation assemblages?		**1** **2** **3**	· Annual vegetation – grasses, reeds and water plants with rapid generation times · Intermediate between High and Low, also include species that have seeds that remain viable for many years · Long-lived trees and shrubs with slow germination and slow generation time		
23. Are invasive species likely to increase with climate change?		**1** **2** **3**	· pretty sure they will not · 50/50 chance · pretty sure they will		
24. Does the habitat have traits that will allow it to bounce back from the new extremes/maxima/minima due to climate exposure?		**1** **2** **3**	· pretty sure it can · 50/50 chance · pretty sure it cannot		

Variable	Score		Definitions	Confidence	Comment
25. Is there adequate space for change. i.e. is there suitable adjacent water, terrain and soils to allow expansion or “movement” of the habitat?		**1** **2** **3**	· There are large areas of suitable land or water adjacent to the wetland for expansion or movement of the habitat and absence of physical barriers. · Intermediate between High and Low · There is small or no areas of land or water suitable adjacent to the wetland for expansion or movement of the habitat.		
26. Are there physical barriers (natural or man-made) that might prevent expansion or “movement” of the habitat?		**1** **2** **3**	· There are no barriers. · There are some barriers · There are major barriers		
27. Could this habitat be a existing or future refuge or other species?		**1** **2** **3**	• pretty sure it will not • 50/50 chance • pretty sure it will		
28. additional question specific to this species ??		**1** **2** **3**	· less vulnerable · more vulnerable		
29. Are biological thresholds exceeded for this habitat, e.g. for keystone species ?			**No** **Don’t know** **Yes = Very Vulnerable**		
Total score			**Average confidence**		

Habitat and Species CC VA Form 4. Species Baseline Conservation Status

Species Baseline Conservation Status Worksheet
Provided in Species VA Tool spreadsheet, 2. S Baseline

Species name	
Expert team	
Wetland name and location	

Variable	Adult Score	Juvenile Score	Egg/ Seed Score		Characteristics of the Species	Confidence	Comment
1. What is the **population** size within the LMB?		na	na	1 2 3	· With in LMB the species is common · Intermediate between Large and Small · With in the LMB the species is rare		
2. What is the **populations trend** in the LMB in the last 50 years?		na	na	1 2 3	· The population is increasing · The population is staying the same · The population is decreasing		
3. What is the **geographic range** size in the LMB ?		na	na	1 2 3	· The species is widespread in the basin · Intermediate between Large and Small · The species is within a small/restricted range		
4. What is the **range size trend** in the LMB in the last 50 years?		na	na	1 2 3	· The range is increasing · The range is the same · The range is decreasing.		
5. Can the species **reproduce** fast?		na	na	1 2 3	· Many offspring, many times a year · Many offspring, once a year · few offspring once a year.		
6. Is the species a generalist or specialist?			na	1 2 3	· Generalist · Intermediate · Specialist		
7. Does the species need a lot of habitat?				1 2 3	· Requires a small habitat · Requires a moderate habitat · Requires a large habitat		

Variable	Adult Score	Juvenile Score	Egg/ Seed Score	Characteristics of the Species		Confidence	Comment
8. Is the species able to disperse?				1 2 3	· Can move long distances easily · Can move short distances easily · Can not move very far.		
9. How does the species survive current floods?				1 2 3	· Recovers fast · Recovers medium · Recovers slow		
10. How does the species survive current droughts?				1 2 3	· Recovers fast · Recovers medium · Recovers slow		
11. Are there threats to survival from humans use?				1 2 3	· The species has low value · The species has medium value · The species has high value		
12. Are there threats to survival from non-humans interactions?				1 2 3	· Is not affected · Is slightly affected · Is highly affected		
13. Does the wetland have effective management?				1 2 3	· Highly effective · Moderately effective · Not very effective		
14. Does the species have a national conservation status?				1 2 3	· Not priority · Priority · High priority		
15. Does the species have a IUCN Redlist status				NA NA 1 2 3 4 5	· Not evaluated · Data deficient · Least Concerned · Near Threatened · Vulnerable · Endangered · Critically endangered		
16. additional question specific to this species				1 2 3	· less vulnerable · more vulnerable		
17. additional question specific to this species				1 2 3	· less vulnerable · more vulnerable		
Average score							

Use the **largest** score for the overall vulnerability calculations adult, juvenile, egg
Note: For the calculations to work, you must fill in the columns for juveniles and eggs. If you do not know, assume that these are the same as for the adult.

