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# Freshwater Ecosystem Assessment Handbook

Minister

Minister

Ministry of Forests and Environment

Singha Durbar, Kathmandu



## Message from the Minister

Freshwater is a vital resource for Nepal, playing a crucial role in our environment, economy, and the well-being of our communities. Our freshwater resources not only sustain the agriculture that is the backbone of our country but also support a rich diversity of aquatic life, making Nepal a recognized biodiversity hotspot. Moreover, the abundant freshwater resources in Nepal hold immense potential for hydropower development, positioning our nation as a key contributor to sustainable energy production.

Sustainable hydropower development is a top priority for Nepal. It is essential not only for alleviating energy poverty but also for fostering economic growth, while ensuring the conservation of our river systems. In pursuit of this long-term vision, we have been actively engaging in science-based, evidence-driven decision-making and enhancing the capacity of our stakeholders.

Our commitment to conservation and sustainable development is unwavering, particularly in managing the environmental and social risks associated with hydropower projects. Engaging with key stakeholders—including government bodies, international agencies, academia, and the private sector—is essential for promoting the sustainable management of Nepal's freshwater resources.

The release of this handbook marks an important milestone in the freshwater management sector. It addresses the growing need to build the capacity of stakeholders in conducting comprehensive freshwater ecosystem assessments. This timely resource will serve as a valuable tool for all those involved in the stewardship of our freshwater ecosystems.

I extend my sincere thanks to the MoFE, FRTC, and the ICIMOD team for their hard work in producing this much-needed handbook, which has been long awaited by our stakeholders.

Ain Bahadur Shahi Thakuri

Honorable Minister

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# माननीय रूपा बि.क. राज्य मन्त्री वन तथा वातावरण मन्त्रालय सिंहदरबार, काठमाडौँ नेपाल।



Hon'ble. Rupa B.k.

State Minister

Ministry of Forests and Environment

Singha Durbar, Kathmandu

## **Message from the State Minister**



We are very pleased to introduce the *Freshwater Ecosystem Assessment Handbook*, a critical tool in our ongoing efforts to safeguard and restore our precious freshwater ecosystems of Nepal. Our rivers, lakes, wetlands, and aquifers are not just sources of water for rich biodiversity, but lifelines for communities, agriculture, and industries. Freshwater ecosystem is essential for the well-being of our environment and economy, providing vital services that sustain life.

However, these ecosystems are under increasing pressure from pollution, climate change, over-extraction, and habitat degradation. This handbook is a response to these challenges. It provides a comprehensive guide for assessing the health of our freshwater ecosystems, integrating the latest scientific methods and practices to help stakeholders—from policy-makers and scientists to —better understand and protect these invaluable resources.

The handbook is designed to be both practical and user-friendly, bridging the gap between science and policy, and promoting collaboration among all who have a stake in the future of our freshwater resources.

I encourage all of you to use this handbook as a resource to enhance our collective efforts in preserving our freshwater ecosystems. By working together, we can ensure that our rivers, lakes, and wetlands remain vibrant, resilient, and bountiful for generations to come. I extend my heartfelt gratitude to the teams at FRTC and ICIMOD for delivering this valuable handbook at such a crucial time, when balancing development aspirations with environmental conservation is essential.

Together, let us commit to the stewardship of our freshwater resources as they are vital to the health, prosperity, and sustainability of our communities.

Rupa Bishwakarma Honorable State Minister



# Government of Nepal Ministry of Forests and Environment Singha Durbar, Kathmandu Nepal



## **Foreword**

Nepal is exceptionally endowed with rich freshwater ecosystems, including a large number of perennial rivers fed by monsoon precipitation, glacier- and snowmelt, and base flows from springs and aquifers. Freshwater sources cover around 5 per cent of the country's land and supply about 237 cubic kilometres of water every year. This is equivalent to 15 per cent of the world's annual irrigation water use. Nepal's freshwater sources support high aquatic biodiversity and the livelihoods of millions of people, and they hold great potential for hydropower development - one of the major economic development potentials of the country.

The Government of Nepal has an ambitious target to harness 10,000 Megawatts of hydropower by 2030, and aims to foster this growth sustainably. It is the government's priority to ensure that hydropower development is technically, environmentally and socio-economically viable. A well-prioritised approach can strengthen Nepal's commitment to the Sustainable Development Goals and promote hydropower development in compliance with environmental and social safeguards as outlined in the Environment Protection Act 2019 and the Environmental Protection Rules 2020, as well as prevailing international standards.

With an aim to contribute to the long-term goal of supporting sustainable hydropower development in the country, the Ministry of Forests and Environment prepared the "Hydropower Environmental Impact Assessment (EIA) Manual of Nepal" in 2018 with support from the International Finance Corporation (IFC) and the International Centre for Integrated Mountain Development (ICIMOD). Prepared through multi-stakeholder participatory processes, the manual provides a set of guidelines in managing the environmental and social risks and impacts specific to hydropower development. The endorsement of the manual was accompanied by an in-depth capacity assessment and gap analysis of Nepal's hydropower sector that featured a particular focus on EIA. The assessment highlighted the need to build the capacity of stakeholders in conducting freshwater ecosystem assessments. It also recommended the development of a handbook to build the capacity of stakeholders and guide freshwater ecosystem assessments using standard tools and techniques.

To address this need, the Forest Research and Training Centre, Ministry of Forests and Environment (MoFE), Government of Nepal with support from ICIMOD, has developed the "Freshwater Ecosystem Assessment Handbook". The handbook is a guiding document created specifically for stakeholders in the environmental sector including the hydropower proponents and EIA reviewers and consultants, researchers, and academia.

The Ministry of Forests and Environment is confident that the handbook will be an important milestone in the freshwater management sector of Nepal. It will help the natural resources manager including the EIA practitioners and hydropower developers to survey and monitor freshwater ecosystems using standard methods. Ultimately, this will help Nepal adhere to and uphold international standards for sustainable hydropower development. I congratulate all the members involved in preparing this handbook and extend special thanks to the FRTC.

Deepak Kumar Kharal, PhD

Secretary

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# Government of Nepal Ministry of Forests and Environment Forest Research and Training Centre

Babarmahal, Kathmandu

# **Acknowledgement**



The Forest Research and Training Centre, Ministry of Forests and Environment, Government of Nepal wishes to thank International Centre for Integrated Mountain Development (ICIMOD) for providing technical support in preparing and finalising the "Freshwater Ecosystem Assessment Handbook". The need for precise and applicable assessment methodologies for evaluating freshwater ecosystems has long been recognized by impact assessors in Nepal. This handbook will undoubtedly meet that need and assist federal, provincial, and local governments in approving Environmental Assessment Reports, ensuring they meet the necessary quality and standards.

We would like to thank the Ministry of Energy, Water Resources and Irrigation, Government of Nepal, academic institutions, development partners, hydropower project proponents, private sectors and the relevant stakeholders for their participation and contribution to the series of consultations during the development of this handbook.

We are thankful to Dr. phil. Nat. Deep Narayan Shah, Dr rer. nat. Ram Devi Tachamo, and Dr Sunita Chaudhary from ICIMOD and Mr. Rabindra Maharjan and Ms. Sunita Ulak from FRTC for drafting and reviewing the Handbook. We are also thankful to Dr Bishwa Nath Oli, Mr Dhirendra Kumar Pradhan, Dr Richard Storey, Ms Kate Lazarus, and Dr Leeanne Alonso for critical review, and inputs in developing this Handbook.

We would also like to thank Dr Arun Bhakta Shrestha, Dr Neera Shrestha Pradhan, Mr Sudip Maharjan, Mr Ramesh Kathariya and Mr Govinda Shrestha from ICIMOD for their overall guidance and contributions in preparing the Handbook, and former ICIMOD staff Dr Eklabya Sharma, Ms Kanchan Shrestha, Dr Nishikant Gupta and Ms Sunita Ranabhat for their valuable contributions.

We are confident that the Handbook will be a user-friendly and useful guide for the EIA/IEE practitioners, experts, reviewers and the personnels involved in the approval process while developing and operating hydropower projects in Nepal.

Finally, we are grateful to the Ministry of Forests and Environment, Department of Forests and Soil Conservation, Department of National Parks and Wildlife Conservation, Department of Plant Resources and Forest Research and Training Centre of all provinces for their active participation and constructive feedback in the National Consultation Meetings on Freshwater Ecosystem Assessment Handbook.

Rajendra K.C., PhD

Director General

# **Abbreviations and Acronyms**

| BES    | Brief Environmental Study                                   | IFC   | International Finance Corporation         |
|--------|---|-------|---|
| BZ     | Buffer Zone   | IEE   | Initial Environmental Examination         |
| CA     | Conservation Area   | IUCN  | International Union for Conservation of   |
| CBD    | Convention on Biological Diversity                          |       | Nature                                    |
| CITES  | Convention on International Trade in                        | L     | Litre                                     |
|        | Endangered Species of Wild Fauna and Flora                  | LC    | Least Concern                             |
|        |   | m     | Meter                                     |
| CR     | Critically Endangered                                       | μg    | Microgram                                 |
| CPUE   | Catch Per Unit Effort                                       | MoFE  | Ministry of Forests and Environment       |
| DBH    | Diameter at Breast Height                                   | NBSAP | National Biodiversity Strategy and Action |
| °C     | Degree Celsius  |       | Plan                                      |
| DoED   | Department of Electricity Development                       | NEA   | Nepal Electricity Authority               |
| eDNA   | Environmental DNA   | NGO   | Non-Government Organization               |
| EIA    | Environmental Impact Assessment                             | NPC   | National Planning Commission              |
| EMP    | Environmental Management Plan                               | NP    | National Park                             |
| EN     | Endangered  | NT    | Near Threatened                           |
| EPA    | Environment Protection Act                                  | NTFP  | Non-Timber Forest Products                |
| FRTC   | Forest Research and Training Centre                         | NWP   | National Wetland Policy                   |
| gm     | Gram  | RHA   | Rapid Habitat Assessment                  |
| GoN    | Government of Nepal   | RPM   | Revolutions Per Minute                    |
| GPS    | Global Positiong System                                     | RQC   | River Quality Class                       |
| HPP    | Hydropower Project  | VU    | Vulnerable                                |
| HR     | Hunting Reserve   | WR    | Wildlife Reserve                          |
| ICIMOD | International Centre for Integrated<br>Mountain Development | WWF   | World Wildlife Fund                       |

## **Glossary**

**Area of influence** Physical space which is likely to be impacted directly or indirectly during the

construction and operation of hydropower projects

**Baseflow** It is the stage at which river discharge is sustained by groundwater inputs only

**Biodiversity hotspot** A biogeographic region with significant levels of biodiversity that is threatened by

human habitation

Breeding ground An area where animals, especially fish and birds, habitually breed

Critical habitat Specific area that provide habitat to endangered and threatened species and have

the physical or biological features essential for their conservation

**Dam** Concrete or earthen barrier constructed across a river

**Diversion reach** A river segment situated between a dam and the confluence of a tailrace with the

river where little or no water is released from the dam. The diversion zone can

extend from a few metres to several kilometres.

**Endangered species** A species very likely to become extinct in the near future, either worldwide or at the

regional or local level

**Glide** An area in the river or stream where the water flow is slow, quiet and non-turbulent.

A glide is too shallow to be a pool but the water velocity is too slow to form a run

**Habitat** Biotic and abiotic factors that are present in an area to support the survival and

reproduction

**Impounding zone** A river segment where water is stored due to transverse damming in the river, and

from where water is diverted through a diversion channel for the production of

hydroelectricity

**Pool** Still water with a deep-water column in the river, generally formed naturally

Rapid High water velocity and turbulent flow as water passes through a relatively steep

riverbed

**Reference site** A site or an area that supports a community of organisms that best represent the

site in a natural or near natural environment

Riffle River flows created while water passes over cobbles and stones of a riverbed

**River reach** A longitudinal section of a river system which has relatively similar flow, water

temperature regimes and substrate composition that best describe the river at the

site

**River segment** A part of a river reach (usually between about 500 and 1000 metres longitudinal

length) which has relatively uniform habitat conditions and other hydrological

characteristics

**Run** Non turbulent flow in a river

**Spawning ground** Area of water where fish species migrate yearly to lay their eggs

**Thalweg** The deepest point of an actively flowing channel

**Threatened species** A species that is vulnerable to endangerment in the near future

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## **Executive summary**

The freshwater ecosystems provide energy, water and food to people and serve as critical habitats for many aquatic animals including keystone species such as Gangetic River Dolphin, Mahseer, Otter, macroinvertebrates (mayflies, stoneflies, caddisflies), and others. Rivers also have great cultural and spiritual significance, and people perform many important rituals along the rivers. Despite their importance, many rivers in Nepal are severely degraded or at risk, which has undermined their ability to provide critical ecosystem services and related benefits.

In recent decades, rivers in Nepal have increasingly been dammed or regulated for hydroelectricity, irrigation, and drinking water supply. This has altered their physical characteristics such as flow regime, mineral habitat, water temperature, and sediment transport. Human interventions have also impacted the upstream and downstream linkages of the river systems. Most importantly, migratory species are under threat as such species migrate seasonally from lowland rivers to highland rivers for spawning. Rivers are also habitats of many instream biota such as periphyton, diatoms, macroinvertebrates (insects, gastropods, crabs, amphipods) which are essential for nutrient cycling in the ecosystem and some of the organisms are important food sources for many local people.

The Environment Protection Act 2019 and Environment Protection Rules 2020 clearly state that all hydropower projects are required to conduct an Initial Environmental Examination (IEE) and an Environmental Impact Assessment (EIA) prior to project commencement in order to avoid, minimize and mitigate the project's negative impacts. Collecting reliable data through scientific studies is crucial for setting the baseline and making evidence-based decisions. A robust scientific methodology is required to detect the changes that river ecosystems have undergone as a result of

hydropower development. In this context, this handbook serves as a step-by-step guide for assessing water flows, physical habitat, water quality and the riparian and instream biotic community of river ecosystems. Site information sheet, field data sheets for each taxonomic group, data presentation sheets, and pictorial illustrations have been designed for systematic collection, processing and presentation of the data. The handbook covers the assessment of aquatic biota such as micro-biota (phytoplankton and zooplankton), periphyton, macrophytes, benthic macroinvertebrates, fish, and riparian vegetation. Introduction, field and laboratory methods, and data analysis and presentation are provided for each component. Further, it includes detailed descriptions of biodiversity hotspots, biological corridors and connectivity, important bird and plant area, protected/conservation area, and ecosystem services. Eventually, this handbook explains the process of assessing and managing environmental impacts.

The number of sites, their distribution, and their frequency over the seasons and years are crucial aspects of ecosystem assessment in environmental studies including Environmental Impact Assessment (EIA) and Initial Environment Examination (IEE). It is recommended that the assessment cover at least six sites spatially distributed in the mainstem and its tributaries in each influence zone – above the dam (in control sites and impounded zone), below the dam (diversion reach), and downstream of the powerhouse. Each site should be adequately representative of the location so that the sample consists of a broad range of organisms residing in the location.

The handbook aims to provide a complete set of information and tools for freshwater biodiversity assessment in order to guide and help practitioners involved in IEE, related processes of hydropower projects and other environment-related studies.



## 1. Introduction

Freshwater ecosystems play a fundamental role in sustaining life and livelihoods because of their important ecological, economic, social and cultural functions. Freshwater ecosystems provide habitat for 10% of known species and over 30% of known vertebrates despite habitat coverage of less than 0.01% on the earth's water (Dudgeon et al., 2006; Strayer and Tockner, 2021). Nepal occupies less than 0.1% of the earth's land surface and freshwater ecosystems cover less than 5% of the country's land surface, harboring large numbers of endemic and rare species (NBSAP, 2014). The country's freshwater ecosystems are the habitat of 256 fish species including 16 species endemic to Nepal and 27 species on the IUCN Red List (Shrestha, 2019; WWF, 2020a).

In this handbook, we focus exclusively on assessment of river ecosystems. River ecosystems is one of the key resources for Nepal's economic development. The country has 83,000 MW of hydroelectricity potential of which 42,000 MW is economically feasible. However, currently Nepal produces only around 2,600 MW of electricity (DoED, 2021). The government's goal is to harness 40,000 MW by FY 2043/44 (NPC/GoN, 2020) and currently over 200 hydropower projects with a total capacity of more than 7,000 MW are under construction (DoED, 2021).

Freshwater ecosystems are already under threat, and there has been a loss of species diversity due to a wide range of anthropogenic activities including water resources development (Dudgeon et al., 2006; Grill et al., 2015). Water resources development, in particular hydropower development (Taylor et al., 2013) without proper planning and compliance with existing policies has exacerbated the loss of genetic and species diversity, as it has altered the morphological characteristics and hydrological regimes of many rivers. A systematic environmental assessment and management can help minimize the loss (Bigard et al., 2017).

In Nepal, there is a need to have a balance between hydropower generation and conservation of freshwater ecosystems. For this, it is important to conduct proper environmental studies including EIA, Initial Environmental Examination (IEE), Brief Environmental Study (BES), and other related studies. EIA is a site-specific planning for biodiversity (Mandelik et al., 2005) and environmental management (Morgan, 2012). An EIA means a detailed study and evaluation carried out to ascertain whether or not the proposal, if implemented, will have significant adverse impacts on the environment, and the measures to be adopted for avoiding or mitigating such impacts (Environment Protection Act, 2019). EIAs typically include ongoing monitoring of environmental indicators during construction and operation, in relation to baseline conditions, to ensure that impacts remain within acceptable limits.

The Environment Protection Regulations (2020) provides different level of assessment (BES, IEE) required while conducting an EIA of a proposed project (MoFE, 2019). Realizing the importance of assessment of hydropower projects impact on the the Ministry of Forests environment, Environment, Government of Nepal published the "Hydropower Environmental Impact Assessment Manual" in 2018 with support from IFC and ICIMOD. The manual seeks to ensure the sustainability of hydropower development in Nepal and promote good practices. The manual provides guidelines for conducting a comprehensive EIA to create baseline information on physical, chemical, biological, socioeconomic and cultural conditions of the sites within the influence area of the hydropower project. However, at the time of preparation of the manual, systematic methodologies for assessment of biodiversity, water quality, physical habitat and the hydrology of rivers, and for acquiring field data, analysing collected data and interpreting the results would need to be further developed through supplementary guides. Therefore, this handbook has been envisaged to supplement the EIA Hydropower Manual 2018 and other studies. It seeks to guide information collection, analysis and interpretation of key ecological variables specific to freshwater ecosystems during the baseline study and monitoring of hydropower projects. The handbook also provides a general background of freshwater ecosystems and riparian and terrestrial ecosystems, their importance and the threats they face.

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# Freshwater Ecosystem Assessment Handbook: A background

The Government of Nepal launched the Hydropower Environmental Impact Assessment Manual in 2018 to guide the process of environmental impact assessment (EIA), in line with good international industry practices in the hydropower sector. After the endorsement of the manual, an in-depth capacity assessment and gap analysis with a focus on EIA was carried out in Nepal's hydropower sector. It highlighted the need to build the capacity of stakeholders for conducting freshwater ecosystem assessments as part of the EIA process. It also recommended coming up with a handbook to build the capacity of stakeholders and guide freshwater ecosystem assessments using standard tools and techniques.

This handbook is useful for IEE, EIA and other water-based projects and research. Several workshops with experts, policy makers, private sector entities, university faculties, EIA practitioners and other stakeholders were conducted before and during the writing of the handbook (Figure 1). The draft handbook was peer reviewed by experts and concerned government agencies. All feedback, comments and suggestions were carefully incorporated.

## 1.1 Purpose of the handbook

Construction and operation of hydropower projects alter habitats and affect organism that are critical to the functioning of ecosystems and serve as indicators of the wellbeing of ecosystems. Assessment of freshwater ecosystems requires standardized sampling protocols for building consistent long-term data sets, which are essential for identifying ecological patterns or changes in patterns over time and for allowing data sharing among different organizations involved in water resource management (Bonar et al., 2009). This handbook provides standard sampling protocols for the EIA process of the hydropower sector. EIAs are required in hydropower projects to:

 determine ecological values in the project area and the area of influence prior to hydropower development (natural values assessment, or baseline assessment); and

Figure 1: Process in the preparation of Freshwater Assessment Handbook



 monitor the potential environmental impacts during the construction and operation of hydropower projects, relative to baseline conditions.

This handbook serves as a complement to the Hydropower EIA Manual 2018 published by MoFE, Government of Nepal. It also sheds light on theoretical concepts and standard tools and techniques for the assessment of different components and parameters of freshwater ecosystems.

Specific objectives of the handbook are to:

- Improve understanding of freshwater ecosystems, their importance, and their key characteristics including biodiversity, critical habitats, functions, structure and services for sustainable hydropower development.
- Equip learners and practitioners with standard tools and techniques for surveying, measuring, quantifying, assessing and monitoring different components and parameters of freshwater ecosystems to fulfill the requirements of EIA in the hydropower sector.

## 1.2 Use of the handbook

Collection of quality and reliable data is essential for accurately depicting the impact of hydropower

projects on river ecosystems and biodiversity. The quality of data largely depends on the method of data acquisition and the work done by IEE and EIA practitioners in the field. Hence, IEE and EIA practitioners are the primary target group of the handbook. With the help of the handbook, they should be able to collect, anlayse and interpret the data using standard methods and techniques. The handbook will also be of use to researchers, academics and university students, who constitue the secondary target group.

Users of this handbook should be familiar with:

- Hydropower Environmental Impact Assessment Manual (2018)
- Environmental Protection Rules (2020)
- Environmental Protection Act (2019)
- Hydropower Development Policy (2001)
- National Wetland Policy (2012)
- National Parks and Wildlife Conservation Act (1973)
- Working Policy on Construction and Operation of Development Projects in Protected Areas and Wildlife Damage Relief Guidelines
- Manual for Developing and Reviewing Water Quality Monitoring Plans and Results for Hydropower Projects (2002)
- Convention on Biological Diversity (CBD, 2002)
- Good Practice Note: Environmental, Health, and Safety Approaches for Hydropower Projects (IFC 2018)
- Guidelines for Construction of Eco-friendly Linear Infrastructure (2023)
- Forest Act 2019
- Forest Regulation 2022

## 1.3 Scope of the handbook

The scope of this handbook is limited to describing scientific methods for the collection, analysis and interpretation of data on freshwater biodiversity, water quality, water flows and physical habitat. To meet the requirements of the Hydropower EIA Manual (2018), these have to be measured prior to the construction of a hydropower project. The handbook can be used for monitoring the effects of hydropower projects on freshwater biodiversity in the project area and the area of influence. The

handbook can also be used for other water-based research in Nepal.

The scope of the handbook is detailed below:

- To help EIA practitioners, experts, EIA report reviewers and personnel involved in the project approval process to identify key freshwater ecosystem components that need to be assessed before, during and after the construction and operation of the hydropower project in the project area and the area of influence.
- To provide standardized protocols for data collection, record keeping, analysing techniques and data presentation.
- To inform practitioners about the requirements of EIA related policy, acts and rules.
- To ensure that hydropower development in Nepal is based on international standards and principles of sustainability.



# 2. Ecosystems and functions

## 2.1 Freshwater ecosystems

Nepal's freshwater ecosystems are most diverse due to the dramatic elevational gradients that exist within 2° latitudinal span, possessing high beta diversity (Tachamo-Shah et al., 2015; NBSAP, 2014; Jüttner et al., 2010). The country's natural rivers are often inhabited by large numbers of endemic and rare species (NBSAP, 2014; Rajbanshi, 2013; Nesemann et al., 2010). These rivers are vital to people as they provide food and water and play an important role in economic development (NBSAP, 2014). They continuously transport minerals and nutrients from upstream to downstream, make sand dunes and bars, regulate water quality, and support high biodiversity.

However, the rivers are under severe threat. One of the major threats to these rivers is modification of flows (Taylor et al., 2013) for irrigation, drinking water supply and hydroelectricity generation, which results in fragmentation of river habitats (see Photo 1). Operation of hydropower projects has often led to trapping of sediments upstream from the hydropower dam on the one hand, and little to no river discharge on the other hand, creating a dewatered zone downstream from the dam. Sometimes, the dewatered zone extends from a few to several kilometres, making it susceptible to mining of riverbed aggregates. This massively alters the morphology of the dewatered zone, further affecting organisms that inhabit the river ecosystems.

The basic characteristics of a natural river and potential changes that might occur downstream of the river due to the operation of a hydropower dam are listed in Box 1.

Studies suggest that organisms that inhabit the rivers are among the most threatened compared to terrestrial fauna (MEA, 2005). Biodiversity changes or loss often have irreversible economic ramifications (WWF, 2020b). Therefore, Nepal must



Photo 1: River stretch below the hydropower dam in the Marshyagdi River. Water is seen in the pool section while the rest of the dewatered zone is dry.

#### Box 1

#### **Natural river**

- 1. Natural flow: varies in magnitude, frequency, duration, timing and rate of change
- 2. Regular transport of sediment and nutrients
- 3. Diverse habitats that can support numerous species
- 4. Good water quality
- 5. Diverse aquatic macroinvertebrates with dominance of reophiles
- 6. Assemblage of native fish species

prioritize sustainable water resources management while maintaining water quality and protecting aquatic biodiversity. However, in many developing countries including Nepal, water resources development is usually undertaken at the expense of habitat and biodiversity. A study carried out by

the Asian Development Bank (2018) in the rivers across the country found that many of the rivers dammed by hydropower projects are inhabited by migratory fish like *Tor putitora*, *Bagarius* sp., and damming of the rivers has threatened their population due to loss of habitat, deterioration of water quality, physical injury caused while passing through inefficient fish passage, and blockage of fish movement (Gubhaju, 2002; Jha et al., 2006).

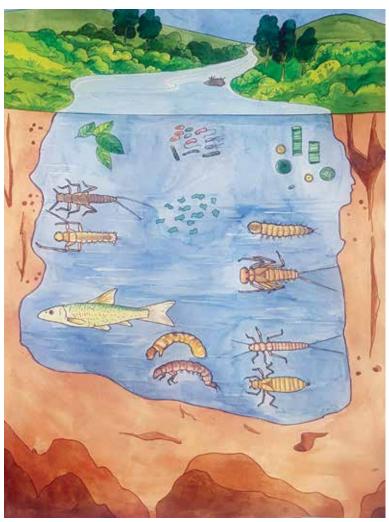
Apart from having their own intrinsic value, aquatic organisms are key components regulating the ecosystems in which they reside. Aquatic organisms process the materials (e.g., nutrients, organic particulate matter) that enter the aquatic ecosystem to maintain water quality and habitat quality (Wantzen et al., 2008). Organisms at the bottom of the food web provide energy to higher trophic levels within the aquatic system, and also to the adjacent terrestrial ecosystem (Figures 2a, b). In small and medium river systems, detritus (leaves and wood) from the surrounding land is colonized by aquatic fungi and eaten by benthic macroinvertebrates (Wantzen et al., 2008). These are then eaten by fish and birds, which may then be eaten by

#### **Upon hydropower development**

- 1. Alteration in natural flow regimes
- 2. Trapping of sediment upstream of dam
- 3. Change in habitat
- 4. Poor water quality
- 5. Dominated by a few aquatic macroinvertebrates, especially water beetles and other tolerant species
- 6. Mixed fish composition

reptiles or mammals. In non-wadeable rivers with little shade, photosynthetic microbiota (diatoms and algae) and large (vascular) plants capture sunlight and uptake nutrients for synthesizing their food and store the synthesized carbon in their tissue.

Figure 2a: Detritus-based food web in a small or medium river system (Redrawn from ISAB, 2011)



Source: ISAB, 2011 for the Northwest Power and Conservation Council, Columbia River Basin Indian Tribes, and NOAA Fisheries

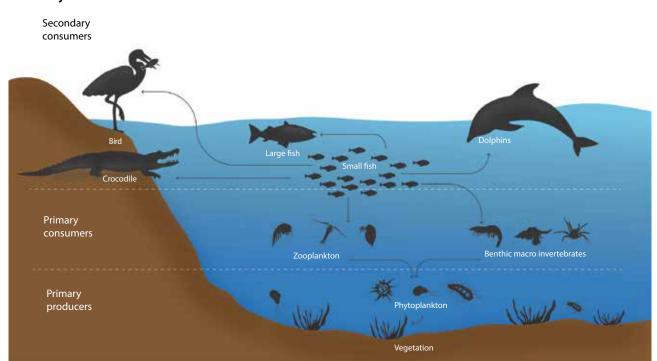


Figure 2b: Food web in a lowland low-gradient river ecosystem from detritus, phytoplankton to tertiary consumers

This living tissue is then available as food for zooplankton, invertebrates and fish (Romo et al., 2004; Neres-Lima et al., 2017). Construction of hydropower projects leads to changes in river morphology and flow regimes, which alters water quality, habitats and river biota and affects overall river functioning. The Environment Protection Act 2019 and Environment Protection Regulations 2020 make it compulsory for infrastructure projects to conduct detailed environment assessments such as IEE and EIA to ensure no net loss of biodiversity and take measures to reduce and mitigate the loss of biodiversity. The Hydropower EIA Manual (2018) provides detailed guideline for conducting an environmental impact assessment.

## 2.2 Riparian vegetation

Riparian zones are narrow vegetation strips or patches that are connected to and influenced by surface and sub-surface hydrologic features of water bodies (Camporeale et al., 2006; Miller and Spoolman, 2012), where species distribution and trophic interaction of terrestrial food webs depend on water availability (Xiang et al., 2016). As such, riparian zones are vital for maintaining the health of aquatic ecosystems (Richardson et al., 2010). They act as a buffer between the aquatic ecosystem and the wider terrestrial landscape, intercepting harmful

substances such as nutrients, sediment and other contaminants running off the land (Dosskey et al., 2010; Vidon et al., 2010). They provide shade that reduces light and temperature in the aquatic system (Richardson et al., 2010a). During floods, they slow the flow rate of flood waters, reducing the intensity of floods downstream, and also retain some of the sediment and nutrients carried by flood waters. Some fish species move into riparian zones during floods to feed and breed, while semi-aquatic species such as frogs also use them (Eskew et al., 2012; Mckergow etal., 2016;). Riparian vegetation provides dead leaves which form the base of the aquatic food web, and wood which provides habitat for aquatic animals, creates a diversity of flow types in the channel and slows water flow (McKergow et al., 2016; Pusey and Arthington, 2003). Riparian vegetation provides habitat for semi-aquatic and terrestrial animals and the adult stages of aquatic insects. Riparian trees with deep roots stabilize banks and reduce erosion (McKergow et al., 2016). The type of riparian vegetation, its diversity and the width of the riparian vegetated zone are all important for maintaining these ecosystem processes. Loss or degradation of riparian vegetation or soil structure can lead to bank erosion, smothering of riverbeds with fine sediment, greater input of terrestrial contaminants, shifts in the aquatic food web, loss of instream

habitat and increased downstream flooding – all to the detriment of aquatic organisms, water quality and the ecosystem services rivers provide to humans (Richardson et al., 2010a, b).

Riparian zones are regularly flooded during high river flows, and their vegetation is often adapted to frequent disturbances. Hydropower projects that reduce the frequency or size of floods may reduce the disturbance regime in riparian zones, leading to a shift in vegetation towards more long-lived species (Sarneel et al., 2019). This shift may affect river channel morphology as well as the fauna inhabiting the riparian zone (Hession et al., 2003). Therefore, a detailed assessment of riparian vegetation, its diversity, form and extent, need to be carried out in the project area and the area of influence as part of the EIA baseline survey.

## 2.3 Terrestrial ecosystem

Nepal has exceptionally high biodiversity due to its geographic position where two major biogeographic regions - Indo-Malayan to the south and Palearctic to the north - co-exist within a less than 200 km latitudinal span. The country occupies less than 0.1% of the world's land surface area but harbours 3.2% and 1.1% of the world's known flora and fauna, respectively (MoFSC, 2014), and these are distributed across different physiographic zones (Table 1). Nepal encompasses a total of 118 ecosystems across the different physiographic zones of the country (MoFSC, 2014) and 35 forest type (FRTC, 2021). The major land covers of Nepal are: forest (41.69%), cropland (24.21%), grassland (13.27%), other wood land (3.62%), and others (18%) which covers snow, bare rock, glacier, built-up area (FRTC, 2022).

Table 1: Distribution of ecosystems by physiographic zones

| Physiographic zone            | Number of ecosystems |
|-------------------------------|----------------------|
| High Himal and High Mountains | 38                   |
| Middle Mountains              | 53                   |
| Siwalik                       | 14                   |
| Tarai                         | 12                   |
| Other                         | 1                    |
| Total                         | 118                  |

Source: NBSAP (2014)

Forest ecosystems alone provide habitat to 56% of Nepal's nationally threatened birds (BCN and DNPWC, 2011).

Nepal's terrestrial vegetation includes tall grasses and broadleaf forests in the Tarai and Siwalik foothills; sub-tropical and temperate broadleaf and conifer forests in the Middle Mountain; mixed and conifer forests in the High Mountains; and alpine meadows above the treeline (MoFSC, 2014).

Species on the IUCN Red List include 9 plants, 55 mammals, 149 birds, 15 herpetofauna, and 27 fish (Table 2). Similarly, 15 species of plants, 52 mammals, 108 birds, 19 reptiles, and 3 insects have been listed in the CITES Appendices. The government of Nepal has enlisted 26 species of mammals, 9 species of birds, 3 species of Reptiles, 10 angiosperms, and 2 gymnosperms under protected species (DNPWC, 2023).

**Table 2: IUCN Red List of Threatened Species of Nepal** 

| ricpai                |        |      |          |          |        |
|-----------------------|--------|------|----------|----------|--------|
| Category              | Plants | Aves | Reptiles | Amphibia | Mammal |
| Critically endangered | 4      | 10   | 4        | 0        | 1      |
| Endangered            | 12     | 8    | 8        | 1        | 14     |
| Vulnerable            | 16     | 26   | 8        | 5        | 21     |
| Near<br>threatened    | 8      | 42   | 9        | 5        | 23     |
| Total                 | 40     | 86   | 29       | 11       | 59     |

Source: IUCN (2020).

# 3. Ecosystem assessment

The following paragraphs describe the minimum requirements for determining the pre-project natural values and establishing a monitoring programme in relation to the biota, water quality, water flows and physical habitat of a river system. The biota includes riparian vegetation, phytoplankton, periphyton, zooplankton, macroinvertebrates and fish in the hydropower project site and its influence area. This handbook presents the requirements outlined in the Hydropower EIA manual 2018 (see Chapter 8: Assessing impacts, p. 43, and Appendix A, p. 76: Fisheries and aquatic ecology), with the addition of a detailed sampling methodology, data analysis, and data presentation techniques.

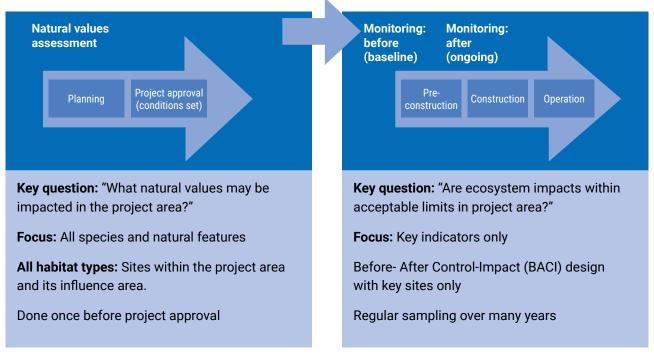
Ecosystem assessment is usually carried out for initial natural values assessment prior to project approval, and for monitoring once a project has been approved (Figure 3). Monitoring itself includes distinct phases: baseline (before construction), and compliance and impact monitoring (during construction and operation): Baseline monitoring should be conducted during the pre-construction phase to fill baseline data gaps and to update baseline information provided in the EIA report.

Impact monitoring should be conducted during the construction and operation phase to detect environmental changes, which may have occurred as a result of project implementation. Compliance monitoring should be conducted periodically or continued over the duration of construction and operation to ensure project compliance with recommended environmental protection standards" (Hydropower EIA Mannual 2018, Chapter 9: Managing impacts, p. 65).

### Natural values assessment

In the first phase of an EIA, we have to identify and assess the natural values of the area that is likely to be influenced by the construction or operation of a hydropower project (Figure 4). This assessment is done prior to project approval, and the information gathered will be used to determine whether the project is acceptable on the basis of its environmental impact. The information can also be used to determine the conditions that the project needs to meet during construction and operation to protect the natural values. Hydropower construction is not allowed in critically sensitive areas.

Figure 3: Environmental Impact Assessment Process in hydropower project



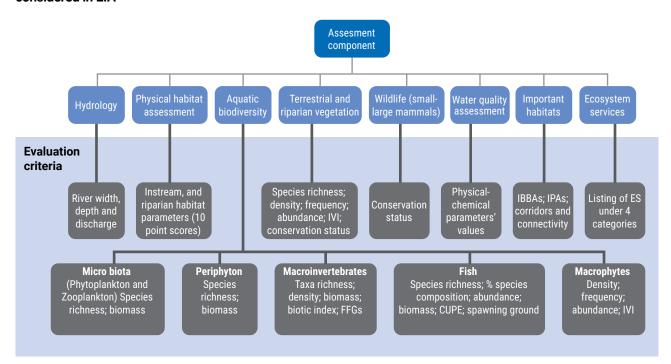


Figure 4: Recommended assessment components of freshwater ecosystems and parameters to be considered in EIA

#### **Variables**

Natural values may include flora, fauna and physical features of the river/riparian environment. Any flora, fauna or physical features may have value; therefore, the assessment should aim to include as wide a range of these as possible (see sections below). Their value may be assessed based on their conservation status, or cultural, social, religious or economic value.

## **Habitat types**

Because the purpose is to identify all natural values that may potentially be impacted by the hydropower project, assessments should include every habitat type that may be impacted. These will likely include the mainstem of the river (including the area that will be flooded by a reservoir or impoundment), tributaries, gravel banks, riparian zones and terrestrial habitats within the area of influence.

Guidance on selecting mainstem sites is given in the Monitoring section below. In case of tributaries, sites should be selected at least 500 m upstream from the confluence point. It is recommended that at least three tributaries each in the different impact zones (above the dam, below the dam-diversion reach, and downstream of the powerhouse) are considered for the assessment. Where possible, tributaries present on both banks of the mainstem

river should be considered for the sampling. In case of limited tributaries, two sites can be considered in the same tributaries, with the sites at least 500 m apart, while multiple samples should be located in the mainstem river in the stretch without tributaries.

Because the area may possess natural values in relation to the wider region (e.g., "this area contains the last remaining example of a certain ecosystem type in the region") the biota and natural features of the area of influence should be assessed in the context of the wider region.

## **Timing**

The natural values assessment is done (see the section: Temporal design) prior to project approval. It will lead to (and inform) a monitoring programme but is distinct from the monitoring programme. Field data should be collected at a time when species are likely to be present at maximum abundance (this is particularly relevant for migratory species).

#### Information sources

Information for the natural values assessment can come from a variety of sources. If reliable and current information can be gathered from the literature or from expert opinion, this may be used to supplement the field data collection.

## Monitoring

The monitoring programme is designed to determine whether the impacts of the hydropower project on natural values, during construction and operation, are within acceptable limits. For this purpose, the monitoring programme requires a robust design whereby impacts of the hydropower project can be measured unambiguously, and a sampling regime that can be sustained for many years. The most robust design is called a Before-After Control-Impact (BACI) design. For a BACI design, the site (location and number of sampling sites) and the timing and frequency of sampling should be decided carefully. Enough data must be gathered to make reliable conclusions.

#### Site selection

Site selection is a crucial aspect of ecosystem assessment in EIA as outcomes of the assessment depend on site characteristics and their number, and the frequency of assessments over the seasons and years. A site should be sufficiently representative of the location so that the sample consists of a broad range of organisms residing in the location.

Spatial design of a sampling site in the project area is important in overall assessment and monitoring of the area as the response of the aquatic species in a particular site varies according to the intensity of the disturbance. In each project area, enough sites should be allocated in all disturbed zones (above the dam including the impounded area, diversion reach, and downstream from the powerhouse) considering both the mainstem and the tributary of the river.

Control (reference) sites should be located upstream of the future impounded river section.<sup>1</sup> Upstream control sites should be as similar as possible to the downstream impact sites in terms of physical characteristics such as riverbed types and river gradient. Usually, control sites are river stretches in natural or near natural state<sup>2</sup> and they help us compare the faunal composition and diversity in "like with like" sites in the project area and influence area of the hydropower project. Similarly, control sites also help us compare the community composition over the years.

# Location and number of sampling sites

It is recommended that six sites each are selected in the different impact zones – above the dam (in control sites and impounded zone), below the dam (diversion reach), and downstream of the powerhouse (Figure 5). The investigation site needs to be representative of the bulk of the water body. Rapid River Assessment (RRA) Protocol (Tachamo-Shah et al., 2020b) shall be used to select sampling sites for the assessment. RRA Protocol is a scientific tool, which determines river quality classes at a site by inspecting sensory features, and instream biota including algae, periphyton and benthic macroinvertebrates (Annex 1).

Eighteen sampling sites including the mainstem of the river and its tributatries should be considered for making an inventory of selected organism groups and determining the ecological values of the project site and the area of influence. Six sampling sites three tributaries and three sites in the mainstem river upstream of the dam (at least one site in the future impounded area) - are to be selected as control sites. Control sites and sites downstream of the powerhouse should be distributed at 1000 m intervals (this may vary depending on the length of the impounded zone) in the mainstem while for the sites in the diversion reach, the sites should be at an equal interval between the dam and the confluence of the river and the tailrace. Site selection may be affected by the accessibility of the sites. In such cases some flexibility may be adopted regarding the distance between the sites; however, the principle of site selection needs to be maintained. It is necessary to summarize the number of sites and habitats in a study map.

#### The reservoir

The reservoir (the area flooded by impounded water, upstream of the dam) requires special consideration. Being a still-water (lake) habitat, it is not comparable to flowing-water (river) sites. Rather, it is a new type of ecosystem created by the hydropower project. As such, it will develop its own natural values as it is colonized by a variety of lake-adapted flora and fauna. The reservoir should

<sup>&</sup>lt;sup>1</sup> Identifying the river section upstream of the hydropower project as a control or reference site is appropriate for most components of a river ecosystem. However, migratory fish in the upstream river sections may be impacted by the hydropower project because the project acts as a migration barrier. For fish, control and impact sites may need to be upstream and downstream, respectively (i.e., reversed).

<sup>2</sup> It does not need to be "natural" if the river reach impacted by the hydropower project was not natural before the hydropower station was built.

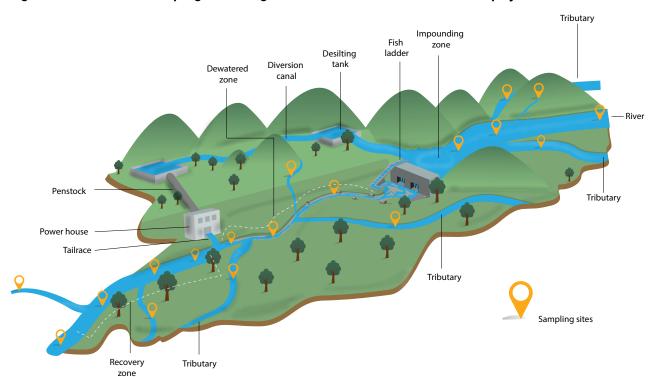


Figure 5: Distribution of sampling sites along the mainstem river and tributaries in a project site

not be part of the BACI sampling design, but its biota, water quality and water levels should be monitored on their own terms to ensure that the reservoir develops into, and remains, a healthy ecosystem. Relevant variables, and methods for monitoring these in lake habitats differ from those for flowing water habitats; and appropriate variables and monitoring methods should be chosen.

# Temporal design: Timing and frequency of sampling

Another important aspect is the temporal design of the assessment, i.e., when and how often the sites should be sampled. In order to measure changes due to a hydropower project, baseline conditions must be determined.

Organisms have different life phases and their growth patterns differ according to the season. Sampling across the seasons allows us to capture species diversity and abundance from the project area. Nepal has four distinct seasons – baseflow/winter (January-February), pre-monsoon/spring (March-May), monsoon/summer (June-September) and post-monsoon/autumn (October-December) – during which river discharge is low, very low, very high, and high respectively.

Water volume and flow regimes affect the diversity and composition of aquatic organisms, and influence the migration patterns of migratory species in the river ecosystem. Significant changes in the biotic community has been observed in Nepal's rivers across seasons - baseflow, premonsoon and post-monsoon - under altered flow regimes (Tachamo Shah et al., 2020a). Usually, sampling is not recommended during the monsoon season (June-September) because the high water level in the river makes it nearly impossible to take a representative sample. Sampling of aquatic organisms including microbiota and macrophytes should be conducted in three seasons - baseflow (January-February), pre-monsoon (March-May) and post-monsoon (October-December) - and in the consecutive years (for at least two years but preferably three or four years), to understand the seasonal and inter-annual variations during the baseline EIA study of the hydropower project. Water quality measurement should be done on a monthly basis for at least two to three years.

Sampling of fish should be conducted at a time when migratory species are present in the river reach. If different species are present at different times, then sampling should be conducted when fish diversity is at a maximum (IFC, 2021).

#### Field crew members

Table 3 below presents the minimum number of people required for the assessment of each component, and their roles and responsibilities:

## **Quantitative analysis**

Data generated during the detailed EIA survey should be entered in an excel spreadsheet. Bar diagram, pie chart or line plot can be prepared in the excel sheet. For data analysis and statistical tests, advanced statistical packages such as R-software packages (https://www.r-project.org/), SPSS software packages (https://www.ibm.com/analytics/spss-statistics-software), python software (https://www.python.org/) or other applicable statistical tools shall be used.

## Site information

Site information data includes a wide range of site-specific physical parameters such as location, land use types, and other related features of the river and its catchment (Sheet 1). Site specific information must be recorded in a systematic way, and must include the following (see Photo 2).

 Geographical location of the project area (including locations of upstream and downstream extent), control sites including dam sites, diversion reach and downstream of the powerhouse. Must include locations of all sampling sites in the form of geographic coordinates (latitude, longitude and altitude).



Photo 2: Researcher filling the site information sheet. This sheet documents information related to the study river reach, weather condition, stream characterization, catchment characteristics, and stressors.

- Map of catchment indicating the project area, sampling sites, major topographic features, major land uses and human habitations
- Map of the project area (river and surrounding land) including relevant features such as tributaries, proposed location of the hydropower scheme, sampling sites, access points, important features such as bridge, temple, monument, etc.
- Catchment land use properties including the proportion of forest, residential area, agricultural area, etc. and the tentative width of riparian vegetation
- Source of river, e.g., glacier, lake, spring, rain-fed
- Climate (rainfall and temperature: annual average, seasonal maximum and minimum)

In addition to the general site information, hydrology and a Physical Habitat Assessment of each site must be conducted. Further, for each biotic component, specific physical habitat information that needs to be collected in the field is embedded within the data collection sheet of the respective biotic group.

## **Hydrology**

### Introduction

The natural flow regime in the river shapes aquatic ecosystem, floodplain and river-induced groundwater (Richter et al., 1998). The natural flow regime maintains the conditions required for a well-functioning aquatic ecosystem (Poff et al., 1997). Flow regime characteristics such as magnitude, frequency, duration, periodicity, and timing of flows across the seasons, discharge at baseflow, coefficient of flow variation, maximum flood during the reporting period, number of flood events above a certain flow threshold, and timing of floods influence river habitats, water quality and organisms thriving in the ecosystems (Poff et al., 1998). Construction of a dam diverts the water and affects the natural flow regime of the river, which in turn affects all other parameters (physical, chemical and biological). Construction of a hydropower project reduces the velocity and discharge of the river and affects habitat availability (Anderson et al., 2015; Richter et al., 1997). Therefore, hydrological information on flow characteristics must be included in the EIA.

Table 3: Assessment components with available measurement methods and minimum number of people required in the field

| Components                          | Methods  | No. of crew members  | Roles and responsibilities  |
|-------------------------------------|--|--|---|
| Hydrology                           | Velocity-Area<br>Method                                    | • 2 members (1 expert; 1 research assistant)   | Expert: Selection of cross-section in a site and determination of calibration factor     Research assistant: Measurement of conductivity and discharge  |
|                                     | Dilution Method  | 2 members (1 expert; 1 research assistant)   | Expert: Selection of cross-section in a site and determination of calibration factor     Research assistant: Measurement of conductivity and discharge  |
|                                     | Acoustic Doppler<br>Current Profiler                       | • 2 members (1 expert; 1 research assistant)   | Expert: Selection of cross-section in a site     Research Assistant: Measurement of velocity  |
|                                     | Moving Boat<br>Method                                      | 3 members (1 expert; 2 research assistant)   | Expert: Selection of cross-section in a site     Research assistant: Measurement of velocity and note taking  |
| Physical habitat assessment         | Visual Estimation  | 2 members (1 expert; 1 research assistant)   | <ul> <li>Expert: Observation and estimation of the parameter in a site</li> <li>Research assistant: Measurement and note taking</li> </ul>  |
| Phytoplankton/<br>Zooplankton       | Water sample<br>collection using<br>plankton net           | 1 research assistant   | Collect samples in the field and submit it to the laboratory for enumeration and determination.   |
| Periphyton                          | Random sampling  | 1 research assistant   | Scrubbing the periphyton and submit it to the laboratory for enumeration and determination.   |
| Macroinvertebrates                  | Multihabitat<br>sampling                                   | 3 members (1 expert; 2 research assistants)  | <ul> <li>Expert: Identify and determine the proportion of micro-habitats in each site and guide the research assistants in sampling</li> <li>2 Research assistants: Take habitat specific sample; process the sample</li> </ul> |
| Fish                                | Cast Netting   | • 3 members (1 expert, 1 fisher, 1 fish handler)   | <ul> <li>Expert: Identify and measure the captured fish</li> <li>Fishers: Catch fish in the field</li> <li>Fish handler: Handle the captured fish and note down</li> </ul>  |
|                                     | Seine-hauls  | • 4 members (1 expert, 2 fishers, 1 fish handler)  | the measurements (Note – in case of collection of vouchers, the fish handler prepares labels for the collected specimen and samples)  |
|                                     | Dip Netting  | • 3 members (1 expert, 1 fisher, 1 fish handler)   | concerca specimen and samples)  |
|                                     | Gill Nets  | • 3 members (1 expert, 1 fisher, 1 fish handler)   |   |
|                                     | Backpack     Electrofishing                                | 5 members (1expert/note<br>keeper, 1 fish handler, 2<br>fishers, 1 netter with<br>backpack electrofishing) |   |
|                                     | Underwater Video   | • 2 Research assistants  | Set up a camera and illustration back in the office   |
|                                     | • eDNA   | • 3 members (1 expert, 2 research assistants)  | Filter water sample in the field, and filtered water<br>samples are sequenced in the genetic laboratory   |
| Macrophytes                         | Quadrat method   | • 2 members (1 expert, 1 research assistant)   | Identify and record number of species in the field  |
| Terrestrial and riparian vegetation | <ul><li>Transect methods</li><li>Quadrate method</li></ul> | • 2 members (1 expert, 1 research assistant)   | Identify and record number of species in the field  |
| Water quality                       | Onsite<br>measurement and<br>water sample<br>collection    | • 1 research assistant   | Analysis of water samples in the field, and water<br>sample collection for the laboratory   |

## **Sheet 1 – Site information sheet (Sample)**

| 1. Site-specific information   |  |   |  |
|--|--|---|--|
| 1.1 River/stream   | 1.2 River system   | 1.3 Place, District, Province   |  |
| 1.4 Site/station codes   | 1.5 Coordinates, Elevation □ N: □ E: □ Altitude:                 | 1.6 Date  |  |
| 1.7 Time   | 1.8 Surveyor   | 1.9 Investigator  |  |
| 1.10. Location Map of Site   |  |   |  |
| 2. River characterization  |  |   |  |
| 2.1. River subsystem:  | 2.2. River type:   | 2.3. River origin:  |  |
| ☐ Perennial  | □ Cold water   | □ Glacial □ Swamp and bog   |  |
| ☐ Intermittent   |  | □ Non-glacial montane □ Mixture of origins □ Spring-fed □ Other (Specify) |  |
| 2.4. Stream order:   |  | , ,   |  |
| 3. Catchment characteristics   |  |   |  |
| 3.1. Predominant surrounding land use:   | 3.2. Riparian vegetation (within 18 m buffer $$                  | in sampling):   |  |
| Indicate at 10% intervals for 1 km river   | 3.2.1. Dominant vegetation type:                                 |   |  |
| stretch (taken upstream of site)  □ Forest%  | ☐ Trees ☐ Shrubs ☐ Grasses ☐                                     | Herbaceous  |  |
| ☐ Folest%         ☐ Field/Pasture%         ☐ Agricultural%         ☐ Residential%         ☐ Commercial%         ☐ Industrial%         ☐ Other (Specify)% | 3.2.2. Dominant species present:                                 |   |  |
|  | 3.3. Canopy cover at zenith:  □ Open □ Partly open □ Partly shad | ed □ Shaded   |  |
|  | 3.4. Local watershed erosion:                                    |   |  |
|  | □ None □ Moderate □ Heavy  |   |  |
| 4. Stressors (if any):   |  |   |  |

Furthermore, the contribution of snow and ice melt in major rivers ranges from less than 5% to more than 45% of the average annual flow (Bookhagen and Burbank, 2010; Marahatta et al., 2010; Siderius et al., 2013). Thus, the contribution of snow and ice melt to river discharge should also be mentioned in the EIA.

#### Field measurement

Hydrological and hydraulic characteristics such as river discharge, velocity, water depth, wetted river width and thalweg profile are crucial for analysing the impact of flow variation on the aquatic environment and the sustainability of the hydropower project (Bockelmann et al., 2004; Maddock, et al., 2013). Changes in the hydrological features may severely impact the amount of power generation and degree of operation of the hydropower project. Therefore, detailed information on river discharge and hydraulic controls should be gathered according to standard proceduces during the environmental impact survey of the hydropower project (Table 4).

## Measurement of river discharge

- 1. Manually set three cross-sections within the selected river reach for the measurement of wetted river width and river discharge (Sheet 2). Choose a section that is relatively straight, free of obstacles such as large rocks, and uniform in width and depth.
- 2. Measure the river depth from six points covering major flow types and calculate the average water depth.

## **Safety precautions**

- Check water and weather conditions before going for sampling.
- · Wear a lifejacket and safety helmet.
- Make sure to carry other safety gear (e.g., ropes, belts) and a first-aid kit.
- River banks and stones might be slippery, wear appropriate clothing with non-slip soles.
- The surveyor must cross the river to measure the river width and river cross-section, so as far as possible the survey should not be conducted during above average flows in the river.
- Use a raft or boat to cross the river.

## **Data analysis**

The hydropower scheme must have gauges to continuously record flow entering and leaving through the systems of the diversion canal as it influences the production of hydroelectricity across the seasons.

Flow time series analysis for the sites within the project's influence area should be done to establish the reference hydrological regime for the study area. Flow time series simulations under present land and water use conditions shall be analysed. Snow and ice melt contribution to river discharge shall also be analysed.

**Table 4: Discharge measurement methods and their requirements** 

| Methods                           | Requirements   | Remarks   |
|-----------------------------------|--|---|
| Velocity-Area Method              | Current Meters or Acoustic Doppler<br>Velocimetry (ADV)     Bathymetric survey instruments | <ul> <li>Hydraulic Survey (Velocity Measurements)</li> <li>For area measurements, bathymetric survey techniques are applicable</li> </ul> |
| Dilution Method                   | Conductivity Meter     Tracers (Chemical/dyes/salts)                                       | Hydraulic Survey  |
| Acoustic Doppler Current Profiler | <ul><li>Boat</li><li>ADCP Setup</li><li>Controller device (e.g., Laptop)</li></ul>         | Hydraulic Survey     (Measure both velocity and area simultaneously)  |
| Moving Boat Method                | <ul><li>Propeller type current meter</li><li>Boat</li></ul>                                | Hydraulic Survey     (For large wide river with no obstruction along cross-section direction)   |

<sup>\*</sup>Note: Use of Total Station is recommended for Topographic Survey, while Level Machine is most suitable for measuring elevation differences. Advanced equipment like ADCP is preferred for measuring high resolution velocity and discharge in large rivers. For smaller hill streams where flow is highly turbulent, dilution methods are appropriate. Regardless of these recommendations, the method depends upon the time, cost, easiness and resolution of data required.