Habitat and Species CC VA **Form 5. Species Climate Change Vulnerability**

Species climate change analysis worksheet **Provided in Species VA Tool spreadsheet, 4. Climate**	
Species name	
Expert team	
Wetland name and location	

Variable	Adult Score	Juvenile Score	Egg/ Seed Score	Score and definitions		Confidence	Comments
Threats from climate change							
1. Is temperature change considered to be an issue				**1** **2** **3**	· Temperature change is not an issue. **· Temperature change is moderate** · Temperature change is a serious issue		
2. Is drought likely to be an issue?				**1** **2** **3**	· Precipitation changes is not an issue. **· Moderate threat to drought** **· major drought issues**		
3. Is increased flooding likely to be an issue?				**1** **2** **3**	· Flooding is not an issue. **. Moderate threat of flood** **. Major flood issues**		
4. Is exposure to hydrological change an issue?				**1** **2** **3**	· Hydrological change is not an issue **· Moderate hydrological changes** · Major hydrological changes		
5. Extreme weather events - typhoons and high winds?				**1** **2** **3**	· Extreme weather is not an issue **· Moderate risk of extreme events** · major risk of extreme events		
6. additional questions specific to the species				1 2 3	· less risk . Moderate risk · More risk		
Exposure to climate change							
7. Are microhabitats or refugia available to reduce exposure to temperature change				**1** **2** **3**	· Temperature exposure is not an issue. · **Refugia are available** to buffer impacts · There is **little option** for the species to find shelter in refugia		

Variable	Adult Score	Juvenile Score	Egg/ Seed Score		Score and definitions	Confidence	Comments
8. Are microhabitats or refugia available to reduce exposure to drought?				**1** **2** **3**	· Precipitation changes is not an issue. · **Refugia are available** to buffer impacts · There is **little option** for the species to **find shelter in refugia**		
9. Are microhabitats or refugia available to reduce exposure to flood?				**1** **2** **3**	· Precipitation changes is not an issue. · **Refugia are available** to buffer impacts · There is **little option** for the species to **find shelter in refugia**		
10. Are microhabitats and refugia available to reduce exposure to hydrological change?				**1** **2** **3**	· Hydrological change is not an issue · **Refugia are available** to buffer impacts · there is **little option for the species to find shelter in refugia**		
11. Are microhabitats or refugia available to reduce exposure to extreme weather events?				**1** **2** **3**	· Extreme weather is not an issue · **Refugia are available** to buffer impacts · there is **little option for the species to find shelter in refugia**		
12. additional questions specific to the species				1 2 3	· less vulnerable · more vulnerable		
Sensitivity to climate change							
13. Does the species have a wide **heat** tolerance ?				**1** **2** **3**	· Tolerant to a broad range · Tolerant to an intermediate range · Tolerant to a narrow range		
14. Does the species have a wide **precipitation** tolerance?				**1** **2** **3**	· Tolerant to a broad range · Tolerant to an intermediate range · Tolerant to a narrow range		

Variable	Adult Score	Juvenile Score	Egg/ Seed Score	Score and definitions		Confidence	Comments
15. Does the species have a wide **hydrological** tolerance?				**1** **2** **3**	· Tolerant to a broad range · Tolerant to an intermediate range · Tolerant to a narrow range		
16. Is the species sensitive to **associated risks** from other species?				**1** **2** **3**	· Tolerant to a broad range · Tolerant to an intermediate range · Tolerant to a narrow range		
Adaptive Capacity							
17. Does this specie have **reproductive traits** that will allow it to bounce back from the new climate exposure				**1** **2** **3**	· pretty sure it can · 50/50 chance · pretty sure it cannot		
18. Does this species have **habitat traits** that will allow it to bounce back from the new climate exposure				**1** **2** **3**	· pretty sure it can · 50/50 chance · pretty sure it cannot		
19. Is the population big enough and with enough **genetic diversity** to withstand the new climate exposure?				**1** **2** **3**	· pretty sure it can · 50/50 chance · pretty sure it cannot		
20. Does the species have **behavior** that will allow it to adapt to the new climate?				**1** **2** **3**	· can acclimatize to the new climate · intermediate between High and Low · has little ability or opportunity to acclimatize		
21. Is there sufficient **habitat connectivity** to allow organisms to reach appropriate habitat/climate space/refugia?				**0** **1** **3**	· pretty sure it can · 50/50 chance · pretty sure it cannot		

Variable	Adult Score	Juvenile Score	Egg/ Seed Score	Score and definitions		Confidence	Comments
22. Is there **adequate time** to allow an individual to develop adaptive changes?				**0** **1** **3**	· pretty sure it cannot · 50/50 chance · pretty sure it can		
23. Will baseline stress be increased by the new climate in the LMB?				**1** **2** **3**	· pretty sure they will not · 50/50 chance · pretty sure they will		
24. additional questions				1 2 3	· less vulnerable · more vulnerable		
25. additional questions				1 2 3	· less vulnerable · more vulnerable		
26. Are biological thresholds exceeded for this habitat ?					**No** **Don't know** **Yes = Very Vulnerable**		
Total score					**Average Confidence**		

Note: For the calculations to work, you must fill in the columns for juveniles and eggs. If you do not know, assume that these are the same as for the adult

Category interval 0.4	Low	High
Very Highly Vulnerable to climate change	**2.7**	**3**
High Vulnerable to climate change	**2.3**	**2.6**
Moderately Vulnerable to climate change	**1.9**	**2.2**
Low Vulnerable to climate change	**1.5**	**1.8**
Very Low Vulnerable to climate change	**1**	**1.4**