## Sheet 2 - Hydrological and hydraulic data sheet (Sample)

| 1. Site information   |      |  |  |   |                       |  |    |  |  |  |               |               |  |                                    |  |  |  |  |  |  |   |  |
|---|------|--|--|---|-----------------------|--|----|--|--|--|---------------|---------------|--|------------------------------------|--|--|--|--|--|--|---|--|
| Site code:  |      |  |  | Date/time:                                    |                       |  |    |  |  |  | Investigator: |               |  |                                    |  |  |  |  |  |  |   |  |
|   |      |  |  | 200,  |                       |  |    |  |  |  |               |               |  |                                    |  |  |  |  |  |  |   |  |
| 2. River depth  |      |  |  |   | 3. Wetted river width |  |    |  |  |  |               |               |  | 4. Proportion of reach represented |  |  |  |  |  |  |   |  |
| (Avgerage of 6 measurements within 100 m stretch)               |      |  |  | (Avg. of 3 measurements within 100 m stretch) |                       |  |    |  |  |  | n             | by flow types |  |                                    |  |  |  |  |  |  |   |  |
| dictory   |      |  |  |   | Siletony              |  |    |  |  |  |               |               |  |                                    |  |  |  |  |  |  |   |  |
|   | ii): |  |  | i) ii)  |                       |  |    |  |  |  |               | Rapid%        |  |                                    |  |  |  |  |  |  |   |  |
| iii)  |      |  |  |   |                       |  |    |  |  |  |               |               |  |                                    |  |  |  |  |  |  |   |  |
| v)  |      |  |  |   |                       |  | v) |  |  |  | vi)           |               |  |                                    |  |  |  |  |  |  | % |  |
| vii) Avg:   |      |  |  | vii) Avg:                                     |                       |  |    |  |  |  | Glide%        |               |  |                                    |  |  |  |  |  |  |   |  |
|   |      |  |  |   |                       |  |    |  |  |  | Pool%         |               |  |                                    |  |  |  |  |  |  |   |  |
| 4. River discharge measurement following Velocity – Area Method |      |  |  |   |                       |  |    |  |  |  |               |               |  |                                    |  |  |  |  |  |  |   |  |
| Bank<br>(Left bank, m)  |      |  |  |   |                       |  |    |  |  |  |               |               |  |                                    |  |  |  |  |  |  |   |  |
| Depth (m)   |      |  |  |   |                       |  |    |  |  |  |               |               |  |                                    |  |  |  |  |  |  |   |  |
| Velocity (m/s)  |      |  |  |   |                       |  |    |  |  |  |               |               |  |                                    |  |  |  |  |  |  |   |  |
| Discharge (m³/s):   |      |  |  |   |                       |  |    |  |  |  |               |               |  |                                    |  |  |  |  |  |  |   |  |

## **Data presentation**

The average and peak discharge for the hydrological station can be presented in line plot or table (Table 5) to show trends across the years (minimum of 10 years' data). Key hydrological metrics should be calculated and reported (Table 6).

## Physical habitat assessment

#### Introduction

In addition to collecting general site information, a physical habitat assessment of each site should be conducted during the EIA/IEE survey within the influence area of the hydropower project. Physical habitat is the template on which all aquatic biota lives. It includes water, mineral substrates and biological components on which biota thrive, breed, move and spend entire or part of their life (Harding et al., 2009). Physical river habitats such as waterpools, stones and boulders, macrophytes, twigs and branches fallen from the riparian vegetation provide shelter to aquatic fauna and protect them from predatory organisms. Coarse organic particulate

matter (COPM) and in-stream biological template such as periphyton, moss and macrophytes are good sources of food for many river organisms.

Hydropower projects significantly alter the physical habitat of rivers in well known ways, e.g., changes in riverbed sediment characteristics, flow regimes, channel incision, channel narrowing and encroachment by riparian vegetation (Schmidt and Wilcock, 2008). These changes alter food availability, spawning ground, and shelter, affecting the distribution and abundance of organisms. This may form novel community composition that is resistant to the modified habitats. Therefore, the IEE/EIA survey should include assessment of river habitats in the area of influence. Detailed habitat assessment allows us to evaluate the magnitude and intensity of impacts on aquatic organisms as different aspects of hydropower development might have contrasting effects on river sediment, channel form and channel behaviour. For example, water diversion may lead to accumulation of fine sediment downstream (Baker et al., 2011), whereas a dam may deplete the downstream riverbed of fine sediment (Schmidt and Wilcock, 2008).

Table 5: Average and peak discharge for a project area river

| Year | Average discharge (m³/s) | Peak discharge (m³/s) |
|------|--------------------------|-----------------------|
|      |                          |                       |
|      |                          |                       |
|      |                          |                       |
|      |                          |                       |
|      |                          |                       |
|      |                          |                       |

Table 6: Hydrological parameters for a project area river

| Hydrological metrics  | Reference sites including dam sites | Diversion reach | Downstream of powerhouse |
|---|-------------------------------------|-----------------|--------------------------|
| Avg. discharge (m³/s)   |                                     |                 |                          |
| Pre-monsoon (m³/s) (M-A-M)  |                                     |                 |                          |
| Monsoon (m³/s) (J-J-A-S)  |                                     |                 |                          |
| Post monsoon (m³/s) (O-N)   |                                     |                 |                          |
| MALF (mean 7-day or 5-day annual low flow)                        |                                     |                 |                          |
| Mean annual flood (m³/s)  |                                     |                 |                          |
| A measure of flood frequency – small to medium floods, e.g., FRE3 |                                     |                 |                          |
| Avg. snow ice contribution (m³/s)                                 |                                     |                 |                          |
| Avg. Rain and baseflow (m³/s)                                     |                                     |                 |                          |
| Snow and ice contribution (%)                                     |                                     |                 |                          |

#### **METHODS**

#### Sampling gear and equipment:

| Stationery                               | Equipment  |  |  |  |  |  |  |
|--|--|--|--|--|--|--|--|
| Topographic map or<br>aerial photographs | Camera     GPS   |  |  |  |  |  |  |
| Field notebook, pencils<br>and clipboard | Measuing tape (30m +)  Water velocity meter or discharge meter |  |  |  |  |  |  |
|  | • 1 m ruler  |  |  |  |  |  |  |
|  | Flagging tape  |  |  |  |  |  |  |

#### **REQUIRED DATA:**

Information that should be collected/observed during field visit is presented in Box 2. River morphology assessment requires field measurements; photopoints require a camera; the remaining variables, which are part of the Rapid Habitat Assessment (see section on RHA for more details), can be estimated by eye.

## Box 2

- River morphology: width of wetted channel, bankfull width, non-vegetated width, water depth and bankfull depth during the flood
- Plan-view channel shape (straight, meandering, sinuous)
- Photopoint (see section: how to take photopoints)
- Riverbed composition (habitat estimation)
- Number of hydraulic components (e.g., rapid, riffle, run, glide, pool) in the river reach
- Diversity of habitat for aquatic biota
- Proportion of habitat for aquatic biota
- Bank alterations (reinforcing by artificial materials)
- Bank vegetation
- Bank erosion
- Riparian buffer width

A drone may be useful for recording some of these in a large, non-wadeable river.

#### **DETERMINATION OF RIVER REACH**

- Establish the start of the reach by marking it with a flagging tape or similar object and GPS.
- 2. Measure the river wetted width at a representative cross-section (or measure 2-3 widths and calculate an average) and calculate the reach length as 20x wetted width. In case of a large/non wadeable river, at least 100 m or a maximum of 500 m should be considered for the study so that the full variety of habitat types is represented.
- 3. Set the river reach length with the help of a flagging tape or GPS.

#### **RIVER MORPHOLOGY**

River morphology includes both channel crosssection and longitudinal form, which can be measured using different methods listed in Table 7.

#### **CHANNEL CROSS-SECTION**

To properly characterize the channel shape of the river reach, hydraulic variables should be measured at a minimum of three cross-sections or transects comprising a riffle, run and pools of the study reach (Table 7). If there is not enough time for this, a

single cross-section may be measured in a run section of the study reach. This may not characterize the reach, but if the location of this cross-section is recorded and the same location is used on every sampling visit, it can show changes in the channel shape over time. The key parameters to be measured (refer to Figure 6) are:

- · Width of the wetted channel
- Channel width from bank to bank (bankfull width)
- Bank height (distance between water surface and top of bank)
- · Water depth at intervals on the cross-section
- Thalweg depth (water depth at the deepest point in the cross-section)
- Water velocity at intervals on the cross-section

The above data can be used to calculate the following:

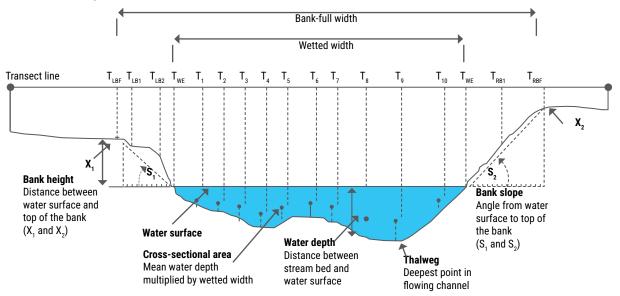
- Cross-sectional area (m²)
- Mean water depth (m)
- Mean current velocity (m/s)
- Channel width/depth ratio

Table 7: Methods for the channel cross-section and longitudinal form measurement<sup>3</sup>

| SN  | Parameter                     | Methods                                 | Requirements  | Remarks   |
|-----|-------------------------------|---|---|---|
| 0.1 | . arameter                    | memouo                                  | redui emente  | Remarks   |
| 1   | River<br>cross-<br>section    | Theodolite and Total<br>Station Surveys | Theodolite, EDM or measuring tape<br>Total station  | Topographic survey/ Bathymetric survey in shallow depth             |
|     | Conton                        | GPS Surveys                             | Base station receiver<br>Rover devices  | Topographic survey/ Bathymetric survey in shallow depth             |
|     |                               | LIDAR Surveys                           | Lidar mounted device like UAV<br>GPS base station<br>Ground control devices for UAV                                   | Topographic survey and Bathymetric survey for shallow depth         |
|     |                               | Arial Photogrammetric<br>Survey         | Specialized UAV or planes   | Topographic survey  |
|     |                               | Eco-Sounder                             | Boat or boat like setup to mount device<br>across the river cross-section<br>Eco-sounder device<br>Optional GPS setup | Bathymetric survey  |
|     |                               | Acoustic Doppler Profiler               | Standard ADP device<br>Optional GPS setup<br>Control device (mobile, laptops, etc.)                                   | Bathymetric survey  |
| 2   | Longitudinal profile of river | Level Survey                            | Leveling machine<br>Leveling rods/staffs<br>Surveyors long tape   | Topographic survey along left bank, right bank and thalweg of river |

<sup>&</sup>lt;sup>3</sup> Please refer to Agor (2015) for details on these surveying methods and instruments

Figure 6: A typical river channel cross-section. The transect line shows the location of offsets at the left bankfull  $(T_{LBF})$ , left bank  $(T_{LB})$ , water's edge  $(T_{WE})$ , water depths  $(T_{1-1}0)$  water's edge  $(T_{WE})$ , right bank  $(T_{RB})$ , and right bankfull  $(T_{RBF})$ . Circles represent measurements of water velocity at 40% water depth for the calculation of stream discharge



Source: from Harding et al., (2009).

#### LONGITUDINAL CHANNEL FORM

To characterize longitudinal channel form, the following should be measured:

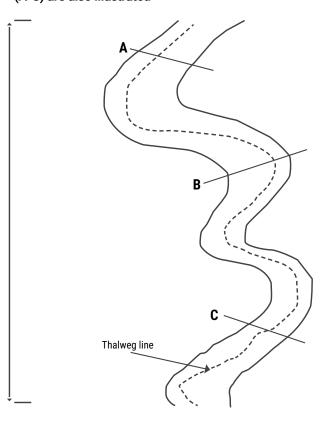
- Channel slope (measured in the field as the change in water surface elevation over the length of the reach. If both ends of the reach are not easily visible it is easier to calculate channel slope by referring to digital elevation maps).
- Channel sinuosity (ratio of thalweg length to straight line length of the study reach; Figure 7)
- Number and size of gravel bars and gravel banks within the study reach.

## **RIVERBED COMPOSITION**

Riverbed composition (also known as habitat estimation) can be easily described based on the visual assessment method. It is usually carried out without stepping into the river. Below is the step-by-step procedure for estimating riverbed composition:

- Rived bed estimation shall be carried out in the same river stretch where benthic macroinvertebrates are sampled (see sub-section: Benthic macroinvertebrates).
- 2. A researcher shall walk back and forth along the river bank to see the entire study river stretch and estimate by eye the percentage of the riverbed that is covered by each of the mineral substrates listed in Sheet 3. The estimation shall be carried out in 5% interval and the total of all the mineral sizes should add to 100%.

Figure 7: Location of the thalweg line (dotted line), which is the deepest and often the fastest part of the river. The ratio of thalweg distance to straight line distance (solid line) is a measure of channel sinuosity. The potential locations of cross-sections (A-C) are also illustrated



Source: Harding et al., (2009).

# **Sheet 3 – Habitat estimation sheet (Sample)**

| Site code: Date/time                              | :Investigator:         |                      |            |      |        |       |       |  |
|---|------------------------|----------------------|------------|------|--------|-------|-------|--|
| Mineral substrate                                 | Coverage<br>(5% steps) | Sampling units (No.) | Flow types |      |        |       |       |  |
| Boulders, bedrock (> 40 cm)                       | (******)               |                      | Run        | Pool | Riffle | Glide | Rapid |  |
| Cobbles (> 20 cm - 40 cm)                         |                        |                      |            |      |        |       |       |  |
| Stones (> 6 cm - 20 cm)                           |                        |                      |            |      |        |       |       |  |
| Pebbles (> 2 cm - 6 cm)                           |                        |                      |            |      |        |       |       |  |
| Gravel (>0.2 cm - 2 cm)                           |                        |                      |            |      |        |       |       |  |
| Sand and mud (>6µm – 2 mm)                        |                        |                      |            |      |        |       |       |  |
| Silt loam, clay (inorganic) (< 6 μm)              |                        |                      |            |      |        |       |       |  |
| Artificial substrates                             |                        |                      |            |      |        |       |       |  |
| Sum   | 100                    | 20                   |            |      |        |       |       |  |
| Biotic substrate                                  |                        |                      |            |      |        |       |       |  |
| Algae   |                        |                      |            |      |        |       |       |  |
| Macrophytes - Emergent                            |                        |                      |            |      |        |       |       |  |
| Macrophytes - Submerged                           |                        |                      |            |      |        |       |       |  |
| Macrophytes - Floating                            |                        |                      |            |      |        |       |       |  |
| Living parts of terrestrial plants                |                        |                      |            |      |        |       |       |  |
| Wood – tree trunks, branches, roots               |                        |                      |            |      |        |       |       |  |
| Coarse particulate organic matter (CPOM) deposits |                        |                      |            |      |        |       |       |  |
| Fine particulate organic matter (FPOM) deposits   |                        |                      |            |      |        |       |       |  |
| Debris – organic and inorganic matter deposits    |                        |                      |            |      |        |       |       |  |

- The estimated percentage of riverbed that is covered by respective mineral substrates is distributed across flow types available in the study stretch.
- In case of turbid water where visual estimation is not possible, estimation should be carried out walking in a zig-zag pattern starting at the downstream end to the upstream end.
- This completed habitat estimation is used for distributing sample units for the collection of benthic macroinvertebrates (see more in sub section: Benthic macroinvertebrates).

#### WHAT IS RAPID HABITAT ASSESSMENT PROTOCOL?

Rapid Habitat Assessment (RHA) Protocol (modified from Clapcott, 2015) consists of 10 parameters that should be assessed in the field during the IEE/EIA survey in the impact zone of the hydropower project. It is recommended that RHA is carried out during the low flow season as the physical parameters can be easily measured in low flow and impacts of flow modifications on the organisms are high during this season (Tachamo-Shah et al., 2020a). At this time of year, river flow is maintained by groundwater recharge. It is recommended that the same person should do the assessment each time.

# FIELD PROCEDURE FOR THE RAPID HABITAT ASSESSMENT PROTOCOL (ANNEX 2)

- First, record site details such as site name, name of river, river system, nearest village, geographic coordinates including altitude, and the date and time of assessment.
- Note down the channel shape by walking along the river reach.

- At each cross-section estimate bankfull depth (Figure 6) and calculate average bankfull depth for the site (Bankfull depth represents maximum river water depth, usually attained during high flood in the section).
- 4. Measure the width of non-vegetated sections on either bank of the study site. A total of three measurements should be carried out from the most downstream, middle and the most upstream reach of the study river reach, and average value is supplied in the protocol.
- 5. Note down whether there is any bank alteration in the study river reach.
- 6. Habitat parameters except for no. 10 (riparian width) are estimated visually at the site.
- 7. For each of the 10 parameters, circle the score that best describes the site.
- 8. Add a circled score under the heading 'Score' for each of the 10 parameters.
- 9. Add all the assigned scores to get the final value for the site.
- The total maximum score is 100 and total minimum score is 10. Describe the final values according to Table 8.
- 11. Draw a detailed river reach map showing typical physical features (bridges, large boulders, etc.), water flow types (rapid, riffle, run, pools, etc.), and channel shape of the study river reach.
- 12. Take good quality photos that capture the physical features and water types of the sampling site from a photopoint (Photo 3).
- 13. For each parameter, one should see the whole study reach; for this the researcher should walk up and down the length of the reach.

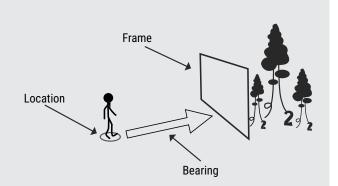
Table 8: Classification of habitat quality score with respective description

| Score   | Habitat Quality Status | Colour Code | Description   |
|---------|------------------------|-------------|---|
| 80-100% | High                   | Blue        | Highly suitable for colonization of sensitive invertebrates     |
| 60-80%  | Good                   | Green       | Suitable for colonization of sensitive invertebrates            |
| 60-40%  | Fair                   | Yellow      | Moderately suitable for colonization of sensitive invertebrates |
| 20-40%  | Poor                   | Orange      | Less suitable for colonization of sensitive invertebrates       |
| < 20%   | Bad                    | Red         | Not suitable for colonization of sensitive invertebrates        |

# What are photopoints?

Photopoints are a simple way of recording important information about a site and how it changes. They are a series of photos taken on many occasions over a period of time:

- at the same location
- in the same direction (or "bearing") and
- with the same "frame" (how wide the view of the camera is).



# How to make a photopoint?

- **Set the location:** Set up a distinctive object or find an existing one (e.g., a fencepost), to place the camera each time. Or locate yourself in relation to a distinctive object that is unlikely to move, like a tree. Mark the object on which the camera is placed, write notes about how to find it and record the GPS coordinates.
- **Set the direction:** Record the bearing (compass direction) and note a distinctive feature that is included in the photo.
- Set the frame: Note the features near the edges of the photo.

(Adapted from NIWA, 2019)



Photo 3: A site photo refelecting catchment properties: riparian vegetation, river bank, types of river flows of the sampling site

### **DATA ANALYSIS**

All scores obtained in the RHA protocol are summed up. The final score of a site is compared against a table that describes the river habitat quality status (Table 8). Additionally, the scores for the diversion reach and downstream of the powerhouse are compared with the score of control sites.

# Safety precautions

- Check water and weather conditions before going for sampling.
- · Wear a lifejacket.
- Make sure to carry other safety gear (e.g., Ropes) and a first-aid kit.
- River banks and stones might be slippery, wear appropriate clothing with non-slip soles.
- The surveyor must walk up and down along the river reach, so as far as possible, this assessment should not be conducted during above average flows in the river.

**Note:** All measurements should be carried out in the river reach where hydrology, biological and water quality assessments are conducted. In-stream information for which the researcher has to wade in the riverbed, such as river depth (maximum, minimum and average), river width, river velocity and river discharge, etc. should be collected after the biological sampling in order to avoid disturbing the fauna.

Table 9: The summary sheet of score of each RHA component (from Annex 2).

| Zone/parameters                   | Site code | Deposited sediment | Substrate embeddedness and compaction | Macroinvertebrate<br>habitat diversity | Macroinvertebrate habitat<br>abundance | Fish cover diversity | Fish cover abundance | Hydraulic heterogeneity | Bank erosion | Bank vegetation | Riparian width | Total score |
|-----------------------------------|-----------|--------------------|---------------------------------------|--|--|----------------------|----------------------|-------------------------|--------------|-----------------|----------------|-------------|
| Control sites including dam sites |           |                    |                                       |  |  |                      |                      |                         |              |                 |                |             |
| Diversion reach                   |           |                    |                                       |  |  |                      |                      |                         |              |                 |                |             |
| Downstream of powerhouse          |           |                    |                                       |  |  |                      |                      |                         |              |                 |                |             |

# **Definition**

**Substrate compaction**: Substrate compactness is a measure of substrate stability in a river. Substrates become highly compacted due to high sedimentation, frequent flow fluctuations, cemented

from physico-chemical weathering and biofilm or moss accumulation (Harding et al., 2009). Substrate compaction reduces interstitial spaces between particles, inhibiting exchange of water organisms between the riverbed and the hyporheic zone under the river (Photo 4).

Substrate embeddedness: It is also a measure of large substrate stability in a river. Large substrates such as rock, cobble, pebble and gravel are fixed due to deposition of fine substrates like silt and sand under the river.



Photo 4: Substrate embeddness and compaction due to cementation resulting from chemical and physical processes under the river.

# DATA PRESENTATION

The final score of RHA protocol is presented for the influence zones of the hydropower project (Table 9). The score of each RHA component (deposited sediment, subtrate embeddedness, etc.) should also be presented to aid the interpretation of the overall score. The values for impacted zones are compared with control sites during monitoring.

The final RHA score is compared against habitat quality classification (Table 8) to determine the suitability of habitats for in-stream organisms (Table 10).

Table 10: Habitat quality status of sites within the influence area of the hydropower project

| Parameters                        | Site code | RHA score | Habitat Quality Status (HQS) |
|-----------------------------------|-----------|-----------|------------------------------|
| Control sites including dam sites |           |           |                              |
|                                   |           |           |                              |
|                                   |           |           |                              |
|                                   |           |           |                              |
|                                   |           |           |                              |
|                                   |           |           |                              |
|                                   |           |           |                              |
| Diversion reach                   |           |           |                              |
|                                   |           |           |                              |
|                                   |           |           |                              |
|                                   |           |           |                              |
|                                   |           |           |                              |
|                                   |           |           |                              |
|                                   |           |           |                              |
| Downstream of powerhouse          |           |           |                              |
|                                   |           |           |                              |
|                                   |           |           |                              |
|                                   |           |           |                              |
|                                   |           |           |                              |
|                                   |           |           |                              |
|                                   |           |           |                              |

# 3.1 Micro-Biota (Plankton)

Plankton are microscopic or minute organisms that live suspended in the water column. Plankton can be divided into two types: phytoplankton and zooplankton. They occur mainly in standing or slow-moving water, making them more abundant in lentic water bodies compared to lotic systems (Mahaseth, 2016; Nakanishi et al.,1988; Sharma, 2020). They are an important source of food for many higher organisms including fish. They move in the water column either via convection or wind-induced currents.

Phytoplankton and zooplankton are useful indicators of the ecological state of the reservoir created by a dam. Increase in water temperature and accumulation of nutrients leads to the proliferation of diverse plankton assemblages in a relatively short time after the impoundment of the river (Okuku et al., 2016).

# **Phytoplankton**

#### INTRODUCTION

Phytoplankton, also known as microalgae, are microscopic or minute photosynthetic organisms suspended in the water column. Diversity and abundance of phytoplankton are much higher in lentic water bodies compared to lotic water bodies (Mahaseth, 2016; Nakanishi et al., 1988). Nevertheless, phytoplankton diversity is relatively high in mountain freshwater ecosystems of the Himalaya compared to other parts of the world (Kammerlander et al., 2015). Phytoplankton (Figure 8) mainly includes green algae (Chlorophyceae), blue algae (Cyanophyceae) and diatoms (Bacillariophyceae). Phytoplankton is the base of several aquatic food webs and provides food for many heterotrophic organisms like zooplankton, shrimps, snails, small fish, etc. Therefore, its population and distribution indicates the ecological status of the water body. Phytoplankton are usually categorized according to their size (Table 11).

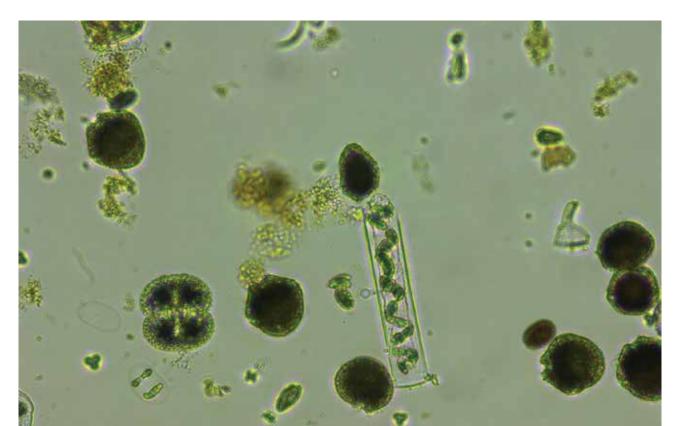


Figure 8: Examples of phytoplankton in aquatic ecosystem

Source: GitBook (2024).

Table 11: Classification of phytoplankton according to their size

| Group              | Linear size (µm) | Common examples  |
|--------------------|------------------|--|
| Picophytoplankton  | 0.2-2.0          | Photosynthetic bacteria, Blue green algae;<br>Synecococcus, Synecocystis Aphanothece, Aphanocapsa  |
| Nanophytoplankton  | 2-20             | Blue green algae – Chroococcus, Merismopedia<br>Green algae – Scenedesmus, Crucigenia, Cryptomonas, Rhodomonas<br>Bacillariophytes – Fragillaria, Cyclotella |
| Microphytoplankton | 20-200           | Dinoflagellates – Ceratium, Peridinium,<br>Bacillariophtes – Pinnularia, Cymbella, Asterionella  |
| Macrophytoplankton | >200             | Green algae – <i>Volvox, Pandorina, Eudorina</i><br>Blue green algae – <i>Anabaena, Microcystis, Nostoc</i>  |

Source: Sigee (2004)

Phytoplankton are sensitive to changes in nutrient inputs, habitat alteration, and the chemical condition of the aquatic environment. Therefore their diversity and biomass are used as indicators of water quality (Medupin, 2011; Reynolds et al., 2000). Phytoplankton communities and their biomass provide more information about water quality than the determination of nutrient concentrations alone (Medupin, 2011). Therefore, it is important to assess both the diversity and biomass of phytoplankton during a detailed EIA baseline survey (see Chapter 8: Assessing impacts in Hydropower EIA Manual 2018) as the baseline for monitoring the impacts of a hydropower dam.

#### **METHODS**

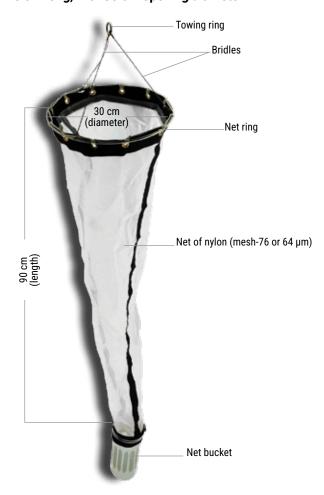
Sampling gear and consumables in the field

- Sample bottle
  - Phytoplankton: Dark brown glass or PET (polyethylene terephthalate) or High density polyethylene (HDPE) bottles are recommended for the collection of phytoplankton
  - Chlorophyll-a: Brown glass bottles (PET or High density polyethylene are acceptable) are recommended for collection of phytoplankton for chlorophyll-a.
- Lugol's solution or 4 to 5% formaldehyde
- Van Dorn sampler (for collecting water samples from desired depths of the reservoir)
- Plankton Tow Net (76 or 64 μm; Figure 9)

### FIELD SAMPLING TECHNIQUE

Phytoplankton samples should be collected properly as their distribution are controlled by water velocity, wind, and water temperature. Prior to phytoplankton sampling in a river, one should get information on river width, depth profile, substrate

Figure 9: A simple plankton tow net made of nylon, 90 cm long, with 30 cm opening diameter



Source: Dynamic Aqua Supply (2024)

mobility, and flow regimes. It is recommended that you do not take samples from a site where fine sediments are washed down from upstream as the fine sediment might clog the plankton net. Since there is horizontal and vertical mixing of water in a river, phytoplankton samples should be taken from 5 cm below the water surface in order to characterize the phytoplankton present in the river. If the river consists of various flow types, samples should be taken from all available flow types and made into a composite sample that is representative of the phytoplankton community present in the river.

In a reservoir: For representative samples in a reservoir, samples shall be taken from the inflow site, main body, and near the dam from both banks (see Figure 10). If the reservoir is shallow (i.e., < 2 m), subsurface grab samples at 0.5 m should be taken (for details, see Hötzel and Croome, 1999). In case of a deep reservoir, integrated samples over the epilimnion or euphotic, grab samples at 5 m intervals should be taken from at least one site. At each site, three water samples should be taken. As far as possible, sample should not be taken from an area with algal scums (Hötzel and Croome, 1999). Field measurements should be entered in a field data sheet provided in Annex 3.

### **SAMPLING PROCEDURE**

 At a site, identify flow types (pool, glide, run, Riffle, Rapid) in a 20-50 m river reach (Since, phytoplankton samples are collected from water

- samples, their diversity and biomass depend on discharge and flow type.
- Document flow types and the amount of water samples to be taken from each flow type in the data sheet (Sheet 4: Phytoplankton data sheet).
- Collect 1 litre of water sample for 2 to 4 times from each flow type and transfer it to a rinsed 15 litre plastic bucket.
- Make a 10 litre composite water sample and filter it through the plankton net of 76 or 64 µm mesh (mesh no. 20) to get a final 100 ml of plankton sample (Photo 5). Since the size of a plankton net mesh is relatively large, majority of pico and nano phytoplankton and some microphytoplankton are unlikely to be included in the sample.
- Transfer the collected sample into a 100 ml dark brown glass or PET (polyethylene terephthalate) or HDPE bottle to be analysed in the laboratory.
- If the determination of Chlorophyll-"a" is deemed, then repeat the entire process to collect an additional 100 ml of plankton sample and transfer the sample into a 100 ml brown glass bottle (PET, HDPE).

# PHYTOPLANKTON SAMPLE STORAGE AND PRESERVATION TECHNIQUE

 The sample bottle should be rinsed thoroughly at least three times with the sample water and the rinse water should be thrown away from the sampling site (or the side of the boat) to avoid disturbing the water to be sampled.

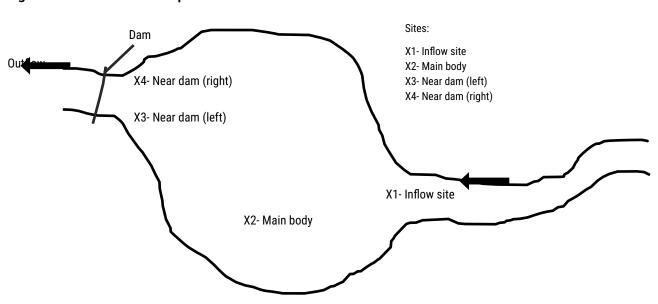


Figure 10: Distribution of samples in a reservoir

Source: Modified from Hötzel and Croome (1999).

# Sheet 4 - Phytoplankton data sheet (Sample)

| Site informa    |                         |                  |     |                              |                                    |
|-----------------|-------------------------|------------------|-----|------------------------------|------------------------------------|
| River name:     |                         | Site code        | :   | Date:                        | Time:                              |
| Hydro-morphol   | logical characteristics | s at sampling si | ite |                              |                                    |
| Water depth (cr | m)                      | River width (c   | m)  | types (L)                    | ollection from representative flow |
| Min:            |                         | Min:             |     | Pool: L  Glide: L  Run:L     |                                    |
| Avg:            |                         | Avg:             |     | Riffle :L Rapid:L            |                                    |
| Max:            |                         | Max:             |     | Amount of filtrate water thr | ough plankton net:L                |
| Sketch of river | reach showing sampl     | ling site        |     |                              |                                    |



Photo 5. Water sample filtration for the collection of phytoplankton samples

- Lugol's solution: This is the most preferred preservative for phytoplankton samples as it preserves the cell shape and stain cells, making them easily visible in the counting chamber.
  - Add 1 ml of Lugol's solution (at a ratio of 1:100) immediately to the sample, adding Lugol's solution at a ratio of 1:100 (Vollenweider, 1969). 2.5 ml of buffered formaldehyde is added to the sample after one hour. This turns the sample into yellowish colour.
- Formalin: It is also used widely for phytoplankton preservation.
  - Add 4 ml of 4% buffered formalin (20g sodium borate + 1 litre of 37% formaldehyde) to the phytoplankton sample.
- All sample bottles should be properly labelled as soon as the samples are stored for preservation.

# **Laboratory procedures**

Laboratory procedures include subsampling and concentration of the phytoplankton sample, and discussion related to identification, enumeration and calculation of results.

#### IDENTIFICATION AND ENUMERATION

An experienced taxonomic phycologist is needed for accurate identification and enumeration of phytoplankton under a microscope.

## **Equipment**

- A standard compound microscope
- Haemocytometer counting slide (Improved Neubauer rulings)
- Cover glass
- Pipettes (Pasteur)

Below is the step-by-step procedure for the identification and enumeration of phytoplankton:

- 1. Place a cover glass over both chambers of the haemocytometer.
- With a soft undulating motion, gently invert the preserved sample for approximately 10−20 times to ensure the sample is mixed thoroughly.

- 3. Fill a Pasteur pipette with the well-mixed sample.
- 4. Load each chamber of the haemocytometer by holding the pipette at a 30–45 degree angle with the open dispensing tip in the V-shaped slash, allowing the pipette tip to touch the slot, then slowly expelling a drop of the liquid. The capillary action will fill the chamber with the sample. It is important to ensure that the liquid spreads over the silver-coloured chamber without overflowing into the moats.
- 5. Repeat the step 2–4 times to fill the other side of the chamber and allow 2–3 minutes for the cells to settle (can be left overnight for sedimentation).
- Identify the phytoplankton to possible higher taxonomic resolution level under the compound microscope using the standard keys of Bellinger and Sigee (2010, 2015). Phytoplankton that are commonly found in water bodies are presented in Annex 4. List out the identified phytoplankton in a table (Table 12).
- 7. Scan the slide initially in the microscope to determine the counting strategy. The whole slide or a selected number of large squares should be counted to obtain a statistically significant number of cells (Andersen and Throndsen, 2004). Each side of the haemocytometer slide has a grid with nine large (1.0 mm x 1.0 mm) squares which are further subdivided depending on the type of haemocytometer. The cell

- suspension is introduced into the cover glass. The cover glass is fixed over the chambers at a height of 0.1 mm. The hemocytometer is placed in the microscope stage. Count the number of organisms in the cell suspension with respect to genus or species and the number of squares and enter the numbers in the record file (Table 13). To avoid counting the cells twice, ensure beforehand that you include cells that touch two of the four sides of each square (i.e., the top and left side of each large square while ignoring the cells that touch the bottom and right side).
- After finishing counting, rinse the haemocytometer slide and cover glass first with running water and then with alcohol, and wipe them with lint-free wipes.

Formulas for calculating the number of cells: Usually four corner cells and one middle cell are counted to enumerate average number of cells per square millimetre.

Average number of cells per square =

$$\frac{\text{No. of cells}}{\text{mL}} = \frac{\text{Total No. of cells}}{\text{number of large 1 sq.mm}} \times 10,000$$

Number of Cells (cells/L) = Total no. of cells/Litre

**Note:** If dilution is done, multiply with the dilution factor.

Table 12: Inventory of the phytoplankton in different impact zones. Indicate "Tick  $(\sqrt{})$ " for presence and "Cross  $(\times)$ " for absence of a taxon (Sample)

| Genus/species | Control sites including dam sites | Diversion reach | Downstream of powerhouse |
|---------------|-----------------------------------|-----------------|--------------------------|
|               |                                   |                 |                          |
|               |                                   |                 |                          |
|               |                                   |                 |                          |
|               |                                   |                 |                          |
|               |                                   |                 |                          |
|               |                                   |                 |                          |
|               |                                   |                 |                          |
|               |                                   |                 |                          |
|               |                                   |                 |                          |
|               |                                   |                 |                          |
|               |                                   |                 |                          |
|               |                                   |                 |                          |

Table 13: Average number of phytoplankton cells and ash-free dry weight in sites within the influence area of the hydropower project (Sample)

| Zone                              | Site code | Average number of phytoplankton cells (cells/L) | Ash-free dry weight (μg/L) or /<br>Chlorophyll-a biomass (mg/L) |
|-----------------------------------|-----------|---|---|
| Control sites including dam sites |           |   |   |
|                                   |           |   |   |
|                                   |           |   |   |
|                                   |           |   |   |
|                                   |           |   |   |
|                                   |           |   |   |
| Diversion reach                   |           |   |   |
|                                   |           |   |   |
|                                   |           |   |   |
|                                   |           |   |   |
|                                   |           |   |   |
|                                   |           |   |   |
|                                   |           |   |   |
| Downstream of powerhouse          |           |   |   |
|                                   |           |   |   |
|                                   |           |   |   |
|                                   |           |   |   |
|                                   |           |   |   |
|                                   |           |   |   |
|                                   |           |   |   |

#### **BIOMASS MEASUREMENT**

Phytoplankton biomass is an important aspect of the aquatic environment as it provides information on the primary productivity of the system, and the amount of organic material available for consumption by heterotrophic organisms such as zooplankton and insect larvae, small fish, etc. Biomass can be measured in two ways – 1) as ash-free dry weight (AFDW) or 2) as the concentration of the photosynthetic pigment chlorophyll-a. However, in an EIA, calculation of biomass is optional.

#### **MEASUREMENT OF ASH-FREE DRY WEIGHT (AFDW)**

Laboratory equipment and consumables:

- · Whatman GF/C glass microfiber filter paper
- · Centrifuge machine
- Oven
- Muffle furnace

Step-by-step procedure for the determination of AFDW is as follows:

- Measure the dry weight of Whatman GF/C glass microfiber filter papers.
- Filter the phytoplankton samples through the glass microfiber filter papers which are then dried at 60°C overnight.
- Keep the ash samples in an oven at 400°C for four hours.
- The difference between the dry weight of glass fiber and the weight of the ash is the organic component (i.e., AFDW) of the phytoplankton.
- Present the AFDW for each sample site (Table 13).

# LIMITATIONS IN DIRECT DETERMINATION OF BIOMASS AS DRY WEIGHT

- The water sample might contain non-algal material such as particulate matter and zooplankton, both of which contribute to dry weight.
- The drying process leads to loss of volatile organic compounds, which underestimates the dry weight of the sample. The effect can be reduced by drying the sample at a lower temperature (less than 80°C).

#### **MEASUREMENT OF CHLOROPHYLL-A:**

Concentration of chlorophyll-a is converted to phytoplankton biomass using an appropriate conversion factor, which is expressed per unit volume or per unit surface area of water.

Laboratory equipment and consumables:

- Acetone
- Magnesium Carbonate (MgCO³)
- GF/C glass microfiber filter paper
- Spectrophotometer
- Centrifuge machine
- Refrigerator
- Mortar
- Test tube

# MEASUREMENT OF CHLOROPHYLL-A INVOLVES THE FOLLOWING STEPS

- 1. Filter the 100 ml of water sample through a GF/C glass microfiber filter paper.
- 2. Place the glass fiber with filtrate onto a mortar.
- 3. Pour 2 ml of acetone in the mortar and crush it.
- 4. Again, add 0.2 gm of MgCO<sub>3</sub> and crush until it forms paste.
- 5. Transfer the paste to a test tube and increase its amount to 10 ml by adding acetone.
- Keep the test tube in the freezer for 2 h and place it in centrifuge for 20 min at 2000–3000 rpm.
- Decant the upper clean solution till you obtain
   ml of decanted solution
- 8. Measure the absorbance at 663 nm, 647 nm and 630 nm wavelength.

Chlorophyll-a concentration is calculated by using the following equation (Jeffrey and Humphrey, 1975):

Chlorophyl-a ( $\mu$ g/L) = [11.64 (Abs<sub>663</sub>) - 2.16 (Abs<sub>645</sub>) + 0.1(Abs<sub>630</sub>)] E(F)/V (L)

Where,

E=Volume of acetone used for extraction (mL)

F= Dilution factor

V=Volume of water filtered

L= The cell path length (cm)

There are several limitations to using pigment concentrations to assess biomass:

- 1. There is no precise relationship between pigment concentration and biomass.
- 2. In general, chlorophyll-a content varies from 0.9-3.9% ash-free dry weight (Reynolds, 1990). Assuming a mean value of 1.5% ash-free dry weight, phytoplankton biomass is estimated by multiplying the chlorophyll-a content by a factor of 67 (Eaton et al., 2005, Table 13).

#### **DATA ANALYSIS**

**Taxonomic richness:** Taxa richness is the number of taxa present in a site.

**Average cell number:** Average number of phytoplankton cells per unit volume is used in calculation.

**Biomass:** Ash-free dry weight or chlorophyll-a of phytoplankton (µg/L or mg/L) is used in calculation.

#### **DATA PRESENTATION**

Phytoplankton determination values shall be presented across sites within the area of influence (Tables 12, 13 and 14).

primary consumers and secondary consumers that feed on phytoplankton and the smaller zooplankton, respectively (Prygiel and Coste, 1993; Williamson, 1987). They are more diverse in lentic water bodies compared to lotic systems and may not survive in running water bodies (Paterson, 2019). Therefore, it is very unlikely that they would be found in abundance in turbulent river systems where hydropower is developed. Zooplankton are highly sensitive to changes in the aquatic ecosystem. The effect of environmental change can be detected through changes in community composition and species abundance. They are also good indicators of trophic status as they respond quickly to nutrient pollution in water bodies. Therefore, zooplankton are considered basic biotic parameters to be analysed during a detailed EIA baseline survey (see Chapter 8: Assessing impacts in Hydropower EIA Mannual 2018) as the baseline for monitoring the imapcts of a hydropower dam.

# MAJOR GROUPS OF ZOOPLANKTON: CLADOCERANS, COPEPODS AND ROTIFERS

**Cladoceran:** Cladoceran are usually the larger zooplankton ranging in size from less than 0.5 mm to over 1 mm. They are also referred to as "water fleas". Cladoceran are microscopic crustaceans

**Table 14: Presentation of phytoplankton data with respect to zone within the area of influence SD stands for standard deviation** 

| Zone                              | Number of phytoplankton cells (cells/L) (mean± SD) | Ash-free dry weight (μg/L) or /Chlorophyll-a biomass (mg/L) (mean± SD) | Remarks |
|-----------------------------------|--|--|---------|
| Control sites including dam sites |  |  |         |
| Diversion reach                   |  |  |         |
| Downstream of powerhouse          |  |  |         |

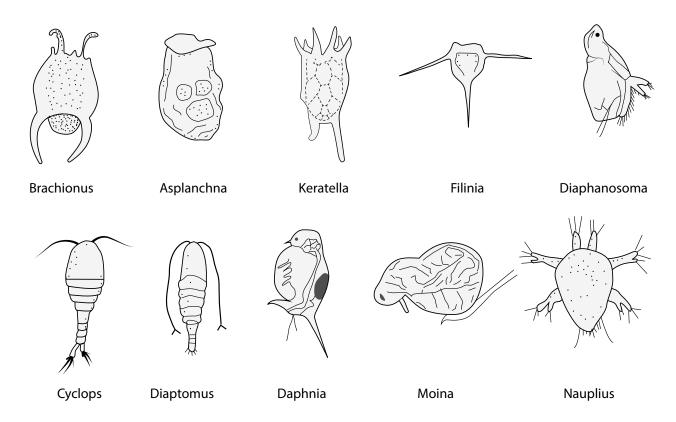
#### **ZOOPLANKTON**

Zooplankton are the heterotrophic microscopic organisms with characteristics of animals that are suspended in the water column. It includes protozoa, rotifera, cladocera and copepod (Figure 11). Rotifera, cladocera and copepoda alone contribute 90% of the total population of freshwater zooplankton (Munshi et al., 2010). They play a key role in the food web as they pass food energy from producers to consumers (Zhao et al., 2018). The zooplankton community is composed of both

and the best-known genus is *Daphnia*. They have a single compound eye and a bivalve carapace that functions as a brood chamber. In most cladocerans, the carapace wraps around the entire body except the head. Cladocerans are usually identified on the basis of their body size and shape, and by their abdominal structure called post abdominal claw.

**Copepods:** Copepods are cylinder-shaped organisms with many small appendages on the head and thorax and range in size from less than 0.05 mm to over 2 mm in length. They have a single

Figure 11: Various forms of zooplankton



eye and large pair of first legs that are used for swimming. Most copepods are transparent or gray or brown in colour but some appear bright red and orange due to accumulation of lipid droplets. Copepods feed on algae, bacteria, and small zooplankton. Female copepods carry their eggs externally.

**Rotifers:** Rotifers are distinct from other zooplankton due to the presence of a corona at the head and trophi. Rotifers are small zooplankton with body size ranging from 0.1 to 0.5 mm in length. Presence of a corona at the anterior end makes it look like a rotating wheel, hence the name 'rotifers'.

Zooplankton that are usually found in river ecosystems are presented in Annex 5.

# **Methods**

## FIELD SAMPLING TECHNIQUE

Field gear and consumables

- Plankton net 37μm, 55 μm or 64 μm mesh sieve
- 100 ml High density polyethene (HDPE) bottle

# **SAMPLING TECHNIQUES:**

There are various methods of sampling zooplankton in the aquatic environment (Malik and Bharti, 2012; Moruff et al., 2016; Viroux, 1999). The most common method is to tow a plankton net (mesh size may vary but preferred size is 37 or 55 or 64 µ m) just below water and let the water pass through the net for 5 minutes and then collect the animals that have been retained by the net (Moruff et al., 2016). Another quantitative method is to collect a defined volume of water and filter it through the plankton net. If the samples are being taken from a different depth, a Schindler-Patalas trap or Van Dorn sampler can be used to collect the zooplankton (EPP, 2009; Viroux, 1999). Zooplankton samples are usually collected between 8:00 and 10:00 am (Malik and Bharti, 2012; Sharma et al., 2016).

Quantitative assessment of zooplankton includes collection of samples, concentration of zooplankton, fixation and preservation, identification, counting and computation of data on zooplankton, and assessment of biomass.

#### **COLLECTION OF ZOOPLANKTON SAMPLES**

- At a site, collect water samples from just below the water surface from pools of littoral sections (in particular pools) of the river banks as there is relatively high abundance of zooplankton in the littoral area of the river (e.g., Thorpe al., 1994).
- Filter a total of 10 litres of water sample through a plankton net to obtain the final 100 ml of plankton sample.
- Transfer the collected sample into a 100 ml High density polyethene (HDPE) bottle for laboratory processing and identification.
- Repeat the entire process to collect an additional 100 ml of zooplankton sample for the determination of biomass. In an EIA, calculation of zooplankton biomass is optional.

Concentration of sample: Concentration of sample can be done by filtration. In this method, the plankton sample is further concentrated by sieving it through a 37µm mesh net or through a membrane (the latter allows adequate sampling of small rotifers without losses or inefficiency due to mesh clogging by phytoplankton and suspended sediments) to get 100 ml of water sample (Berner-Frankhauser, 1987; Orcutt and Pace, 1984).

In a reservoir: For representative samples in a reservoir, samples should be taken from the inflow site, main body, and near the dam from both banks (Figure 10). If the reservoir is shallow (< 2 m), subsurface grab samples at 0.5 m should be taken (for details, see Hötzel and Croome, 1999). In case of a deep reservoir, integrated samples over the epilimnion or euphotic, grab samples at 5 m intervals should be taken for at least one site. At each site, three water samples should be taken. As far as possible, sample should not be taken from an area with algal scums (Hötzel and Croome, 1999). Field measurements of water quality parameters for zooplankton samples are the same as those for phytoplankton samples (Annex 3).

Sample processing and preservation in the field

 The collected samples are immediately preserved in 5–6% formalin (especially for medium-size cladocera and copepod) for further laboratory procedures.

# **Laboratory procedures**

**Identification:** Identification of zooplankton requires a stereoscopic dissecting microscope,

good quality glass slides, cover slips, stainless steel fine forceps, dissecting needles, pipettes and chemical reagents. Identification is carried out to the level possible considering the available time and resources. However, it must be carried out at least to genus level.

#### **EQUIPMENT AND CONSUMABLES**

- · Sedgewick-Rafter cell or haemocytometer
- Compound microscope
- Centrifuge (can also be managed without it)
- Cover glass
- Pipettes (Pasteur)
- Dissecting needles (prepared from thin tungsten wires of 0.005 and 0.010 inch diameter)

Sample processing and identification (modified from Burger et al., 2002)

- At first, the preserved sample is mixed properly and a 5 ml aliquot is removed using a pipette and placed on a Sedgwick-Rafter cell or haemocytometer on a movable stage.
- Repeat the sub-samples until 100 individuals of the most dominant species are obtained.
- If these are not obtained in the first aliquot, three or more sub-samples should be taken to reach the desired level.
- Samples are enumerated with the aid of an Olympus SZ 60 stereo microscope at 30× magnification.
- Zooplanktonic organisms can be identified to generic level using the standard books of Dang et al. (2015), Edmondson (1959), Hutchinson (1957), Needham and Needham (1962), and Pennack (1989).

If samples are difficult to visualize under the microscope, further treatment of samples is necessary:

Centrifuge the sample at 1500 to 2000 rpm for 8–12 min to allow the zooplankton samples to settle to the bottom and siphon the supernatant, leaving the bottom samples to be enumerated using the Sedgwick-Rafter cell method (if the samples were diluted, note down the dilution factor; Df = Final Volume/ Initial Volume) and place the bottom samples in the gridded Sedgwick-Rafter cell.

Note: If dilution is done, multiply with the dilution factor.

# Sheet 4 - Zooplankton data sheet (Sample)

|           | ormation                       |                 |           |                                       |  |  |  |  |  |
|-----------|--------------------------------|-----------------|-----------|---------------------------------------|--|--|--|--|--|
| River na  | River name:Time:               |                 |           |                                       |  |  |  |  |  |
| Hydro-mo  | rphological characteristics a  | t sampling site | e         |                                       |  |  |  |  |  |
| Water dep | oth (cm)                       | River width (   | em)       | Amount of water sample collection (L) |  |  |  |  |  |
| Min:      |                                | Min:            |           | PoolsL RunL                           |  |  |  |  |  |
| Avg:      |                                | Avg:            |           |                                       |  |  |  |  |  |
| Max:      |                                | Max:            |           |                                       |  |  |  |  |  |
| Amount o  | f filtrate water through plank | ton net         | L         |                                       |  |  |  |  |  |
| Sketch of | sampling site showing the s    | ample collecti  | on points |                                       |  |  |  |  |  |
|           |                                |                 |           |                                       |  |  |  |  |  |
|           |                                |                 |           |                                       |  |  |  |  |  |
|           |                                |                 |           |                                       |  |  |  |  |  |
|           |                                |                 |           |                                       |  |  |  |  |  |

#### **MEASUREMENT OF BIOMASS**

Equipment and consumables

- · Blotting paper
- Measuring cylinder
- GF/C glass microfiber filter paper
- Muffle furnace

Biomass denotes the live weight or the amount of living matter present in the zooplankton sample. The value obtained is used to evaluate the secondary productivity and fishery potential of the study area. The biomass is estimated by the following methods:

- Volumetric (displacement volume and settling volume) method
- 2. Gravimetric (ash free dry weight) method
- 3. Chemical method
- 1. Volumetric (displacement volume and settling volume) method: The total zooplankton volume is determined by the displacement volume method, which can be carried out in the field and laboratory. In this method, the zooplankton sample is filtered through a net with mesh of the same size or smaller than the one used for collecting the zooplankton samples. Then, the interstitial water between the organisms is removed with blotting paper and the samples have to be transferred to a measuring cylinder with a known volume of 4% buffered formalin. The difference in the levels of solution in the measuring cylinder is equivalent to the volume of plankton. The zooplankton is allowed to settle for at least 24 hours before the settled volume is recorded (for more details, see Varghese et al., n.d.).
- **2. Gravimetric method:** The weight measurement is carried out in a laboratory. The step-by-step procedure is described below:
- The zooplankton sample is passed through weighted filter paper (mg).
- The filtered zooplankton sample is then kept in an oven at a constant temperature of 60°C for 24 hours. The dried aliquot is kept in desiccators until weighing.
- The final weight of the sample is measured.
- The values are expressed in milligram per litre.
   Ash-free dry weight: The ash-free dry weight method is also used for biomass estimation.

- Measure the dry weight of Whatman GF/C glass microfiber filter papers.
- Filter the zooplankton samples through the glass-fiber filter papers which are then dried at 60°C overnight.
- Keep the ash samples in a muffle furnace at 500°C for four hours.
- Weigh the ash sample after sample has been allowed to cool
- The difference between the dry weight of glass fiber and the weight of the ash is the organic component (i.e., AFDW) of the zooplankton.

Ash-free dry weight ( $\mu$ g/m³) = Dry weight- ash weight.

3. Chemical method: In this method, the live zooplankton samples are dry frozen. Prior to analysis, the samples are rinsed with distilled water. Major constituents namely carbon, nitrogen, phosphorus and biochemical elements, viz. protein, lipid and carbohydrates, are measured. Sometimes the biochemical values of a particular taxon and species are measured to evaluate food energy transfer at higher trophic levels. The calorific content of the plankton is used as an index of zooplankton biomass.

#### DATA ANALYSIS

**Taxonomic richness:** Taxa richness is the total number of taxa present in a site.

**Biomass:** Ash-free dry weight of zooplankton (mg/m<sup>3</sup>).

Both taxonomic richness and biomass parameters are presented for the sites of hydropower project (Tables 15 and 16).

#### **DATA PRESENTATION**

Zooplankton diversity, community composition and biomass can be displayed with respect to subgroups in sites and across the sites of the project area and its area of influence (Tables 15 and 16). Multivariate analysis such as non-metric multidimensional scaling (NMDS) or Detrended correspondence analysis (DCA) is recommended for visualizing differences among sites of the project area and its influence area.

Table 15: Zooplankton species with respect to group in different impact zones. Indicate "Tick  $(\checkmark)$ " for presence and "Cross  $(\times)$ " for absence of a taxon (Sample)

| Group | Genera | Species | Control sites including dam sites | Diversion reach | Downstream of powerhouse |
|-------|--------|---------|-----------------------------------|-----------------|--------------------------|
|       |        |         |                                   |                 |                          |
|       |        |         |                                   |                 |                          |
|       |        |         |                                   |                 |                          |
|       |        |         |                                   |                 |                          |
|       |        |         |                                   |                 |                          |
|       |        |         |                                   |                 |                          |
|       |        |         |                                   |                 |                          |
|       |        |         |                                   |                 |                          |
|       |        |         |                                   |                 |                          |
|       |        |         |                                   |                 |                          |
|       |        |         |                                   |                 |                          |
|       |        |         |                                   |                 |                          |
|       |        |         |                                   |                 |                          |
|       |        |         |                                   |                 |                          |

Table 16: Zooplankton candidate metrics in sites of project influence area (Sample)

| Zone                                    | Site code | Biomass (mg/m³) | Biomass (mg/m³)<br>(mean±SD) | Total no. of groups | Major genera | Species richness |
|---|-----------|-----------------|------------------------------|---------------------|--------------|------------------|
| Control sites including above dam sites |           |                 |                              |                     |              |                  |
| Diversion reach                         |           |                 |                              |                     |              |                  |
| Downstream of powerhouse                |           |                 |                              |                     |              |                  |

# 3.2 Periphyton

### Introduction

Periphyton refers to the growth of benthic algae, diatoms, bacteria, fungi, microbial communities along with detritus on the submerged surfaces of substrates like stones, wooden logs, etc. At the base of the trophic level, periphyton serves as food source for fish, tadpoles and macroinvertebrates, shelter for macroinvertebrates and absorbs pollutants and toxins in the water. Excessive growth of periphyton also affects the habitat quality of the river and can influence dissolved oxygen and deteriorate habitat quality (Serra et al., 2010). Thick or extensive growths of periphyton can smother the hard rocky substrate that macroinvertebrates require as habitat. Extensive thick growths can also reduce dissolved oxygen levels at night, reducing water quality for aquatic animals (fish and invertebrates). Further, thick growths can reduce the aesthetic appeal of a river. Some types of periphyton (cyanobacteria) are known to be toxic to domestic and wild animals (McAllister et al., 2016).

Periphyton growth is favoured by stable flows (lack of floods), warm water temperatures and high light at the riverbed (Snelder et al., 2014). In natural rivers, periphyton is frequently scoured from rocks by floods, reducing its biomass, after which it begins to regrow (Biggs, 1995; Snelder et al., 2014). Periphyton responds rapidly to environmental changes including flow alteration and turbidity, and they are often the first organisms to respond to and recover from stress (Omar, 2010). The periphyton assemblage, primarily algae, is useful for water quality monitoring due to convenience of sampling, and the high sensitivity and fast response to short-term stressors which may not visibly/directly affect other aquatic assemblages at low intensities (Barbour, 1998). Similarly, low flow downstream of the dam may result in high biomass of periphyton in comparison to control sites (Ghosh and Haur, 1998; Zvanut and Mikos, 2014). Biomass and chlorophyll-a have direct relevance to water quality, habitat quality and the aesthetics of a riverbed. Hydropower projects are usually expected to lead to an increase in periphyton biomass due to reduced flow variability (lack of flooding) downstream of the dam in comparison to reference sites (Zvanut and Mikos, 2014), but also due to increased water temperatures and reduced river depth. Therefore, assessment of periphyton biomass is considered a

basic biotic parameter to be determined during a detailed EIA baseline survey (see 'Chapter 8: Assessing impacts' in Hydropower EIA Manual 2018).

#### Methods

#### **FIELD GEAR AND EQUIPMENT**

- White enameled tray 1
- Soft hand scrub brush 1
- Measuring tape

#### PREPARATION OF SAMPLE BOTTLE PRIOR TO FIELD VISIT:

A 100 ml polypropylene bottle is filled with distilled water in the laboratory for periphyton sample collection in the site.

Step-by-step procedure for periphyton sample collection:

- At each sampling site, identify a "riffle" or "run" section (shallow areas with fast- or mediumflow) and a little shade.
- In wadeable river, cross the river on foot and mark two transects across the river from near the shoreline to farther along the shoreline within the sampling stretch. In case of a nonwadeable river, mark two transects from near the shoreline to where the river gets about knee-deep.
- Randomly collect five stones from the two transects, from less than 0.5 m water depth. To minimize bias, pick up the stones from the depth without looking into the water (Photo 6). Each stone should be "cobble" sized (about 15–25 cm diameter).
- Measure water depth in situ at each stone location after removal of the stone from the riverbed.
- On each stone, estimate the percentage of the top surface (the surface exposed to light) covered by each of three periphyton categories: thin films, mats and long filaments. Record these percentages in the data sheet (Sheet 5).
- Place the stone on a white tray and remove the periphyton using a hand scrub brush. Rinse it with distilled water from the polypropylene

# Sheet 5 - Periphyton data sheet (Sample)

| Site infor  | Site information |               |            |                    |                  |                  |
|---|------------------|---------------|------------|--------------------|------------------|------------------|
| River nam   | e:               |               | Site code: | Date:              | Т                | ime:             |
| Periphyton to coverage or study river s   | n stones in      | Thin films: % |            | Mats:%             | Long filaments:% |                  |
| Stone meas  | surement for per | iphyton       |            |                    |                  |                  |
| Stone   | Dimensions (c    | nensions (cm) |            | Circumference (cm) |                  | Water depth (cm) |
| 1   |                  |               |            |                    |                  |                  |
| 2   |                  |               |            |                    |                  |                  |
| 3   |                  |               |            |                    |                  |                  |
| 4   |                  |               |            |                    |                  |                  |
|   |                  |               |            |                    |                  |                  |
| Sketch of sampling site showing the points from where the stones were picked up |                  |               |            |                    |                  |                  |

bottle, and continue scrubbing until no change in the rinse water is evident (Photo 7).



Photo 6: Hand picking the stone from periphyton under the river

#### **SAMPLE PRESERVATION IN THE FIELD**

- Transfer the periphyton sample from the white tray into the bottle.
- Store the collected sample in an ice box in the field so that it is frozen within 12 hours of collection. This will be used for the determination of periphyton biomass (ash free dry weight).
- Measure the dimensions of each stone whereby x represents the longest axis, y represents the longest horizontal axis perpendicular to x, and z represents the longest vertical axis of the stone. Note these down on the data sheet (Sheet 5).

While sampling periphyton, you must ensure that:

- Stones should be picked up from the intact area i.e., area that is not disturbed by benthic macroinvertebrate sampling activities as such activities dislodge the periphyton.
- Stones are picked up only from the part of the channel that is inundated all year round.



Photo 7: Researcher removes the periphyton with a scrub brush and rinses it with distilled water.

# **EQUIPMENT AND CONSUMABLES**

- Whatman GF/C glass microfiber filter paper
- Muffle furnace

#### **SAMPLE ANALYSIS**

Step-by-step procedure for the determination of AFDW:

- Measure the total dry weight by filtering the sub-sample portion through Whatman GF/C glass- microfiber filter papers which are then dried at 60°C overnight.
- Place the sample in a muffle furnace at 400°C for four hours till it turns to ash.
- The difference between the dry weight and the weight of the ash is the organic component (i.e., AFDW) of the periphyton (Table 17).

Calculate the surface area of each stone using the following equation:

Stone surface area (m<sup>2</sup>)
$$= \frac{0.014 (xy+xz+yz) + 33.819}{10.000}$$

Where, x, y, z are the stone dimensions in cm.

 Multiply AFDW values for each stone by the surface area of that stone to obtain a biomass per unit stone surface area.

#### **DATA PRESENTATION**

Ash-free dry weight shall be presented across sites within the area of influence of the hydropower project (Table 18). A statistical test such as Analysis of Variance (ANOVA) is required to test whether the differences across the sites are significant.

Table 17: Periphyton data presented in terms of ash-free dry weight in sites within the influence area of project (Sample)

| Zone                | Site code-stone<br>number | Biomass as ash-free dry weight (AFDW) (μg/m²) | Stone<br>surface<br>area (m²) | Biomass per unit stone surface area | Average<br>biomass at each<br>site (µg/m²) |
|---------------------|---------------------------|---|-------------------------------|-------------------------------------|--|
| Control sites       | S1                        |   |                               |                                     |  |
| including above dam | S2                        |   |                               |                                     |  |
| uaiii               | S3                        |   |                               |                                     |  |
|                     | S4                        |   |                               |                                     |  |
|                     | S5                        |   |                               |                                     |  |
|                     | S1                        |   |                               |                                     |  |
|                     | S2                        |   |                               |                                     |  |
|                     | S3                        |   |                               |                                     |  |
|                     | S4                        |   |                               |                                     |  |
|                     | S5                        |   |                               |                                     |  |
|                     | S1                        |   |                               |                                     |  |
|                     | S2                        |   |                               |                                     |  |
|                     | S3                        |   |                               |                                     |  |
|                     | S4                        |   |                               |                                     |  |
|                     | S5                        |   |                               |                                     |  |
|                     | S1                        |   |                               |                                     |  |
|                     | S2                        |   |                               |                                     |  |
|                     | S3                        |   |                               |                                     |  |
|                     | S4                        |   |                               |                                     |  |
|                     | S5                        |   |                               |                                     |  |
|                     | S1                        |   |                               |                                     |  |
|                     | S2                        |   |                               |                                     |  |
|                     | S3                        |   |                               |                                     |  |
|                     | \$4                       |   |                               |                                     |  |
|                     | S5                        |   |                               |                                     |  |

| Zone                     | Site code-stone<br>number | Biomass as ash-free dry weight (AFDW) (µg/m²) | Stone<br>surface<br>area (m²) | Biomass per unit stone surface area | Average<br>biomass at each<br>site (µg/m²) |
|--------------------------|---------------------------|---|-------------------------------|-------------------------------------|--|
| Diversion reach          | S1                        |   |                               |                                     |  |
|                          | S2                        |   |                               |                                     |  |
|                          | S3                        |   |                               |                                     |  |
|                          | S4                        |   |                               |                                     |  |
|                          | S5                        |   |                               |                                     |  |
|                          | S1                        |   |                               |                                     |  |
|                          | S2                        |   |                               |                                     |  |
|                          | S3                        |   |                               |                                     |  |
|                          | \$3                       |   |                               |                                     |  |
|                          |                           |   |                               |                                     |  |
|                          | S5                        |   |                               |                                     |  |
|                          | S1                        |   |                               |                                     |  |
|                          | S2                        |   |                               |                                     |  |
|                          | S3                        |   |                               |                                     |  |
|                          | S4                        |   |                               |                                     |  |
|                          | S5                        |   |                               |                                     |  |
|                          | S1                        |   |                               |                                     |  |
|                          | S2                        |   |                               |                                     |  |
|                          | S3                        |   |                               |                                     |  |
|                          | \$4                       |   |                               |                                     |  |
|                          | S5                        |   |                               |                                     |  |
|                          | S1                        |   |                               |                                     |  |
|                          | S2                        |   |                               |                                     |  |
|                          | S3                        |   |                               |                                     |  |
|                          |                           |   |                               |                                     |  |
|                          | - S5                      |   |                               |                                     |  |
| 5                        |                           |   |                               |                                     |  |
| Downstream of powerhouse | S1                        |   |                               |                                     |  |
| powermouse               | S2                        |   |                               |                                     |  |
|                          | S3                        |   |                               |                                     |  |
|                          | \$4                       |   |                               |                                     |  |
|                          | S5                        |   |                               |                                     |  |
|                          | S1                        |   |                               |                                     |  |
|                          | S2                        |   |                               |                                     |  |
|                          | S3                        |   |                               |                                     |  |
|                          | S4                        |   |                               |                                     |  |
|                          | S5                        |   |                               |                                     |  |
|                          | S1                        |   |                               |                                     |  |
|                          | S2                        |   |                               |                                     |  |
|                          | S3                        |   |                               |                                     |  |
|                          |                           |   |                               |                                     |  |
|                          | S5                        |   |                               |                                     |  |
|                          | S1                        |   |                               |                                     |  |
|                          |                           |   |                               |                                     |  |
|                          | S2                        |   |                               |                                     |  |
|                          | S3                        |   |                               |                                     |  |
|                          | S4                        |   |                               |                                     |  |
|                          | S5                        |   |                               |                                     |  |
|                          | S1                        |   |                               |                                     |  |
|                          | S2                        |   |                               |                                     |  |
|                          | S3                        |   |                               |                                     |  |
|                          | S4                        |   |                               |                                     |  |
|                          | S5                        |   |                               |                                     |  |

**Table 18:** Periphyton biomass presented in terms of ash-free dry weight in sites within the influence area of project (SD stands for standard deviation) (Sample)

| Zone                              | Site code | Average biomass at each site $(\mu g/m^2)$ | Average biomass of a zone (μg/m²) mean±SD | Remarks |
|-----------------------------------|-----------|--|---|---------|
| Control sites including above dam |           |  |   |         |
|                                   |           |  |   |         |
|                                   |           |  |   |         |
|                                   |           |  |   |         |
|                                   |           |  |   |         |
|                                   |           |  |   |         |
|                                   |           |  |   |         |
|                                   |           |  |   |         |
| Diversion reach                   |           |  |   |         |
|                                   |           |  |   |         |
|                                   |           |  |   |         |
|                                   |           |  |   |         |
|                                   |           |  |   |         |
|                                   |           |  |   |         |
|                                   |           |  |   |         |
|                                   |           |  |   |         |
| Downstream of powerhouse          |           |  |   |         |
|                                   |           |  |   |         |
|                                   |           |  |   |         |
|                                   |           |  |   |         |
|                                   |           |  |   |         |
|                                   |           |  |   |         |
|                                   |           |  |   |         |
|                                   |           |  |   |         |

## 3.3 Benthic macroinvertebrates

## Introduction

Benthic macroinvertebrates are the bottom-dwelling invertebrates that can be seen with the unaided eye and are found attached to rocks, macrophytes, logs and sticks or burrowed into the bottom sand and sediments in an aquatic environment. These are diverse groups of organisms comprising insects, arachnids, crustaceans, annelids and molluscs, commonly found in most aquatic environments (Figure 12).

Benthic macroinvertebrates feed on algae, organic particulate matter including leaf litters, zooplankton and small invertebrates. They constitue a primary food source for fish. Based on their food acquisition mechanism, benthic macroinvertebrates are broadly categorized into five groups: shredders, scrapers, collector-gatherers, collector-filterers, and predators. These categories are considered functional feeding groups (Table 19).

Functional feeding group is a commonly used biotic metric for quantifying the composition of benthic macroinvertebrates that depend on a particular food resource in a given aquatic environment. Availability and composition of food resources determine the structure of macroinvertebrate community composition. Construction and operation of a hydropower project alters flow regimes and habitats and leads to fluctuations in food availability, changing the species composition in a river. Therefore, information on community composition and functional feeding groups should be considered in an EIA baseline survey and for monitoring the impacts of construction and operation of hydropower projects within an area of influence.

Benthic macroinvertebrates are commonly used as indicators of the river's ecological health by scientists and regulatory agencies around the world.

Figure 12: Benthic macroinvertebrates representing different orders



Photos: RD Tachamo-Shah

Table 19: Functional feeding groups and food resources of benthic macroinvertebrates

| Functional feeding groups (FFGs) | Food resources   | Family/Order                                 |
|----------------------------------|--|--|
| Shredders                        | Coarse organic particulate matter including twigs and leaves | Amphipoda, Limnocentropodidae                |
| Scrapers                         | Periphyton, Diatom   | Brachycentridae, Glossosomatidae, Coleoptera |
| Collector-gatherers              | Diatoms, Bacteria, Fine organic particulate matter           | Trichoptera, Ephemeroptera                   |
| Collector-filterers              | Fine organic particulate matter                              | Simuliidae, Chironomidae                     |
| Predators                        | Zooplankton, small invertebrates                             | Plecoptera, Megaloptera, Odonata             |

This is because they are sedentary (do not migrate across large distances), have relatively short life cycles, are easy to identify and include a wide range of species with different levels of tolerance to degraded conditions. They are regarded as a good biological indicator of hydropower impacts as they are highly responsive and sensitive to changes caused by a dam, such as water temperature, flow regimes, substrates, sediment transport, etc. As the different species have different preferences regarding temperature, substrate type, water flow velocity and depth, changes in the nature of the river (from lotic to lentic) and flow regime caused by water diversion can be observed through changes in the community of macroinvertebrates (Zhao et al., 2019; Tachamo-Shah et al., 2020a). Operation of a hydropower dam impounds water in the dam section while reducing river discharge downstream of the dam, leading to changes in the physico-chemical properties of river water and affecting the composition and diversity of benthic macroinvertebrates. Usually, species belonging to Ephemeroptera, Plecoptera and Trichoptera (EPT) prefer faster river flows, cleaner substrates and cooler water (Bonada et al., 2007; Buffagni et al.,

2021). In diversion reach areas with warm water flow, there is a decline in EPT Index. Therefore, as part of an EIA, a detailed ecological study should be carried out to document benthic macroinvertebrate richness and their composition across the zones for different seasons.

## **Methods**

#### **FIELD GEAR AND EQUIPMENT**

Equipment required during sampling and processing of benthic macroinvertebrates are provided below:

### SPECIFICATIONS OF THE KICK NET

Shape of the frame: Square metallic frame

Frame dimensions: Width 25 cm and height 25 cm.

Net mesh size: Standard size (500µm)

Shape of the net: Bag shaped, 70 cm from mouth

to tip

Height of the net: 70 cm long and attached to the

metallic frame

| Stationery  | Macroinve  | ertebrate samples  | Water Chemistry  | Hydrology  |  |
|---|--|--|--|------------|--|
|   | Wadeable river   | Non-wadeable river   |  |            |  |
| <ul> <li>Field notebook, pencils, sharpener, eraser</li> <li>Waterproof marker</li> <li>Labelling tape</li> <li>Transparent tape</li> </ul> | <ul> <li>Kick net (25× 25 cm) with a 500 µm mesh</li> <li>Wading boots</li> <li>Hand gloves</li> <li>Medical gloves</li> <li>Plastic buckets (5 litre</li> <li>Plastic sample boxes</li> <li>Plastic vials (8-10 ml)</li> <li>White tray</li> <li>Forceps</li> <li>Hand shovel</li> <li>Ethanol (99%)</li> </ul> | <ul> <li>Net plastic bucket (10 litre capacity)</li> <li>Fish net, nylon rope</li> </ul> capacity) | <ul> <li>Multi-parameter probe</li> <li>Water sample bottle</li> </ul> | Flow-probe |  |

#### **SAMPLING TECHNIQUES**

A multi-habitat sampling approach is a common method for collecting benthic macroinvertebrates (Tachamo Shah et al., 2020b). In this method, samples are taken from representative habitats in a river stretch. A habitat distribution and estimation sheet (Sheet 3) is used to distribute sub-sampling units on different substrates and flow types with respect to their coverage in the selected 50–100 m river stretch. A microhabitat with relative coverage of 5% is considered one sub-unit. Substrates with relative coverage of less than 5% in the selected river reach is not considered for sampling. A total of 20 sub-samples should be taken from each river stretch and made into a composite sample.

Step-by-step procedure for collecting samples of benthic macroinvertebrates:

- 1. Select a 50–100 m river reach that is easily accessible.
- Distribute 20 sub-samples and record the number of micro-habitats across flow types according to its coverage in the Habitat Estimation Sheet (Sheet 3). Microhabitat coverage of less than 5% is not considered for collection of benthic macroinvertebrate sample.
- 3. Collect a benthic macroinvertebrate sample using a standard kick net with a 25 × 25 cm frame and a 500 µm (0.5 mm) mesh (Photos 8-10). Sample should be taken from where the river bottom is disrupted to a depth of about 5 cm over an area 25 cm long and as wide as the mouth of the net (25 cm), such that the total area for 20 sub-samples is about 1.25 m2. The river bottom is disrupted by kicking the riverbed, which dislodges the sediment and releases the benthic organisms, which are then transported by the water current into the net for each sub-sample. Large substrates such as boulders or large wood that cannot be dislodged can be scrubbed with a scrubbing brush to dislodge the macroinvertebrates. Both mineral and organic microhabitats are considered for taking benthic samples. To sample from aquatic plants, the kick net should be pushed through the plants in a "jabbing" motion, covering the same sample area (25 cm x 25 cm) as in other substrates.
- 4. Repeat the process for taking benthic samples from the remaining micro-habitats.
- 5. In case of a non-wadeable river, the sampling stretch should be long enough to include all the main micro-habitats. The operator should not go farther than knee deep, especially where the





Photo 8-9: Researcher takes a benthic macroinvertebrate sample following a multi-habitat sampling approach. Sample shall be collected using (a) hand or (b) leg/kick depending upon the available habitat.



Photo 10: The researcher is cautious while sampling benthic macroinvertebrates in a non-wadable river. The specialized waders and wading boots, life jacket and a colleague at the bank watching the researcher shall be helpful.



Photo 13: A researcher prepares an artificial substrate sampler to place them in an appropriate location along the bank of the watercourse. The artificial substrate sampler consists of a polyethylene netting bag filled with mineral substrates of different sizes.

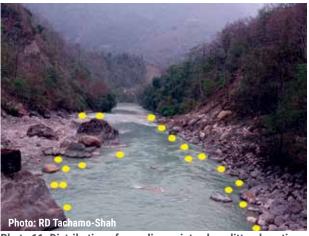


Photo 11: Distribution of sampling points along littoral section in a non-wadeable river



Photo 14: Researchers remove the sampler, taking special care to minimize losses of organisms. The sampler was left in the water for four weeks to allow sufficient time for colonization.



Photo 12: Sampling gear for collecting benthic macroinvertebrate samples



Photo 15: A researcher carefully cleans the netting and mineral substrates in a bucket half-filled with water after placing the artificial substrate sampler on the large white tray.

current is swift. Sample is taken from available micro-habitats in the shallow sections of the river along both the banks (see photos 11-12). Follow steps 2 and 3. If the stretch is not suitable for sampling, an artificial substrate needs to be placed (See subsection: Artificial substrate (Photos 13-16).

Make a composite sample for each site by combining all the subsamples in one container.

#### SAMPLE PROCESSING TECHNIQUE IN THE FIELD

The preliminary processing of the samples is done to reduce large stones and coarse organic debris (e.g., leaves and twigs) and pre-sort individuals for reference specimen in the field. The sample volume can be reduced using procedures described below (Photos 17-18).

- 1. First, the composite benthic samples are transferred into a bucket half-filled with water.
- The large organic debris (twigs, leaves) and stones are removed by hand after rinsing and inspection for clinging organisms but too much time need not be spent inspecting small debris in the field.
- 3. The remaining sample is stirred vigorously so that organic material and invertebrates are caught up in the swirling water. This water and organic material are passed through a circular hand net with mesh size 0.5 mm (500 µm), leaving only heavy mineral sediments at the bottom of the bucket.
- 4. The process is repeated a few times until only the mineral substrate remains at the bottom. These sediments must be inspected carefully for heavy macroinvertebrates such as those with shells or cases, which may sink with the mineral substrates. After inspection, the mineral substrates may be discarded.
- 5. The samples are then transferred onto a white tray to inspect for the presence of rare or IUCN Red List species (see the section 'Handling IUCN Red List Species'). If IUCN Red List Species are present, they are carefully picked out and transferred to another white tray for close observation, recorded and then released back into the river.
- 6. Now the remaining sample is ready for preservation.



Photo 16: Researchers sieve the benthic macroinvertebrate sample using a hand net with a 500 µm mesh that was retained in the bucket after cleaning the artificial substrate sampler.



Photo 17: A researcher passes the composite benthic macroinvertebrate sample through a circular hand net with a 500 µm mesh, leaving only heavy mineral sediments at the bottom of the bucket.



Photo 18: A researcher carefully inspects for any benthic macroinvertebrates left in the mineral substrate after passing the stirred sample through a circular hand net with a 500  $\mu$ m mesh for a few times.

#### SAMPLE PRESERVATION IN THE FIELD

- Transfer the benthic macroinvertebrate sample from the hand net into a sample container. (with a white tray underneath to catch any sample that falls outside the container), using hands.
   Macroinvertebrates and organic matter clinging to the net can be washed into the sample container using a wash bottle, or carefully picked off using fingers or forceps (Photo 19).
- Pour 99.9% ethanol into the sample container until the sample is immersed in the liquid (Photo 20). The final concentration of ethanol in the sample container (including rinse water) must be above 70%.
- 3. In case of fragile specimen, a few specimen shall be preserved separately.
- 4. All sample containers and vials for the site need to be properly labelled with Sample code, Site name, Date, Total no. of containers (if more than one used). For a code, a unique coding system can be used (Tachamo Shah et al., 2020b). For example: TR011. This sample code consists of five characters (two letters and three digits).



Photo 19: Researchers pack the processed sample in the field for preservation.



Photo 20: Researchers preserve the benthic macroinvertebrate sample in 99.9% ethanol. The sample should be immersed in the preservative.

- Each character has a specific meaning. The first two letters indicate the name of the river. For example, **Trishuli River** could be coded 'TR'. The third and fourth digits are used to indicate the order in which the samples were taken from different sites in the river, i.e. the first sample from the Trishuli River would be "TR01", the second sample "TR02" and so on. The fifth digit indicates the season in which the sample was taken, i.e., 1 spring (pre-monsoon; March–May); 2 summer (monsoon; June–September); 3 autumn (post-monsoon; October-December); 4 winter (post-monsoon; January–February).
- Labels shall be written on waterproof paper with pencils and put inside the sample container.
   Another label with the sample code and the date of sample collection is also placed on the box from the outside.

#### HANDLING PROTECTED SPECIES

- Pick out the unique taxon from the collected sample to check whether the species fall under the IUCN Red List, and transfer them onto another white tray for close observation.
- If the species fall under the IUCN Red List, then record the number on the "Back sheet of RRA protocol" (Annex 1) and release the species safely back into the river.

## **LABORATORY ANALYSIS**

Equipment/consumables

- · White trays
- Plastic vials (10 ml)
- Ethanol (99.9%)
- Identification key books/literature
- Stereomicroscope
- Petri-dishes
- Forceps
- Notebook and pencils

# LABORATORY PROCEDURES

#### Sorting

- In a laboratory, rinse the benthic macroinvertebrate samples in clean water and transfer them onto white trays.
- Samples may be easier to sort if large materials and organisms are separated from smaller ones by gently wet-sieving the sample through a series of 2-3 sieves with mesh sizes (for

- example) 4 mm, 1 mm and 0.5 mm (the smallest sieve must be no larger than 0.5 mm).
- Use of a high-powered halogen lamp and sharp forceps is advised for sorting.
- All specimens are picked up from the sediments and preserved with respective of their "Order" in transparent plastic vials containing 99.9% ethanol (Photo 21).
- A paper label with the sample code is placed on each vial before it is sealed firmly and stored for identification.

#### **SUB-SAMPLING**

If a sample has too many macroinvertebrates or too much organic debris for the whole sample to be sorted, a sub-sample may be sorted instead. Various methods are available for sub-sampling (e.g., Stark et al., 2001). Here the 200+ count method is recommended:

- Divide the white tray into 12–16 squares by marking lines on the bottom with a permanent marker.
- Spread the samples evenly on the white tray.
- Randomly choose a grid square and collect all
  the invertebrates from that square, counting
  how many have been collected. Repeat in
  randomly chosen grid squares until the total
  count of invertebrates is above 200 individuals.
  A grid square that is started must be finished.
  Record how many grid squares have been
  sampled and note this as a proportion of the
  total number of grid squares.
- Scan the entire sample for rare taxa (species) that have not been collected in any of the sampled grid squares. Add these to the vial.
- To calculate the total number of invertebrates belonging to each taxon, divide the number recorded by the proportion of grid squares counted.



Photo 21: Sorting of macroinvertebrates from the sediments and preserved in a plastic vials with ethanol in the laboratory

#### **IDENTIFICATION**

Sorted macroinvertebrates are identified using a stereomicroscope with the aid of available identification keys (Photo 22). Identification is carried out to the level possible considering the available time and resources. However, it must be carried out at least to family level, and preferably up to genus level (see the region-specific keys: Dudgeon, 1999; Nesemann et al., 2007; Nesemann et al., 2010; Nesemann et al., 2011, Shah et al., 2015, Tachamo-Shah et al., 2020a). Identified taxon

with respective to their family are recorded with abundance in Table 20.

#### **DATA ANALYSIS**

Richness measures, composition measures, tolerance measures, and functional measures are usually applied to evaluate the effects of hydropower projects on the biotic community (Table 21). The values of most of these measures decrease with increased impacts of hydropower.



Photo 22: A researcher identifies benthic macroinvertebrates to the lowest possible taxonomic resolution using a stereomicroscope.

Table 20: Inventory of macroinvertebrates with abundance for a site (Sample)

| SN | Order | Family | Genus/Species | Abundance |
|----|-------|--------|---------------|-----------|
|    |       |        |               |           |
|    |       |        |               |           |
|    |       |        |               |           |
|    |       |        |               |           |
|    |       |        |               |           |
|    |       |        |               |           |
|    |       |        |               |           |
|    |       |        |               |           |
|    |       |        |               |           |

Table 21: Biological measures for assessing the river health

| Candidate metrics                | Calculation   |
|----------------------------------|---|
| Enumerative measures             |   |
| Density                          | No. of individuals per sq. meter  |
| Biomass                          | Dry biomass of individuals in a site gm per sq. meter   |
| Richness measures                |   |
| EPT richness                     | Number of Ephemeroptera, Plecoptera, and Trichoptera taxa   |
| COH richness                     | Number of Coleoptera, Odonata and Hemiptera taxa  |
| Total richness                   | Total number of taxa present  |
| Biotic measures                  |   |
| Biotic Index                     | Biotic inddex = $\sum_{i=1}^{n} TSS_i/n$<br>Where, $TTS_i$ is the Taxa Sensitive Score of taxon; $i$ and $n$ is the total number of scored taxa |
| Functional measures              |   |
| % Shredder individuals           | Percentage of shredder individuals  |
| % Scraper individuals            | Percentage of scraper individuals   |
| % Collector-gatherer individuals | Percentage of collecter-gatherer individuals  |
| % Collector-filterer individuals | Percentage of collector-filterer individuals  |

# **DATA PRESENTATION**

A macroinvertebrate community structure should be presented for each site category in terms of average value and standard deviation for each metric in Tables 22 and 23. Data for control and impact sites, both before and after hydropower development, should be presented together. Bar charts (also known as column graphs) show results most clearly.

Biotic measures such as FFGs can be presented in a pie chart or stacked bar plots.

Multivariate analysis such as non-metric multidimensional scaling (NMDS) or detrended correspondence analysis (DCA) is recommended for differentiating the community composition across the sites of the project influence area.

# **Safety precautions**

- Avoid working alone, particularly in a large river or a remote region.
- Avoid sampling in a river that is in spate or where construction is taking place.
- Put on wading boots before going to the river.
   Wading boots present an additional hazard if the wearer falls. Special training is needed to stay safe in a river with wading boots on.
- In case of a river with turbulent flow, a rope is tied around the waist of the surveyor.
- Precaution should be taken in the river as the riverbed might be slippery due to algal growth.
- Wear hand gloves while preserving samples to protect skin from drying.
- A first-aid kit should be kept handy in the field.

# **ANALYSIS**

A statistical test such as Analysis of Variance (ANOVA) should be carried out for each biotic measure to test whether the differences between zones are significant.

A procedure called ANOSIM (analysis of similarities) can be used to test for significant differences between sites in NMDS.

Macroinvertebrates vary across sites due to dam-induced flow regime changes and habitat changes (Table 23). This information can be displayed with bar plots or pie charts.

Table 22: Macroinvertebrate community parameters (Mean±SD, SD stands for standard deviation) in control sites, diversion reach and downstream of powerhouse

| Biotic measures                  | Control sites including dam sites (mean±SD) | Diversion reach (mean±SD) | Downstream of powerhouse (mean±SD) |
|----------------------------------|---|---------------------------|------------------------------------|
| EPT richness                     |   |                           |                                    |
| COH richness                     |   |                           |                                    |
| Biotic Index                     |   |                           |                                    |
| % Shredder individuals           |   |                           |                                    |
| % Scraper individuals            |   |                           |                                    |
| % Collector-gatherer individuals |   |                           |                                    |
| % Collector-filterer individuals |   |                           |                                    |
| Density                          |   |                           |                                    |
| Biomass                          |   |                           |                                    |

Table 23: Proportion (Mean±SD) of macroinvertebrate taxa across sites within the influence area of hydropower project

| Taxonomic group                                | Control sites including dam sites (mean±SD) | Diversion reach<br>(mean±SD) | Downstream of powerhouse (mean±SD) |
|--|---|------------------------------|------------------------------------|
| Ephemeroptera +Plecoptera +Trichoptera (EPT %) |   |                              |                                    |
| Coleoptera + Odonata + Hemiptera (COH %)       |   |                              |                                    |
| Mollusca (%)                                   |   |                              |                                    |
| Annelida (%)                                   |   |                              |                                    |

# 3.4 Fish

# Introduction

With its diverse topography, altitudinal variation and climatic conditions ranging from subtropical to temperate, Nepal provides unique habitat for diverse fish. Altogether 256 fish species are recorded including both native (n= 240) and exotic (n=16) species that belong to 108 genera, 39 families and 14 orders in Nepal's river system (Shrestha, 2019; WWF, 2020a). Among these, 27 species fall under different threat categories. These include Critically Endangered (n=3), Endangered (n=2), Vulnerable (n=5), and Nearly Threatened (n=17) (Table 24; IUCN, 2019).

**Table 24: List of fish species in different threat categories** 

| SN | Species                      | IUCN status           |
|----|------------------------------|-----------------------|
| 1  | Schizothorax nepalensis      | Critically Endangered |
| 2  | Schizothorax raraensis       | Critically Endangered |
| 3  | Glyptothorax kashmirensis    | Critically Endangered |
| 4  | Schismatorhynchus nukta      | Endangered            |
| 5  | Tor putitora                 | Endangered            |
| 6  | Cyprinion semiplotum         | Vulnerable            |
| 7  | Tor chelynoides              | Vulnerable            |
| 8  | Schizothorax richardsonii    | Vulnerable            |
| 9  | Schistura prashadi           | Vulnerable            |
| 10 | Physoschistura elongata      | Vulnerable            |
| 11 | Anguilla bengalensis         | Near Threatened       |
| 12 | Chitala chitala              | Near Threatened       |
| 13 | Labeo pangusia               | Near Threatened       |
| 14 | Neolissochilus hexagonolepis | Near Threatened       |
| 15 | Systomus clavatus            | Near Threatened       |
| 16 | Garra rupecula               | Near Threatened       |
| 17 | Balitora brucei              | Near Threatened       |
| 18 | Ompok bimaculatus            | Near Threatened       |
| 19 | Ompok pabda                  | Near Threatened       |
| 20 | Wallago attu                 | Near Threatened       |
| 21 | Ailia coila                  | Near Threatened       |
| 22 | Bagarius bagarius            | Near Threatened       |
| 23 | Bagarius yarrellii           | Near Threatened       |
| 24 | Pseudambassis lala           | Near Threatened       |
| 25 | Ctenops nobilis              | Near Threatened       |
| 26 | Schistura devdevi            | Near Threatened       |
| 27 | Ompok pabo                   | Near Threatened       |

Native fish: Native fish occur in a river, stream or lake historically and is not introduced into that water body by humans. In Nepal, a total of 240 native fish species are recorded (Annex 6), of which 16 species are endemic (Table 25).

**Exotic fish**: A fish species that is not native to the river and has been intentionally or unintentionally introduced to the water body beyond its geographical territory by humans is called exotic species. In Nepal, exotic fish species are introduced for aquaculture development (NBSAP, 2014). Among the introduced fish species, Tilapia is an invasive species. In Nepal, a total of 16 exotic species are recorded (Table 26).

Migratory fish: Large numbers of fish show distinct migratory habits as they move in search of suitable spawning and feeding grounds. The distance covered during migration varies from species to species and upstream to downstream and vice versa. There are some known migratory fish species in the rivers of Nepal (Table 27). However, information on the migratory behaviour of freshwater fish is poorly documented (Gubhaju, 2011).

**Table 25: List of endemic species recorded in water bodies in Nepal** 

| SN  | Scientific name             |
|-----|-----------------------------|
| 1   | Balitora eddsi              |
| 2   | Batasio macronotus          |
| 3   | Erethistoides ascita        |
| 4   | Erethistoides cavatura      |
| 5   | Myersglanis blythi          |
| 6   | Pseudecheneis crassicaudata |
| 7   | Pseudecheneis eddsi         |
| 8   | Pseudecheneis serracula     |
| 9   | Psilorhynchus nepalensi     |
| 10  | Psilorhynchus pseudechenies |
| 11  | Schizothorax macropthalmus  |
| 12  | Schizothorax nepalensis     |
| 13  | Schizothorax raraensis      |
| 14  | Neoanguilla nepalensis      |
| 15  | Turcinoemacheilius himalaya |
| 16. | Turcinoemacheilius himalaya |

SN

# **Table 26: List of exotic species recorded in water** bodies in Nepal

Scientific name

| 1  | Carassius auratus           |
|----|-----------------------------|
| 2  | Carassius carassius         |
| 3  | Ctenopharyngodon idellus    |
| 4  | Cyclocheilichthys apogon    |
| 5  | Cyprinus carpio             |
| 6  | Barbonymus gonionotus       |
| 7  | Hypophthalmichthys molitrix |
| 8  | Aristichthys nobilis        |
| 9  | Clarias gariepinus          |
| 10 | Oncorhynchus rhodurus       |
| 11 | Oncorhynchus mykiss         |
| 12 | Salmo trutta                |
| 13 | Gambusia affinis            |
| 14 | Oreochromis mossambica      |
| 15 | Oreochromis niloticus       |
| 16 | Pangasius hypophthalamus    |

Table 27: List of migratory fish

| Long distance migratory species | Short/mid distance migratory species |  |  |
|---------------------------------|--------------------------------------|--|--|
| Anguilla bengalensis            | Chagunius chagunio                   |  |  |
| Tor putitora                    | Labeo angra                          |  |  |
| Tor tor                         | Bangana dero                         |  |  |
| Bagarius yarrelli               | Labeo dyocheilus                     |  |  |
| Clupisoma garua                 | Neolissochilus hexagonolepis         |  |  |
|                                 | Tor chelynoides                      |  |  |
|                                 | Schizothorax plagiostomus            |  |  |
|                                 | Schizothorax richardsonii            |  |  |
|                                 | Monopterus cuchia                    |  |  |

# ECOLOGICAL REQUIREMENTS AND SIGNIFICANCE

Fish have intrinsic conservation value (see above) and are also an important component of the aquatic food web (Figures 2a, b). They feed on smaller aquatic plants and animals (e.g., macroinvertebrates) and are themselves eaten by larger fish and birds. In this way they support terrestrial species, and act to transfer energy and nutrients from the aquatic ecosystem to adjacent terrestrial ecosystems.

Each fish species is adapted to a specific range of habitat conditions. Each species shows a preference for a particular range in water temperature, water clarity, flow velocity and depth. In addition, they require particular food sources and habitat types for feeding, breeding and resting. Migratory species (juvenile and adult) require uninterrupted passage between breeding habitats. All of these factors may be altered by hydropower development. The conversion of the ecosystem destroys fish habitat, which in turn affects the fish diversity of the river stretch, especially for migratory fish as the spawning beds are inundated or lost (ADB, 2018).

Some of the ways in which hydropower development may impact fish communities are:

- Blockage of migration by the dam, such that river reaches upstream of the dam become inaccessible as habitat for migratory fish species
- Habitat alteration and loss in the diversion reach and downstream of powerhouse
- Change from lotic (running water) to lentic (still water) habitat in the area flooded for the reservoir
- Possible changes in water quality (temperature, dissolved oxygen, water clarity) downstream of the dam

### **METHODS**

## Sampling techniques

The sampling technique is deployed based on the target [overall species, snow trout (adults, juveniles), and golden mahseer (adults, juveniles)] and river habitat/location [tributaries (large and small), main river channel, upstream and downstream of the hydropower project, and altered environments (e.g., above the dam including the reservoir, diversion reach, downstream of the powerhouse)]. Usually, more than one type of sampling technique are used in each site to capture a representative number of fish species (Table 28) (Also see: IFC, 2021).

In each site, sampling reach length is estimated to be 40 times the mean wetted channel width of the river (Barbour et al., 1999), or at least a 400 m river reach is selected for fish sampling based on feasibility and accessibility to the river. For smaller streams, a sampling length of at least 200 m is maintained if the conditions are not favourable.

Table 28: Fish sampling techniques appropriate to the rivers of Nepal

| SN | Method                                   | Field gear and equipment   | Sampling effort                               | Remarks   |  |
|----|--|--|---|---|--|
| 1  | Cast netting<br>(Photo 23)               | Cast nets (mainstem - diameter 4m; net<br>length 2m; 25.0 mm and 35.0 mm mesh;<br>tributaries - diameter 3m; net length<br>1.5m; 15.0 mm mesh), Chest waders | Time: 2 hours<br>Cast: minimum 100 times      | Recommended for rivers without large boulders and turbulent flows                     |  |
| 2  | Seine-hauls<br>(Photo 24)                | Seine net, Chest waders  | Time: 1 hour<br>Deployed: minimum 25<br>times | Recommended for wadeable rivers in turbid conditions                                  |  |
| 3  | Dip netting<br>(Photo 25)                | Dip net, Chest waders  | Time: 1 hour<br>Deployed: minimum 25<br>times | Recommended for shallow and clean water and mainly employed for capturing larval fish |  |
| 4  | Backpack<br>electrofishing<br>(Photo 26) | Backpack electro-fisher with extra battery and charger, Chest waders   | Time: 30 mins                                 | Recommended for wadeable and littoral sections of non wadeable rivers                 |  |
| 5  | Visual assessment using underwater video | Water-proof video camera (e.g., GoPro),<br>Batteries and cables, Chest waders  | Time: 1 hour                                  | Recommended for documenting juveniles and fish spawning grounds                       |  |
| 6  | eDNA                                     | Chest waders   |   | Optional (recommended for non-wadeable rivers)  |  |

Note: Data for each method used shall be presented both separately and in a combined form.

# Cast net

A cast net is a circular net made from nylon thread (Photo 23). It is wider at the circumference and gradually tapers towards the apex. Sinkers, a cylindrical piece of iron, is attached to the rim of the net to make it sink in the water. Cast nets are mostly used in shallow water of up to 15 feet depth. The area of water selected for cast netting should be free of rocks, plants, woody debris or algae in order to prevent snagging of the cast net. The net is then hurled into the water by hand so that it spreads out into a great circle as it touches the water. After a while the net is dragged with the help of a central rope and the fish caught are placed in a bucket filled with water. Cast net samplings are performed 100 times at each site along a 400 m river reach except in very small tributaries with very limited discharge. Only small cast nets are used in such tributaries.

# Seine hauls

Seine hauls are comparatively non-invasive to fish and are mostly used in turbid water. A suitable flat sampling site free from woody debris, algae, and rocks is selected. In this method, a fishing net, called a seine, hangs vertically in the water with its bottom edge held down by weights and its top edge buoyed by floats (Photo 24). A 'U" shape is maintained in order to prevent fish from escaping. The seine is then slowly swung towards the shore end. The seine haul is placed 25 times at each site.

# Dip net

A dip net, also called a scoop net or hand net, is a net or mesh basket held open by a hoop (Photo 25). The equipment is inexpensive and easy to use. It requires little time and a single operator for actual in-water sampling. This method is the only reliable method for capturing larval fish and provides evidence of species recruitment and identifies spawning/nursery areas.

Some challenges of this method are:

- requires visually spotting larval fish in shallow water
- · is extremely size selective, and
- is only suitable in shallow and clear water



Photo 23: Collecting fish samples from the river using a cast net. A cast net is a circular net with small weights distributed around its edge.



Photo 24: Fish sampling using seine-haul fishing method.



Photo 25: Dip net/ Scoop net

# **Electrofishing**

Electrofishing is a scientific method used to sample fish populations in shallow water (fast or slow) and in rocky habitats (Simon and Sanders, 1999; Goffaux et al., 2005; Porreca et al., 2013). The method is effective in obtaining high species diversity and large numbers of fish in a short time (Goffaux et al., 2005). During electrofishing, an electric field is created between the anode and the cathode, which causes fish to swim towards the anode, where they can be caught or stunned (Helfman, 2007). Usually, electrofishing causes no permanent harm to fish, which return to their natural state immediately after a couple of minutes (Reynolds and Holliman, 2000). Application of electrofishing requires special permission from relevant government offices in Nepal. For example, the Department of National Parks and Wildlife Conservation (DNPWC) issues such permits for rivers within the protected areas while the forest department (DoFSC) issues permits for rivers outside protected areas.

**Sampling techniques:** Begin at the downstream end of the site, walk in a zigzag fashion from bank to bank moving upstream. Two netters should follow the electrofisher, capturing fish that are stunned and placing them in a bucket. The person carrying the bucket should follow the netters. Electrofishing activity should cover about a 150 m stretch of the river per site (Joy et al., 2013).

**Electrofishing machine setting:** The ambient conductivity of the river determines the intial voltage to be set in the electrofishing machine (Photo 26). Pulse rate also needs to be adjusted depending on whether large fish or small fish are to



Photo 26: Smith-Root (2024)

be caught. For fish larger than 200 mm, a pulse rate of 30 pps with a pulse width of 3 msec is used while for small fish, a pulse rate of 60–70 pps is used (Joy et al., 2013). The electorfisher should carefully read a manual on the operation of an electrofishing machine prior to using it in the field.

#### **eDNA**

Fish environmental DNA (eDNA) studies is based on the capture of DNA from a water sample. This method has been substantially improved over the past decade and is frequently used in fish status assessment in rivers. (Wang et al., 2021). The method is highly effective in detecting the presence of high numbers of species, including species that are very difficult to collect with other methods, and can be employed in essentially all water conditions.

The method is still in a developing phase; therefore, some anomalies still need scientific validation

(sensu Schill and Galbraith, 2019). The method requires specific and bulky field equipment/ supplies, specialized training, expensive laboratory analysis and a team of at least 3–4 people. In addition, abundance data remains questionable (though it's improving), false positives are possible and obtaining final results takes a substantial amount of time (Shu et al., 2020).

Collection of water samples: Minimum of 10 litres of water sample is filtered in the field. Filtering can be carried out for 30 mins to 1 hour using traditional methods while genetic analysis of the samples might take several months.

# Fish processing and preservation technique in the field

- The fish specimens are collected in separate buckets according to the fishing method used, taxonomically identified (Box 4), photographed, counted, and recorded. A separate data sheet is maintained for each fishing method.
- All fish specimens shall be weighed using a weighing scale and their weights noted down on Sheet 6.
- Anaesthetize the fish by placing a drop of clove oil with water on a tray and leaving the fish on the tray for 2 minutes. When the fish's gills stop moving, it is considered anaesthetized.
- The standard length (SL) of all fish specimens shall be measured using a ruler and noted down on Sheet 6. SL is the length of a fish measured from the tip of the snout to the posterior end of the last vertebra or to the posterior end of the midlateral portion of the hypural plate, i.e., it excludes the length of the caudal (tail) fin. Other possible length measures are Total Length (TL), which is the length to the distal end of the caudal fin; and Fork Length (FL) which is the length to the fork of the caudal fin. The type of length measured must be recorded.
- Place a representative fish from each species on a white laminated A4 sheet and take a photo of it. The ruler and the fish tag should appear in the photo. Then spread all the fins and the tail and take more photos.
- In case of unidentified species, the voucher specimens are brought to the laboratory for identification by a specialist.
- Place the fish in an individual perforated Ziploc bag, with a label written on cryotags inserted into the bag.

### Box 4

Identification of the fish shall be based on the morphometric characters, meristic characters, descriptive characters, and PCR tools (*if required*). Most old identification keys fail to identify newly described species. Therefore, it is important to use updated identification keys and papers that describe newly discovered species. Below are some reference books that are useful for fish identification:

- Jayaram, K.C. (2012). The Freshwater Fishes of the Indian Region, 2nd Edition. Narendra Publishing House, Delhi, India.
- Jayaram, K.C. (2017). Fundamentals of Fish Taxonomy. Narendra Publishing House. Delhi, India.
- Mishra, S.K. (2012). Hill Stream Fishes along the Indo-Nepal Border. Mittal Publications, New Delhi, India.
- Nelson, J.S., Grande, T.C. and Wilson, M.V.H. (2016). Fishes of the World, 5th Edition. John Wiley & Sons, Inc., Hoboken, New Jersey, USA.
- Shrestha, T. K. (2019). Ichthyology of Nepal: A Study of Fishes of the Himalayan Waters. B.J. Shrestha Publisher, Kathmandu, Nepal
- Label each cryotag with the sampling site, date, sample type (F for fish), sampling method (C for cast net; E for electrofisher; D for dip net), and sample number.
- Store the voucher specimens in a container with 10% formalin for preservation.

# Handling protected species

For the conservation of fish species, Aquatic Animal Protection Act, 1960 prohibits the use of harmful methods of killing and catching aquatic animals. Under this act, there exists a regulation for capturing native fish of certain species, size and seasonality. Based on the regulation, capturing certain fish during the spawning season is prohibited. Fish included in the IUCN Red List (see Table 24) should be handled carefully and released live back into the river.

#### **DATA ANALYSIS**

Richness, abundance, composition and biomass measures are usually applied to evaluate the effects of hydropower projects on the fish community structure. The impact of the

# Sheet 6 - Fish assessment sheet (Sample)

| Site inf   | ormation                   |                                   |      |                           |                 |
|------------|----------------------------|-----------------------------------|------|---------------------------|-----------------|
| River r    | name:                      | Site code:                        | Da   | ate:Time                  | e:              |
| Start poir | nt Latitude:<br>Longitude: | End point Latitude:<br>Longitude: |      |                           |                 |
| Fish asse  | essment                    |                                   |      |                           |                 |
| Catch me   | ethod:                     |                                   | Effo | orts unit:                |                 |
| SN         |                            | Species name                      |      | Standard fish length (cm) | Fish weight (g) |
| 1          |                            |                                   |      |                           |                 |
| 2          |                            |                                   |      |                           |                 |
| 3          |                            |                                   |      |                           |                 |
| 4          |                            |                                   |      |                           |                 |
| 5<br>6     |                            |                                   |      |                           |                 |
| 7          |                            |                                   |      |                           |                 |
| 8          |                            |                                   |      |                           |                 |
| 9          |                            |                                   |      |                           |                 |
| 10         |                            |                                   |      |                           |                 |
| 11         |                            |                                   |      |                           |                 |
| 12         |                            |                                   |      |                           |                 |
| 13         |                            |                                   |      |                           |                 |
| 14         |                            |                                   |      |                           |                 |
| 15<br>16   |                            |                                   |      |                           |                 |
| 17         |                            |                                   |      |                           |                 |
| 18         |                            |                                   |      |                           |                 |
| 19         |                            |                                   |      |                           |                 |
| 20         |                            |                                   |      |                           |                 |
| 21         |                            |                                   |      |                           |                 |
| 22         |                            |                                   |      |                           |                 |
| 23         |                            |                                   |      |                           |                 |
| 24         |                            |                                   |      |                           |                 |
| 25         |                            |                                   |      |                           |                 |
| 26<br>27   |                            |                                   |      |                           |                 |
| 28         |                            |                                   |      |                           |                 |
| 29         |                            |                                   |      |                           |                 |
| 20         |                            |                                   |      |                           |                 |

| Safety precautions                   |  |
|--------------------------------------|--|
| Methods                              | Safety precautions   |
| Cast netting/Seine-hauls/<br>Dip net | <ul> <li>Check water and weather conditions before going for sampling.</li> <li>Wear a lifejacket.</li> <li>Make sure to carry safety gear and a first-aid kit.</li> <li>River banks and stones might be slippery, wear appropriate clothing with non-slip soles.</li> </ul>   |
| Electrofishing                       | <ul> <li>A trained person is needed to operate the eletrofisher.</li> <li>Be sure to read and follow all instructions in the User's Manual associated with the electrofisher model used.</li> <li>Everyone in the water during electrofishing must wear rubber gloves and waders, and dipnets used must have insulated handles to prevent shock.</li> <li>Set voltage and current such that fish are stunned, but not killed.</li> </ul> |
| Underground video                    | <ul> <li>A trained person is needed to operate the underwater camera.</li> <li>Be sure to read and follow all instructions in the User's Manual associated with camera operation.</li> </ul>   |
| eDNA                                 | A trained person is needed to collect and filter the water samples in the field.   |

hydropower scheme is evaluated by comparing the values of the richness measures between control and impact zones, before and after the construction of the hydropower project. Most of the measure values decrease with increased impacts of the hydropower project. A significant difference between control and impact zones can be detected using a statistical test such as Analysis of Variance (ANOVA).

In addition to the univariate indices in Table 29, fish community data can be compared among sites using multivariate methods such as Non-metric Multidimensional Scaling (NMDS). Significant differences among sites can be tested using ANOSIM (Analysis of Similarities).

**Size data:** Length and weight data can be presented as a size-frequency or weight-frequency histogram (graph) for the sites in the project area and its

influence area. This type of graph provides insights on the impacts of the hydropower project on fish (e.g., if juvenile fish are absent upstream of the dam, this indicates the dam is creating a barrier to fish migration).

#### **DATA PRESENTATION**

Fish species documented in each site is presented according to order, family, genus and species in tabular form (Table 30). The IUCN and CITES category for each fish species should be noted down.

Fish community structure is presented for each site category in terms of average value and standard deviation (Table 31). A decline in species richness from the control site to the diversion reach indicates degradation of the fish community, while an increase in sites downstream of the powerhouse

Table 29: Fish community metrics for evaluating the impact of operation of hydropower dam

| Candidate metrics              | Calculation  |  |  |  |
|--------------------------------|--|--|--|--|
| Species richness               | Number of present fish species                                 |  |  |  |
| Abundance (CPUE)               | Total number of fish individuals                               |  |  |  |
| Fish community composition (%) | Proportion of fish individuals across different orders of fish |  |  |  |
| Biomass (gm)                   | Wet biomass of all individual fish                             |  |  |  |

Table 30: Inventory of fish species presented with respect to order, family, genus and species in control sites (CS) including impounded zone, diversion reach (DR) and downstream of powerhouse (DP)

| SN  | Order | Family | Genus species | Local<br>name | Conservation status |      |          | Influence area of the project (CS/ DR/DP) |
|-----|-------|--------|---------------|---------------|---------------------|------|----------|---|
|     |       |        |               |               | CITES               | IUCN | National |   |
| 1   |       |        |               |               |                     |      |          |   |
| 2   |       |        |               |               |                     |      |          |   |
| 3   |       |        |               |               |                     |      |          |   |
| 4   |       |        |               |               |                     |      |          |   |
| 5   |       |        |               |               |                     |      |          |   |
| 6.  |       |        |               |               |                     |      |          |   |
| 7.  |       |        |               |               |                     |      |          |   |
| 8.  |       |        |               |               |                     |      |          |   |
| 9.  |       |        |               |               |                     |      |          |   |
| 10. |       |        |               |               |                     |      |          |   |
| 11. |       |        |               |               |                     |      |          |   |
| 12. |       |        |               |               |                     |      |          |   |
| 13. |       |        |               |               |                     |      |          |   |
| 14. |       |        |               |               |                     |      |          |   |
| 15. |       |        |               |               |                     |      |          |   |
| 16. |       |        |               |               |                     |      |          |   |
| 17. |       |        |               |               |                     |      |          |   |
| 18. |       |        |               |               |                     |      |          |   |
| 19. |       |        |               |               |                     |      |          |   |
| 20. |       |        |               |               |                     |      |          |   |
| 21. |       |        |               |               |                     |      |          |   |
| 22. |       |        |               |               |                     |      |          |   |
| 23. |       |        |               |               |                     |      |          |   |
| 24. |       |        |               |               |                     |      |          |   |
| 25. |       |        |               |               |                     |      |          |   |
| 26. |       |        |               |               |                     |      |          |   |
| 27. |       |        |               |               |                     |      |          |   |
| 28. |       |        |               |               |                     |      |          |   |
| 29. |       |        |               |               |                     |      |          |   |
| 30. |       |        |               |               |                     |      |          |   |
| 31. |       |        |               |               |                     |      |          |   |
| 32. |       |        |               |               |                     |      |          |   |
| 33. |       |        |               |               |                     |      |          |   |
| 34. |       |        |               |               |                     |      |          |   |
| 35. |       |        |               |               |                     |      |          |   |

Table 31: Fish community parameters (Mean±SD, SD stands for standard deviation) in control sites, diversion reach and downstream of powerhouse

| Biotic measures                       | Control sites including above dam (mean±SD) | Diversion reach<br>(mean±SD) | Downstream of powerhourse (mean±SD) |
|---------------------------------------|---|------------------------------|-------------------------------------|
| Species richness                      |   |                              |                                     |
| Abundance (CPUE)                      |   |                              |                                     |
| Fish community composition (%)        |   |                              |                                     |
| Abundance of migratory species (CPUE) |   |                              |                                     |
| Total Biomass (gm)                    |   |                              |                                     |
| Fish parameter                        |   |                              |                                     |
| Length (cm)*                          |   |                              |                                     |
| Weight (gm)*                          |   |                              |                                     |
| Presence of spawning grounds          |   |                              |                                     |

<sup>\*</sup> Mean±SD of each important fish species shall be presented separately

indicates recovery of the fish community. A decline in fish density, CPUE or biomass may result from a decrease in habitat area (e.g., Almodovar and Nicola, 1999), food resources or water quality.

If a migratory species previously found in an upstream site is no longer found there after the construction of a dam, this may indicate that the dam is acting as a barrier to migration of this species.

Multivariate analysis such as non-metric multidimensional scaling (NMDS) or detrended correspondence analysis (DCA) is recommended for differentiating the community composition across the sites of the project area and its influence area. Similarly, a size-frequency histogram shall be presented to provide insights such as failure in recruitment or high mortality. Lack of small-sized (juvenile) fish in a particular species upstream of a dam indicates that the dam is acting as a barrier to migration of that species.

Also see *The Trishuli Assessment Tool* (Box 5) for assessing and monitoring aquatic biodiversity (macroinvertebrates and fish) for a hydropower project in Nepal (IFC 2021).

# Box 5: Example of Standardized Protocol for Assessing and Monitoring Aquatic Biodiversity

### **Trishuli Assessment Tool**

The Trishuli Assessment Tool is a standardized methodology for field sampling and data analysis for EIAs and long-term monitoring for the aquatic environment, specifically designed for Himalayan rivers. The Tool was developed by a group of 30 Nepali and international scientists led by the International Finance Corporation (IFC) in 2019 and field tested in 2020. The Tool includes a set of field sampling techniques focused on sampling fish and macroinvertebrates in order to:

- · establish a robust baseline for long-term monitoring of aquatic biodiversity
- · allow for comparisons of fish abundance over time
- evaluate the impacts of a hydropower project on aquatic biodiversity
- evaluate the success of hydropower project mitigation efforts
- · demonstrate No Net Loss of Biodiversity.

The Tool requires sampling at six sites in each region: above the dam, within diversion reach between the dam and the powerhouse, and below the powerhouse.

The Tool is composed of six field sampling methods:

- Cast nets and Backpack Electrofishing to sample fish in mainstem and tributaries
- Underwater video and Dip nets to sample juvenile fish, primarily in tributaries
- Environmental DNA (eDNA) to be used where appropriate/feasible to assess fish diversity
- Standardized macroinvertebrate sampling protocol (based on Tachamo-Shah et al. 2020b)

Reference: IFC (2021).

# 3.5 Macrophytes

### Introduction

Macrophytes include a diverse group of plants adapted to a freshwater environment comprising vascular plants, ferns, mosses, liverworts and some macro algae, which may occur seasonally or permanently in the environment (Jones et al., 2010; Wantzen, et al., 2008). They form an important component of freshwater ecosystems and their establishment provides diversified habitat for instream faunas such as macroinvertebrates and fish. Macrophytes provide habitat to aquatic macroinvertebrates and fish, and may affect water quality by taking up nutrients and alternately releasing and taking up dissolved oxygen. Small growths confined to littoral areas are usually known to enhance river habitat. However, in some situations macrophytes may overgrow river channels, impeding water flow and reducing water and habitat quality (O'Hare et al., 2016).

The abundance, diversity and composition of macrophytes are most sensitive to flow velocity and the frequency and intensity of flow disturbances (floods) (Chambers et al., 1991; Dar et al., 2014; O'Hare et al., 2011; Riis and Biggs, 2003). Rooted and floating vascular plants will only be found in low-flow areas of a river and places with stable flows (infrequent flooding). Macrophytes are also sensitive to the sediment characteristics of the riverbed (Riis and Biggs, 2003). Rooted vascular plants prefer fine sediments (sand and mud) while mosses and liverworts may be found on hard surfaces of boulders and stones. Light at the riverbed and water temperature are two other important factors affecting macrophyte growth. Both of these may increase with reduced water depth (e.g., in the dewatered zone) and reduced suspended sediment (often a result of damming a river).

Hydropower development that involves interrupting river flow with a dam is likely to result in more stable flows (fewer, less intense floods) and reduced flow (at least within the dewatered zone). These two effects are likely to result in increased growth of macrophytes. Increased light and water temperature may further increase macrophyte growth. In some situations, macrophyte growth may reach nuisance levels. In Nepal, about 25% of vascular plants are dependent on aquatic ecosystems (NBSAP, 2014). Only a small proportion of macrophytes occur in Nepal's rivers

because the rivers are highly active and have unstable gravel beds. In deeper rivers, macrophytes are absent as their habitats are reduced as a result of water turbidity or water current. Altogether, 318 wetland dependent plant species have been recorded in the Tarai wetlands (IUCN, 2004). Therefore, it is normally possible to identify all to species level during a field survey.

#### **METHODS**

Macrophyte sampling requires the following minimum field materials.

| Stationery   | Equipment   |
|--|---|
| <ul> <li>Topographic map or aerial photographs</li> <li>Field notebook, pencils, waterproof permanent markers, and clipboard</li> <li>Identification keys</li> <li>Plastic bags for plant sample collection</li> </ul> | Boat with additional safety equipment including life jacket     Quadrat (1 m x 1 m)     Hand lens (x 10)     GPS     Camera |

## Sampling design

Macrophyte survey is carried out along a 100 m river stretch. In a wadeable river, macrophyte records are gathered from the entire channel and the corresponding banksides (JNCC, 2016) while in a non-wadeable river, macrophyte survey is conducted only on the banksides. Separate records should be kept for macrophytes found in the river and those found on the banks.

#### Note:

It is recommended that only emergent and submerged macrophytes in the study river stretch are recorded as fluctuation in river water levels largely influence species distribution and composition (*sensu* Regmi et al., 2021). "Usually, floating macrophytes are not used in the calculation of indices because their impact on ,clogginess' is minimal and a high density of floating plants would skew measures of total cover and % native cover" (Collier et al., 2014).

A quadrat of 1 m x 1 m is used for sampling of macrophytes (Figure 13) but if a river stretch is densely populated with macrophytes, then use of a  $0.5 \text{ m} \times 0.5 \text{ m}$  quadrat is recommended. A total of

Quadrat

1m

Photo: RD Tachamo Shah

100 m

Figure 13: Distribution of quadrat along both littoral section of a river for sampling of macrophytes.

20 quadrats are randomly laid down in a 100 m river stretch on the littoral and instream main channel (if macrophytes are available) of the river in a wadeable river. In case of a non-wadeable river, the quadrat of 1 m x 1 m are randomly laid down along each bankside of the study river. Species present in each quadrat is identified and their numbers are noted. In case of unidentified macrophyte species, a voucher specimen is collected for further identification in a laboratory or museum.

# **Safety precautions**

- Check the water and weather conditions before going for sampling
- Make sure to carry safety gear (e.g., rope) and a first-aid kit.
- River banks and stones might be sliperry, wear appropriate clothing with non-slip soles.

# **DATA ANALYSIS**

River

Phytosociological attributes: species richness, absolute density, relative density, abundance, relative abundance, frequency, relative frequency, and importance value index (IVI) shall be calculated (see Table 32).

# DATA PRESENTATION

Phytosociological attributes are compared across sites within the area of influence (Table 33).

Other ways of data presentation are:

- Changes in species composition (richness or abundance) over the seasons can be displayed in pie charts or bar plots. A statistical test such as Analysis of Variance (ANOVA) is required to test whether the differences between zones are significant.
- Multivariate analysis such as non-metric multidimensional scaling (NMDS) or Detrended correspondence analysis (DCA) is recommended for differentiating the community composition across the sites of the project area and its influence area. Differences in community composition can be tested for significance using ANOSIM (Analysis of Similarities).

Table 32: A list of vegetation analysis methods

| Phytosociological attributes  Species richness (s) | Calculation method  Number of species in the study river stretch                                       |
|--|--|
| Absolute density                                   | Total number of individuals of a species in all quadrats taken  Total number of quadrats taken         |
| Relative density percentage                        | Density of a species x 100  Sum of density of all species  |
| Abundance  | Total number of individuals of a species in all quadrats  Total number of quadrats of species occurred |
| Relative abundance                                 | Abundance of a species x 100  Total abundance of all species   |
| Frequency  | Number of quadrats of occurrence of a species x 100  Total number of quadrats lay out                  |
| Relative frequency percentage                      | Frequency of a species x 100  Total frequency of all species   |
| IVI <sup>4</sup>                                   | Relative density + Relative abundance + Relative frequency  3  |

**Table 33:** Data presentation of phytosociological attributes across sites within the influence area of hydropower project

| Phytosociological attributes  | Control sites including above dam (mean±SD) | Diversion reach (mean±SD) | Downstream of powerhouse (mean±SD) |
|-------------------------------|---|---------------------------|------------------------------------|
| Species richness              |   |                           |                                    |
| Absolute density              |   |                           |                                    |
| Relative density percentage   |   |                           |                                    |
| Abundance                     |   |                           |                                    |
| Relative abundance            |   |                           |                                    |
| Frequency                     |   |                           |                                    |
| Relative frequency percentage |   |                           |                                    |
| IVI <sup>5</sup>              |   |                           |                                    |

 $<sup>^{4\,\&</sup>amp;\,5}$  Bhadra and Pattanayak (2016)

# 3.6 Terrestrial ecosystem and riparian vegetation

## Introduction

Terrestrial vegetation, for the purpose of the EIA/ IEE, refers to plant species that grow on land within the influence area of a hydropower project. Construction of a hydropower project is likely to damage natural vegetation by removing or introducing weeds or invasive species (during the construction of a road, dam, building and other infrastructure), and cause flooding of terrestrial habitats by the reservoir behind the dam. The most important objective of a terrestrial vegetation survey is to reveal the conservation value of the forest area. This is not just about the extent of diversity harboured by the forest. It is more about how important the forest is in the wider landscape. Key questions are: i. Does it have plant species of conservation value? ii. Is it a rare forest type (see section 'Important habitat') iii. Does it have a mix of vegetation types that is rare in the region or country? The idea is to ensure that terrestrial species and ecosystems of high conservation value are not harmed by the hydropower project. The focus should be on recording species of conservation value and the diversity and uniqueness of terrestrial ecosystems within the zone of influence (see section 5.4). Therefore, vegetation diversity, abundance and community composition shall be considered in addition to the phytosociological characteristics mentioned in the Hydropower EIA Manual 2018 (see Chapter 8: 'Assessing impact' and Appendix "A") during a detailed EIA baseline survey.

Riparian vegetation is the plant community sustained by river flow, groundwater or generally moist conditions along river margins, and is typically distinct in species composition from adjacent terrestrial communities (Naiman et al., 2005). Riparian vegetation plays a central role in the functioning of riverine ecosystems: bank erosion is reduced through anchoring by plant roots; overhanging banks anchored by riparian plant roots, and overhanging riparian vegetation may provide refuge for fish; water quality is maintained through trapping of sediment, nutrients and other contaminants, and shading regulates river water temperature, reducing primary productivity and temperature stress on aquatic organisms; food is provided for riparian animals in the form of fruits, nuts and leaves, and for aquatic macroinvertebrates in the form of leaf litter; the plants themselves offer a diverse array of habitats as well as a corridor for the movement of migratory terrestrial and semiaquatic animals.

One possible result of hydropower development is an ecological shift in gravel bars and banks within the river channel. As flows become more stable and floods are eliminated, vegetation can invade previously unvegetated gravel bars and banks. Gravel bars and banks that had annual plant species could become overgrown with perennial plant species. Some of the newly established plants may be weeds, which need to be identified. Vegetation changes will inevitably lead to changes in animal species (e.g., small mammals), and these should also be monitored (see 3.7). These ecological shifts can be important and should be included in an EIA.

#### **METHODS**

Vegetation assessment requires the following minimum field materials (Table 34).

Table 34: Equipment for vegetation assessment in the field

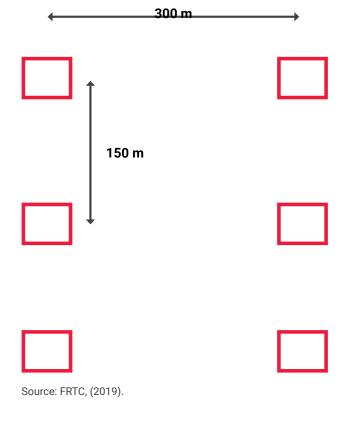
#### Stationery Measurement tools Laminated topographic Measuring tape (50-100 maps or aerial m open reel fiberglass photographs tape) · Field notebook, pencils, Diameter at breast height waterproof permanent (DBH) tape to measure markers, and clipboard trees Plant identification keys GPS Plastic bags for plant Camera sample collection 1 m x 1 m quadrat

# Forest assessment

Field sampling design: Stratified systematic cluster sampling design is recommended for sampling of vegetation in the area of project influence. This is the method used to sample from a population across the country (FRTC, 2019). If sub-populations vary considerably, sampling shall be carried out from each sub-population (stratum) independently. In each stratum, a cluster of sample plots is designated according to forest type. A total of six sample plots per cluster shall be considered. The plots should be 300 m apart from each other along

two parallel lines in north-south direction. Three plots are distributed at equal intervals (i.e., 150 m) on either side of the lines (Figure 14).

Figure 14: Three vegetation assessment transects in each site within the area of project influence



# Sample plots:

- a) Trees: Concentric Circular Sample Plots (CCSPs) are used for counting trees in the project's area of influence (see FRTC, 2019). The circles of a CCSP with different radii for counting trees with respect to diameter at breast height of the tree is presented in Table 35.
- b) Seedlings and saplings: Seedlings and saplings are measured from four sub-plots with a 2 m radius (area: 12.6 m²) that are located 10 m from the centre of the CCSP in the four cardinal directions (N, E, S and W). Number of stems is counted by estimating their mean height (FRTC, 2019).
- c) Shrubs: Shrubs are measured from the same sub-plots as seedlings and samplings. Both diameter near the root collar and height are assessed for each sampled shrub.

Table 35: Plot redii for counting trees with respect to DBH

| Radius (cm) | Counting of trees with respect to diameter at breast height (DBH) |
|-------------|---|
| 20          | Big-size trees with DBH ≥ 30 cm                                   |
| 15          | Big-size trees with DBH 20 to < 30 cm                             |
| 8           | Big-size trees with DBH 10 to < 20 cm                             |
| 4           | Big-size trees with DBH 5 to < 10 cm                              |

d) Herbaceous plants: An inventory of herbaceous plants is prepared from four rectangular plots; the centre of each plot is at a 5 m distance from the cardinal points (N, E, S and W). The herbaceous plants include all non-woody and emergent species of all heights (including bryophytes).

In case of unidentified plant species, a voucher specimen is collected for further identification in a laboratory or a herbarium centre.

### Riparian vegetation assessment

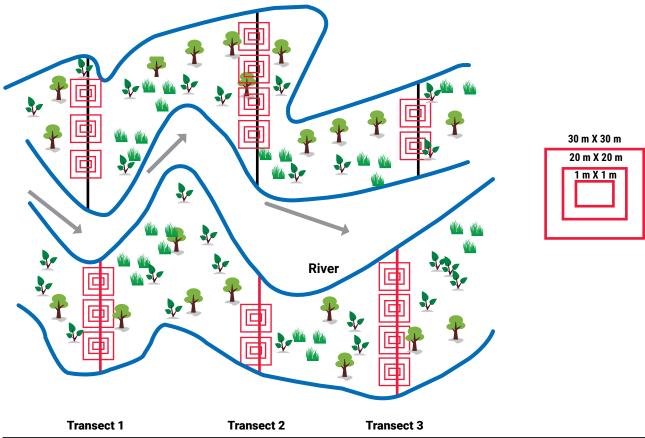
Riparian vegetation survey is carried out in six transects established across a river within the area of project influence. Transects should be established perpendicularly from the river (Figure 15) and adequately represent the vegetation cover types present in the study site. Additional transects should be established if time and resources allow, particularly for a highly diverse riparian zone.

A systematically random sampling approach shall be applied for establishing sampling stations along the transects within the identified cover types (e.g., herbaceous plants every 5 m, shrubs every 15 m and trees every 30 m). Vegetation assessment shall be carried out from a minimum of 12 sampling stations at each site. At each sampling station, available vegetation cover – herbaceous, sapling and shrub, and tree – is estimated.

Sampling of vegetation at each sampling station:

a) Trees: Trees are sampled within a 9 m (approx.30ft) radius of the station.

Figure 15: Systematic distribution of 6 sampling stations in each transect across the river covering both river banks appropriately. Each station consists of a squared of 30 m  $\times$  30 m, 20 m  $\times$  20 m and 1 m  $\times$  1 m for listing trees, shrubs and herbaceous plants, respectively.



100 m

Source: Modified from Collins et al., (2007)

- b) Sapling and shrub: The sapling/shrub layer is sampled within a 5 m (approx. 16 ft) radius of the sampling station.
- c) **Herbaceous plants:** Herbaceous plants are sampled using a quadrat of 1m x 1m (10.8 ft²) frame made of a PVC pipe or a similar method.

# Safety precautions

- Check weather conditions before going for forest inventory and vegetation survey.
- · Make sure to carry safety gear and a first-aid kit.

## DATA ANALYSIS

**Phytosociological attributes:** Absolute density, relative density, frequency, relative frequency, absolute coverage, relative coverage, species

richness, species diversity, dominance and importance value index (IVI) are calculated using the formulae given in Table 36.

## DATA PRESENTATION

Phytosociological attributes are compared across sites within the area of influence of the hydropower project (Table 37). In general, phytosociological parameters decrease with increased disturbances or introduction of exotic species in the project site (Table 38). The parameters are tested for significant differences in vegetation communities across the reaches using Analysis of Variance (ANOVA) or non-parameteric tests.

Multivariate analysis such as Non-metric multidimensional scaling (NMDS) or Detrended correspondence analysis (DCA) is recommended for differentiating the forest community composition across the sites of the project area and its influence area.

Table 36: A list of vegetation analysis methods

| Phytosociological attributes  | Calculation method   |
|-------------------------------|--|
| Species richness (S)          | Number of species in the study area  |
| Absolute density              | Total number of individuals of a species in all quadrats taken  Total number of quadrats taken                             |
| Relative density percentage   | Total number of individuals of a species in all quadrats x 100  Total number of individuals of all species in all quadrats |
| Frequency                     | Number of quadrats of occurrence of a species x 100  Total number of quadrats laid   |
| Relative frequency percentage | Frequency of a species x 100  Total frequency of all species   |
| Cover                         | Total cover (cm) of a species  Total number of the species   |
| Relative cover                | Total cover (sq cm) of all species present in all quadrats x 100  Total cover (sq cm) of species present in all quadrats   |

**Table 37:** Inventory of plants in sites within the project's influence area. Here CS - control site, DR - diversion reach, DP - downstream of powerhouse (Sample)

| SN  | Local name | Scientific name | Family |       |      | Conservation status |                     |
|-----|------------|-----------------|--------|-------|------|---------------------|---------------------|
|     |            | Hallie          |        | CITES | IUCN | Government of Nepal | project (CS/ DR/DP) |
| 1.  |            |                 |        |       |      |                     |                     |
| 2.  |            |                 |        |       |      |                     |                     |
| 3.  |            |                 |        |       |      |                     |                     |
| 4.  |            |                 |        |       |      |                     |                     |
| 5.  |            |                 |        |       |      |                     |                     |
| 6.  |            |                 |        |       |      |                     |                     |
| 7.  |            |                 |        |       |      |                     |                     |
| 8.  |            |                 |        |       |      |                     |                     |
| 9.  |            |                 |        |       |      |                     |                     |
| 10. |            |                 |        |       |      |                     |                     |
| 11. |            |                 |        |       |      |                     |                     |
| 12. |            |                 |        |       |      |                     |                     |
| 13. |            |                 |        |       |      |                     |                     |
| 14. |            |                 |        |       |      |                     |                     |
| 15. |            |                 |        |       |      |                     |                     |
| 16. |            |                 |        |       |      |                     |                     |
| 17. |            |                 |        |       |      |                     |                     |
| 18. |            |                 |        |       |      |                     |                     |
| 19. |            |                 |        |       |      |                     |                     |
| 20. |            |                 |        |       |      |                     |                     |
| 21. |            |                 |        |       |      |                     |                     |
| 22. |            |                 |        |       |      |                     |                     |
| 23. |            |                 |        |       |      |                     |                     |
| 24. |            |                 |        |       |      |                     |                     |
| 25. |            |                 |        |       |      |                     |                     |

Table 38: Data presentation of phytosociological attributes across sites within the project area

| Phytosociological attributes  | Control sites above dam (mean±SD) | Diversion reach (mean±SD) | Downstream of powerhouse (mean±SD) |
|-------------------------------|-----------------------------------|---------------------------|------------------------------------|
| Species richness (S)          |                                   |                           |                                    |
| Absolute density              |                                   |                           |                                    |
| Relative density percentage   |                                   |                           |                                    |
| Frequency                     |                                   |                           |                                    |
| Relative frequency percentage |                                   |                           |                                    |
| Cover                         |                                   |                           |                                    |
| Relative cover                |                                   |                           |                                    |
| IVI                           |                                   |                           |                                    |

# 3.7 Wildlife

### **MEDIUM AND LARGE-SIZED MAMMALS**

Large mammals comprise charismatic organisms like red panda, snow leopard, tiger, etc. They are considered key ecological indicators of intact terrestrial landscapes and have been widely used in large-scale monitoring programs across the world (Benchimol cited in Larsen, 2016). They are important for structuring the community composition and proper functioning of the ecosystems. Nepal is endowed with 208 species of mammals that contribute 4.2% of the world's mammalian fauna (Jnawali et al., 2011).

Construction of hydropower projects may likely expose habitats by removing trees and cause other disturbances that threaten wildlife population and their habitats. A comprehensive survey is recommended for documenting current mammal species and their populations occurring in the project area in order to anticipate the potential effects of the construction on wildlife population and their corridors.

# Requirements

- Site information and familiarization with the survey sites prior to designating transects
- Transects should encompass different habitats or forest types if possible

Trapping methods; observation methods including direct observation; identification of dungs, tracks and other signs and camera trapping; and indirect survey of mammals in markets (Hoffmann et al., 2010) are recommended for making an inventory of medium and large-sized mammals.

Inventory of species at each site should be made separately for each sampling method used or presented in combined form (Table 39).

#### **SMALL MAMMALS**

Small mammals include groups of bats, rodents, shrews and tree shrews whose body weight are approximately less than 1 kg (Jnawali et al., 2011; Larsen, 2016). Many of the small mammals are nocturnal and are easily identified in live specimen. Traps or pitfalls (Hoffmann et al., 2010) with capture-mark-recapture protocols (Caughley, 1977;

Krebs, 199; Smith et al., 1975) are recommended for sampling small mammals. It is widely used as it is foldable, very portable and efficient for trapping small mammals (Photo 24).

Inventory of species should be presented for each site (Table 40).



Photo 24: Commonly available traps.
a) Collapsible Tomahawk Trap for squirrels, small carnivores, and large rats; b) Standard-sized Collapsible Sherman Trap; c) Victor Rat Trap; d) Museum Special Snap Trap.
Source: Hoffmann et al., (2010).

#### **HERPETOFAUNA**

Nepal harbours a moderate level of herepetofauna diversity, which mainly includes amphibians and reptiles. A total of 52 species of amphibians and 125 species of reptiles have been reported in the country (Hermann and Kästle, 2002). Construction of hydropower projects may likely influence their habitat, threatening their current population. Therefore, a comprehensive study should be carried out during the EIA baseline survey in the project's influence area. Presence and absence of herpetofauna shall be recorded via a transect visual encounter survey (Gillespie 1997), patch sampling (Lambert, 2008), and opportunistic observation (Durkin et al., 2011). The recommended time for the herpetofauna survey is mid-day as most species come out from their refuge for basking when the ambient temperature becomes warmer (Hill et al., 2005).

Inventory of species should be presented separately for each of the sampling method deployed. If multiple methods are used, information on the methods should be indicated in the table for each site (Table 41).

Table 39: Checklist of medium and large-sized mammals in sites within the project's influence area. Here CS - control site, DR - diversion reach, DP - downstream of powerhouse (Sample)

| SN  | Species | Methods (presence/absence)              | C     | Influence area of the project (CS/ |                        |        |
|-----|---------|---|-------|------------------------------------|------------------------|--------|
|     |         | Trap/Direct observation/Indirect survey | CITES | IUCN                               | Government of<br>Nepal | DR/DP) |
| 1   |         |   |       |                                    |                        |        |
| 2   |         |   |       |                                    |                        |        |
| 3   |         |   |       |                                    |                        |        |
| 4   |         |   |       |                                    |                        |        |
| 5   |         |   |       |                                    |                        |        |
| 6.  |         |   |       |                                    |                        |        |
| 7.  |         |   |       |                                    |                        |        |
| 8.  |         |   |       |                                    |                        |        |
| 9.  |         |   |       |                                    |                        |        |
| 10. |         |   |       |                                    |                        |        |
| 11. |         |   |       |                                    |                        |        |
| 12. |         |   |       |                                    |                        |        |
| 13. |         |   |       |                                    |                        |        |
| 14. |         |   |       |                                    |                        |        |
| 15. |         |   |       |                                    |                        |        |
| 16. |         |   |       |                                    |                        |        |
| 17. |         |   |       |                                    |                        |        |
| 18. |         |   |       |                                    |                        |        |
| 19. |         |   |       |                                    |                        |        |
| 20. |         |   |       |                                    |                        |        |
| 21. |         |   |       |                                    |                        |        |
| 22. |         |   |       |                                    |                        |        |
| 23. |         |   |       |                                    |                        |        |
| 24. |         |   |       |                                    |                        |        |
| 25. |         |   |       |                                    |                        |        |

Table 40: Checklist of small mammels in sites within the influence area of the project (Sample)

| SN  | Species | Conservation status |      |                     | Influence area of the project (CS/DR/DP) |
|-----|---------|---------------------|------|---------------------|--|
|     |         | CITES               | IUCN | Government of Nepal | project (00/DII/DI )                     |
| 1   |         |                     |      |                     |  |
| 2   |         |                     |      |                     |  |
| 3   |         |                     |      |                     |  |
| 4   |         |                     |      |                     |  |
| 5   |         |                     |      |                     |  |
| 6.  |         |                     |      |                     |  |
| 7.  |         |                     |      |                     |  |
| 8.  |         |                     |      |                     |  |
| 9.  |         |                     |      |                     |  |
| 10. |         |                     |      |                     |  |
| 11. |         |                     |      |                     |  |
| 12. |         |                     |      |                     |  |
| 13. |         |                     |      |                     |  |
| 14. |         |                     |      |                     |  |
| 15. |         |                     |      |                     |  |
| 16. |         |                     |      |                     |  |
| 17. |         |                     |      |                     |  |
| 18. |         |                     |      |                     |  |
| 19. |         |                     |      |                     |  |
| 20. |         |                     |      |                     |  |
| 21. |         |                     |      |                     |  |
| 22. |         |                     |      |                     |  |
| 23. |         |                     |      |                     |  |
| 24. |         |                     |      |                     |  |
| 25. |         |                     |      |                     |  |
|     |         |                     |      |                     |  |

Table 41: Checklist of herpetofauna in sites within the project's influence area (Sample)

| SN  | Species | Methods (presence/ absence)   | C     | Influence area of |                        |                            |
|-----|---------|---|-------|-------------------|------------------------|----------------------------|
|     |         | Visual Encounter Survey/ Patch<br>Sampling/ Opportunistic Observation | CITES | IUCN              | Government of<br>Nepal | the project (CS/<br>DR/DP) |
| 1.  |         |   |       |                   |                        |                            |
| 2.  |         |   |       |                   |                        |                            |
| 3.  |         |   |       |                   |                        |                            |
| 4.  |         |   |       |                   |                        |                            |
| 5.  |         |   |       |                   |                        |                            |
| 6.  |         |   |       |                   |                        |                            |
| 7.  |         |   |       |                   |                        |                            |
| 8.  |         |   |       |                   |                        |                            |
| 9.  |         |   |       |                   |                        |                            |
| 10. |         |   |       |                   |                        |                            |
| 11. |         |   |       |                   |                        |                            |
| 12. |         |   |       |                   |                        |                            |
| 13. |         |   |       |                   |                        |                            |
| 14. |         |   |       |                   |                        |                            |
| 15. |         |   |       |                   |                        |                            |
| 16. |         |   |       |                   |                        |                            |
| 17. |         |   |       |                   |                        |                            |
| 18. |         |   |       |                   |                        |                            |
| 19. |         |   |       |                   |                        |                            |
| 20. |         |   |       |                   |                        |                            |
| 21. |         |   |       |                   |                        |                            |
| 22. |         |   |       |                   |                        |                            |
| 23. |         |   |       |                   |                        |                            |
| 24. |         |   |       |                   |                        |                            |
| 25. |         |   |       |                   |                        |                            |

# Animal handling and release

- Wear sturdy protective gloves while handling live animals and disposable laboratory gloves while processing dead animals.
- Wear a mask while handling the captured animals.
- After being identified or photographed, the captured specimens should be released in situ.

### **BIRDS**

Nepal is internationally known for its rich diversity of bird species. A total of 892 bird species found in the country (BCN, DNPWC and DOFSC, 2011). Distribution and abundance of birds are useful indicators for defining important bird and biodiversity areas (IBAs), which are key sites for conservation. Birds have high cultural and economic significance because they eat crop pests, pollinate flowers, disperse seed and act as scavengers. They are good ecological indicators of a healthy environment. Construction of a hydropower project likely affects their habitat and consequently their distribution and composition. A comprehensive bird survey, with a focus on riverdependent birds, is recommended during an EIA baseline survey in the hydropower project site and the project's area of influence. Bird survey along the river should be conducted during field survey. A vantage point count survey method (Bibby et al., 2000) can be used to list the birds in the study area. Additionally, a structured social survey of people residing near the river is also recommended for making an inventory of bird species. The birds should be listed along with their conservation status for each site within the influence area of the hydropower project (Table 42)

Table 42: Checklist of birds in sites within the project's influence area. Here CS - control site, DR - diversion reach, DP - downstream of powerhouse

| SN  | Species | Count survey/<br>Social survey | CITES | Conservation<br>IUCN | status<br>Government of<br>Nepal | Influence area of the project (CS/ DR/DP) |
|-----|---------|--------------------------------|-------|----------------------|----------------------------------|---|
| 1.  |         |                                |       |                      |                                  |   |
| 2.  |         |                                |       |                      |                                  |   |
| 3.  |         |                                |       |                      |                                  |   |
| 4.  |         |                                |       |                      |                                  |   |
| 5.  |         |                                |       |                      |                                  |   |
| 6.  |         |                                |       |                      |                                  |   |
| 7.  |         |                                |       |                      |                                  |   |
| 8.  |         |                                |       |                      |                                  |   |
| 9.  |         |                                |       |                      |                                  |   |
| 10. |         |                                |       |                      |                                  |   |
| 11. |         |                                |       |                      |                                  |   |
| 12. |         |                                |       |                      |                                  |   |
| 13. |         |                                |       |                      |                                  |   |
| 14. |         |                                |       |                      |                                  |   |
| 15. |         |                                |       |                      |                                  |   |
| 16. |         |                                |       |                      |                                  |   |
| 17. |         |                                |       |                      |                                  |   |
| 18. |         |                                |       |                      |                                  |   |
| 19. |         |                                |       |                      |                                  |   |
| 20. |         |                                |       |                      |                                  |   |
| 21. |         |                                |       |                      |                                  |   |
| 22. |         |                                |       |                      |                                  |   |
| 23. |         |                                |       |                      |                                  |   |
| 24. |         |                                |       |                      |                                  |   |
| 25. |         |                                |       |                      |                                  |   |

# 4. Water quality assessment

# Introduction

Construction and operation of a hydropower project in a river basin alters the river's hydrologic regimes, hydraulic character, and geological condition, which directly or indirectly influence water quality parameters (ADB, 2018; Zhang et al., 2010). Therefore, establishing baseline data of physicochemical parameters of the water body across sites within the area of influence involves documenting any changes in the water quality status during construction and operation of the hydropower project.

# **Key water quality parameters**

Hydropower development can affect water quality in a number of ways. Construction involves major earthworks that can result in fine sediment entering the river. This increases turbidity, and may increase phosphate, dissolved and suspended organic matter, and oxygen. Clearing of riparian vegetation can reduce shading, which may increase water temperature and have indirect effects on nutrients and dissolved oxygen via periphyton growth.

After construction, water quality will mainly be impacted by alterations to flow. Reduced flow in the diversion reach is likely to lead to increased water temperatures, and possibly decreased dissolved oxygen (particularly if sediments have high organic matter). If the level of dissolved oxygen becomes very low, then certain chemicals such as sulphides, and ferrous and manganese ions may appear. Low oxygen and appearance of these chemicals may also occur if the outlet of the dam is at the bottom of the reservoir (where water is low in oxygen). If this is the case, then the outflow water may also be very cold, and the river immediately downstream of the dam may be colder than normal.

# Measurements of physico-chemical parameters

Among physical parameters, water temperature is critical as it influences many other physical and chemical parameters of water and determines the survival of stenothermic aquatic organisms.

Reduced flow induced by the operation of the

hydropower project increases water temperature downstream of the dam. This affects water quality and increases nutrient concentration, adversely impacting the habitat of aquatic organisms.

# **Timing**

Water quality parameters change naturally with changes in the weather. Therefore, to adequately characterise water quality, sampling should be conducted every month throughout the year (under all flow conditions). Monitoring should begin at least one year, but preferably 2–3 years, before contruction begins, and should continue at monthly intervals afterwards.

Because some water quality parameters vary over the course of a day, water quality measurements should be done at the same time of day (or as near as possible) during each round of sampling.

#### Field methods

Certain parameters such as water temperature, pH, turbidity, electrical conductivity, total dissolved solids, turbidity, and percentage of dissolved oxygen saturation (DO %) are to be measured *in situ* with a portable digital probe (Photo 25). Chemical parameters of water, such as contaminants (e.g., sulphides, selenium, ferrous and manganese ions and organic mercury), nutrients (e.g., orthophosphate and nitrate) (Photo 26), total hardness, total alkalinity, concentration of ions (calcium, magnesium, chloride), biological oxygen demand,



Photo 25: A researcher measures the water quality parameters (water temperature, pH, dissolved oxygen, EC, TDS, turbidity) using a Hanna probe.



Photo 26: The researcher is measuring the water quality parameters (Nitrate, Phosphate, Ammonia) using a Hanna probe.

chemical oxygen demand, total and fecal coliform, oil and grease, pesticide (DoED, 2002) should be determined during a detailed EIA study using chemical and instrumental methods, usually in a laboratory.

Chemical analysis: Chemical parameters should be analysed using the methods given in Baird et al., 2017 or equivalent standard methods.

Water quality measurements and samples should be taken from the main flow of the river (Photo 27). If the main flow is not safe to enter, sample bottles can be lowered from a bridge. If no bridge is available, the sample bottle can be attached to an extendible "arm" which the operator holds while standing safely on the bank or in quiet water. The operator should approach the sampling site from downstream, disturbing the sediments as little as possible, and after arriving at the sampling position, wait a few seconds for any disturbed sediment to be washed downstream. While taking a sample the operator should be facing upstream. Sample bottles and lids should have been properly cleaned in the laboratory. In the field, they should be rinsed



Photo 27: Researcher is collecting water sample to analyse water quality parameters in the laboratory.

three times in sample water before the final sample is taken. To rinse the bottles and take the sample, turn the sample bottle upside down and push it a few centimetres below the water surface. Turn it over so it fills with water below the surface. Screw the lid on while the bottle is underwater. Bottles must be carefully labelled with a permanent marker.

# Water sample storage

Water samples must be immediately placed in a "cooler" (insulated bin) with ice and stored in the dark. They must be processed within 6–8 hours of sampling, or else preserved according to standard methods appropriate to the parameters being measured.

# Measurements of suspended sediment

A representative suspended sediment sample should be taken from each sampling station. Table 43 provides a list of methods that can be used for the collection of suspended sediment samples (Gray and Landers, 2014).

Table 43: Various methods of collecting suspended sediment samples from sites within the influence area of a hydropower project

| Method            | Requirement/Equipment  |
|-------------------|--|
| Bottle sampling   | Depth integrating samplers (DH-59, DH-49, DH-48)                                     |
|                   | Point integrating samplers (US P-61, Neyrpic Sediment Sampler, Nielsen Type)         |
| Acoustic sampling | Transducer's setup   |
| Pump sampling     | <ul> <li>Pump</li> <li>Bottle container</li> <li>Intake system activation</li> </ul> |
| Laser diffraction | Laser beam setup   |

# **Sheet 7 – Water Quality Assessment sheet (Sample)**

| River name:                                | Site code:              | Date:                    | Time:                              |
|--|-------------------------|--------------------------|------------------------------------|
|  |                         |                          |                                    |
|  |                         |                          |                                    |
|  |                         |                          |                                    |
| Physical properties of water               |                         |                          |                                    |
|  |                         |                          |                                    |
|  |                         |                          |                                    |
| A  |                         | Water Odam               |                                    |
| Appearance:                                |                         | Water Odor:              |                                    |
| □ Clear □ Opaque                           |                         | □ None □ Mudd            |                                    |
| ☐ Slightly ☐ Turbid                        |                         | ☐ Sewage ☐ Che           | emicai                             |
| ☐ Stained ☐ Turbid                         |                         | ☐ Fishy                  |                                    |
| Other (Specify)                            |                         | ☐ Other (Specify)        |                                    |
| Water Quality Parameters (in Field)        |                         |                          |                                    |
| _  |                         |                          |                                    |
| Temperature°C                              | pH<br>                  |                          | DO, DO Saturation<br>mg/L,%        |
|  |                         |                          | ,                                  |
| Electrical Conductivity                    | Total Dissolved         | Solids (TDS)             | Turbidity                          |
| μS/cm                                      | (mg/L)                  |                          | NTU                                |
|  |                         |                          |                                    |
| Water Quality Parameters (in Laboratory)   |                         |                          |                                    |
|  |                         |                          |                                    |
|  |                         |                          |                                    |
| Free CO <sub>2</sub>                       | Total Alkalinity        | •                        | Total Hardness                     |
| (mg/L)                                     | (mg                     |                          | (mg/L)                             |
| Tatal Milana man                           | Tatal Dhaanha           |                          | Objective Course Descript (OOD)    |
| Total Nitrogen<br>( mg/L)                  | Total Phospha<br>(mg,   |                          | Chemical Oxygen Demand (COD)(mg/L) |
|  |                         |                          |                                    |
| Contaminants (as necessary)                |                         |                          |                                    |
| Total Sulphide (TS)                        | Manganese ior           | ns (mg/L)                |                                    |
| (mg/L)                                     | Wanganese loi           | 15 (111g/ L)             |                                    |
|  |                         |                          |                                    |
|  |                         |                          |                                    |
| Biological parameters (as necessary if use | d for drinking water su | ipply or recreational pu | ırposes)                           |
|  |                         |                          |                                    |
|  |                         |                          |                                    |
| Total coliform (CFU in 100 mL)             | Fecal coliform          | (CFU in 100 mL)          |                                    |
|  |                         |                          |                                    |
|  |                         |                          |                                    |
| Suspended sediments (mg/L):                |                         |                          |                                    |
| ouspended sediments (IIIg/L).              |                         |                          |                                    |
|  |                         |                          |                                    |
|  |                         |                          |                                    |

Because temperature varies widely over a day and a year, it is necessary to log the temperature (measuring repeatedly at frequent intervals) to characterize water temperature. A small temperature logger, 'HOBO Water Temp Pro' from onset, can be used as this device has an accuracy of ±0.2°C. Temperature loggers should be set up permanently at each hydropower influence zone (control site and the impounded reach, diversion reach, downstream of the powerhouse). Temperature loggers need to be anchored to an immovable object in the river. They must be placed within the main flow but places where they might be washed away by a flood should be avoided. They should be inserted deep enough so that they are not above the water during low flow periods. Loggers should be programmed to record a measurement every 30 minutes. Data should be downloaded as frequently as possible to reduce the chances of loss.

### **DATA ANALYSIS**

General values such as mean and standard deviation can be calculated for the different sites within the influence area separately for the mainstem and tributaries. For baseline monitoring, particular attention should be given to identifying seasonal cycles and longitudinal trends.

# Safety precautions

- Check water and weather conditions before going for sampling.
- Wear a lifejacket.
- Make sure to carry other safety gear (e.g., ropes) and a first-aid kit.
- Don't take samples from a highly turbulent or deep section of the river.
- Avoid taking samples during the monsoon season or flooding period.

#### **DATA PRESENTATION**

Physical and chemical values obtained from measurement on the site and in the laboratory should be summarized in Table 44. The sites can be grouped together for each impact zone. A statistical test such as Analysis of Variance (ANOVA) or a non-parameteric test is required to evaluate differences in water quality across the reaches.

As indicated in Appendix A of the EIA Manual (MoFE, 2018), drinking water quality parameters can also be compared against National Drinking Water Quality Standards, 2005 (2062 B.S.).

**Table 44: Summary sheet of physical and chemical parameters (Sample)** 

| Impact zone                       | Sites | Temperature (° C) | Hd | DO (mg/L) | EC (µS/cm) | TDS (mg/L) | Turbidity (NTU) | COD (mg/L) | TS (mg/L) | TP (mg/L) | SS (mg/L) |
|-----------------------------------|-------|-------------------|----|-----------|------------|------------|-----------------|------------|-----------|-----------|-----------|
| Control sites including above dam |       |                   |    |           |            |            |                 |            |           |           |           |
|                                   |       |                   |    |           |            |            |                 |            |           |           |           |
|                                   |       |                   |    |           |            |            |                 |            |           |           |           |
|                                   |       |                   |    |           |            |            |                 |            |           |           |           |
|                                   |       |                   |    |           |            |            |                 |            |           |           |           |
|                                   |       |                   |    |           |            |            |                 |            |           |           |           |
| Diversion reach                   |       |                   |    |           |            |            |                 |            |           |           |           |
|                                   |       |                   |    |           |            |            |                 |            |           |           |           |
|                                   |       |                   |    |           |            |            |                 |            |           |           |           |
|                                   |       |                   |    |           |            |            |                 |            |           |           |           |
|                                   |       |                   |    |           |            |            |                 |            |           |           |           |
|                                   |       |                   |    |           |            |            |                 |            |           |           |           |
| Downstream of powerhouse          |       |                   |    |           |            |            |                 |            |           |           |           |
|                                   |       |                   |    |           |            |            |                 |            |           |           |           |
|                                   |       |                   |    |           |            |            |                 |            |           |           |           |
|                                   |       |                   |    |           |            |            |                 |            |           |           |           |
|                                   |       |                   |    |           |            |            |                 |            |           |           |           |
|                                   |       |                   |    |           |            |            |                 |            |           |           |           |

Note: Physical parameters: pH - potential of hydrogen, DO - dissolved oxygen, EC - electrical conductivity, TDS - total dissolved solids, and turbidity; Chemical parameters: BOD - Biological Oxygen Demand; COD - Chemical Oxygen Demand, TS - Total Sulphide, TP - Total Phosphorus, TN - Total Nitrogen, SS - Suspended Sediment



# 5. Important habitats

# 5.1 Biodiversity hotspots

A biodiversity hotspot is a biogeographic region that is both a significant reservoir of biodiversity and is threatened with destruction (CI, 2021). Such species include (i) IUCN Red List of Threatened or Critically Endangered/Endangered Species, (ii) Species with restricted range, i.e., endemic species, (iii) Large numbers of important migratory species and/or congregatory species, (iv) Highly threatened species, and/or (v) Areas associated with key evolutionary processes. Nepal lies at the centre of the Himalayan Biodiversity hotspot (MoFSC, 2014). Nepal has one of the longest bioclimatic elevation gradients in the world and provides habitats to 3.2% and 1.1% of the world's known flora and fauna, respectively (MoFSC, 2014). Due to its significant biodiversity, the country has designated 12 National Parks, one Wildlife Reserve, 1 Hunting Reserve, 6

Conservation Areas, and 13 Buffer Zones, and 2 Zoological gardens extending from lowland Terai to high mountains, covering 23.39% of the total country's land (DNPWC, 2021)(Figure 16).

While developing a hydropower project, the proponent should identify any of the following that are within the area of influence of the hydropower project (Table 45).

- nationally or internationally designated protected areas
- important aquatic habitats
- biodiversity hotspots
- · biological corridors and connectivity
- important bird and biodiversity areas (IBBAs)
- important plant areas and other important habitats including forests
- Critically Sensitive Areas



Figure 16: Protected areas of Nepal

Source: DNPWC

Table 45: List of Important Bird Areas and potential Important Bird Areas in Nepal

| SN | IBA  | SN | IBA  |
|----|--|----|--|
| 1  | Annapurna Conservation Area                            | 22 | Kohalbi and Baragadi                             |
| 2  | Api Nampa Conservation Area                            | 23 | Khutiya  |
| 3  | Argha  | 24 | Koshi Tappu Wildlife Reserve and Koshi Barrage   |
| 4  | Banke National Park and Buffer Zone                    | 25 | Langtang National Park and Buffer Zone           |
| 5  | Bardiya National Park and Buffer Zone                  | 26 | Limi valley                                      |
| 6  | Barekot  | 27 | Madane Forest Conservation Area                  |
| 7  | Chitwan National Park and Buffer Zone                  | 28 | Mai Valley Forests                               |
| 8  | Dang Deukhuri Foothill Forests and West Rapti Wetlands | 29 | Makalu Barun National Park and Buffer Zone       |
| 9  | Devdaha  | 30 | Manaslu Conservation Area                        |
| 10 | Dhanusadham Protected Forest and Associated Farmlands  | 31 | Morang   |
| 11 | Dharan Forests   | 32 | Panchase Forest Conservation Area                |
| 12 | Dhorpatan Hunting Reserve                              | 33 | Parsa National Park and Buffer Zone              |
| 13 | Gadhi Siraichuli                                       | 34 | Phulchoki Mountain Forest                        |
| 14 | Gaurishankar Conservation Area                         | 35 | Rampur Valley                                    |
| 15 | Ghodaghodi Lake Area                                   | 36 | Rara National Park and Buffer Zone               |
| 16 | Jagdishpur Reservoir/Lumbini Farmlands                 | 37 | Reshunga Forest Conservation Area                |
| 17 | Janakinagar-Murtiya Forest and Associated Farmlands    | 38 | Sagarmatha National Park and Buffer Zone         |
| 18 | Kanchenjunga Conservation Area                         | 39 | Shey-Phoksundo National Park                     |
| 19 | Kapilvastu   | 40 | Shivapuri Nagarjun National Park and Buffer Zone |
| 20 | Khandbari - Num Forests                                | 41 | Shukla Phanta National Park and Buffer Zone      |
| 21 | Khaptad National Park and Buffer Zone                  | 42 | Triyuga Watershed                                |

Source: BCN, DNPWC & DOFSC (2024)

During the EIA survey (see sections: 'Fish, terrestrial ecosystem and riparian vegetation, wildlife'), available species should be categorized according to their conservation value in the national context (i.e. National Parks and Wildlife Conservation Act of 1973) and international context (i.e., IUCN Red List). Likely changes in biodiversity within the project's area of influence should be described adequately. In case of hydropower projects inside protected areas, the Working Policy on Construction and Operation of Physical Infrastructure in Protected Areas (2065 BS) shall be followed.

# 5.2 Biological corridors and connectivity

Biological corridors connect fragmented habitats that facilitate species movement and serve to maintain/increase species richness and diversity, increase population sizes of particular species and decrease probability of extinction, allow reestablishment of extinct local populations, and maintain genetic variation within populations (Christie and Knowles, 2015). Therefore, biological corridors are used as a conservation tool maintaining connectivity to other national and/or

cross-border reserves by establishing networks (Chaudhary and Subedi, 2019).

With regard to aquatic habitats, very little is known about fish migration route in the country. Migratory species follow the main river channel to spawn in upstream tributatries. Therefore, a telemetry method is applied to trace migratory fish species routes prior to consruction of hydropower projects. In an EIA survey, existing biological corridors and connectivity including likely effects of hydropower development on them should be properly mentioned in order to minimize the impacts on fish migration (see section 3.4), terrestrial ecosystesms (see section 3.6) and wildlife population (see section 3.7) (MoFE, 2018). Key species that follow the corridors should be mentioned in the EIA report.

# 5.3 Important Bird and Biodiversity Areas

Important bird and biodiversity area (IBA) are the area of global importance for the conservation of birds and biodiversity (Donald, 2019). To date more than 13,000 IBAs have been identified globally that includes (i) globally threatened species,

(ii) restricted range species (iii) bioregion-restricted assemblages, and (iv) congregatory species (Birdlife International, 2024). A total of 42 IBAs has been identified in Nepal, covering 28% of the Nepal's land area in addition of five potential IBAs included (BCN, DNPWC & DOFSC, 2024). Depending on the type of IBA, bird population trend of at least five years shall be analysed for the project's area of influence. Additionally, a detailed bird survey shall be carried out during EIA field visits (see section 3.7 'Birds'). The EIA should include an inventory of birds with their conservation status and the potential risks posed by the project, such as changes in bird population, alteration of habitats and shifting of nesting grounds.

#### 5.4 Important Plant Areas

Important Plant Areas (IPAs) are sites of high botanical importance, particularly with respect to threatened and/or endemic species, habitats and plant diversity (Anderson, 2002). IPAs include areas with one or more globally threatened species, exceptionally high species richness within defined habitat or vegetation type, and critical and/or threatened habitat or vegetation types (Darbyshire, et al., 2017).

In Nepal, 16 large IPA Complexes (based on river basins & mountain ranges), 54 Sites within the Complexes (equivalent to districts) and 230 micro-IPAs within the Sites (appropriate for community management) have been identified (Hamilton & Radford, 2007).

Some of the Nepal's IPAs are: Karnali (Sites: Humla, Mugu, Jumla, Kalikot, Dolpa), Narayani (Sites: Makawanpur, Bara), Terai Arc Landscape-Nepal (Sites: Kailali, Bardiya, Banke, Dang, Palpa, Nawalparasi, Chitwan, Parsa), Upper Bagmati (Dhading, Nuwakot, Rasuwa, Sindhupalchok), etc. Before starting a hydropower project, a thorough study should be conducted in the proposed project area to gather information on IPAs. An EIA shall provide a list of plant species that are endangered and/or threatened in the region or have high scientific and cultural values (Tables 46 and 47). The EIA shall further discuss likely impacts of the project within the area of influence and associated risks for existing important plants and/or vegetation.

National parks including Ramsar Sites have been created to protect wilderness and natural heritage. Development of hydropower projects near and/or inside protected areas would very likely have negative impacts on wildlife. Development of a hydropower project inside a national park should align with the provisions of the National Parks and Wildlife Conservation Act (1973), and National Parks and Wildlife Conservation Rules (1974).

#### 5.6 Keystone species

Keystone species are relatively rare species in a community whose removal severely impacts other species, triggers a significnt change in the composition of community and can even cause extinction of certain species (Krebs, 2014). Generally, keystone species are known to be more common in aquatic communities than in terrestrial communities (Krebs, 2014). Some keystone species that occur in Nepal's rivers are Gangetic River Dolphin and Mahseer (Shah et al., 2020; Poudyal et al., 2018; Shrestha, 2019). Keystone species are unevenly distributed across river basins. Keystone species in the potential area of influence shall be documented and listed along with their status in the IUCN Red List and the CITES Appendices. Their distributions are mapped across space and time with reference to known habitat.

#### **Data presentation**

Information on important habitats, which is also listed in the Hydropower EIA Manual (MoFE, 2018), shall be presented in a table. This should include keystone species within the area of influence, along with their status in the IUCN Red List and the CITES Appendices. Most of the information on important habitats shall be collected from exsiting literature while the list of species with their conservation values shall be prepared based on the EIA baseline survey.

Occurrence of important habitats within the project's area of influence should be presented through maps.

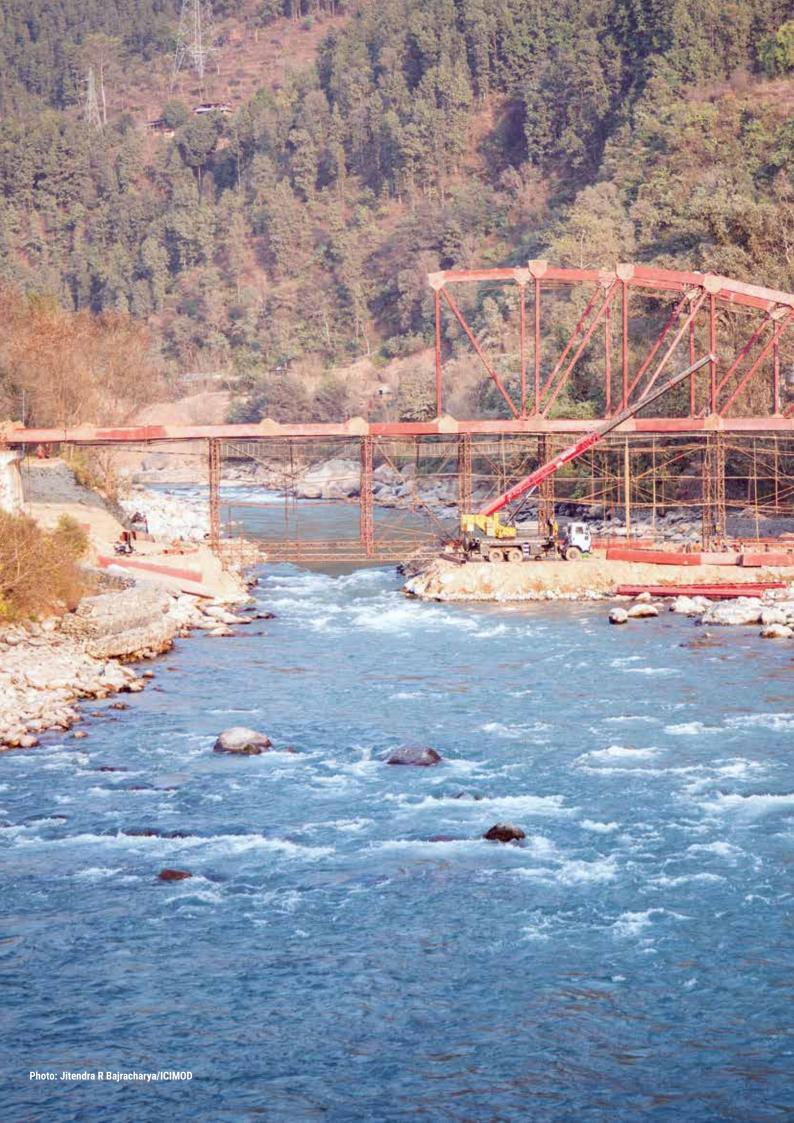
#### 5.5 Protected and conservation area

Table 46: List of parameters of important habitats within the project's area of influence. Here, P/A - Presence/ Absence; KS - Keystone species (Sample)

|                                 | Important habitats   | Con | trol sites | s above      | dam            |     | Diversion | on reach     |                | Downs | stream o | of power      | house          |
|---------------------------------|--|-----|------------|--------------|----------------|-----|-----------|--------------|----------------|-------|----------|---------------|----------------|
|                                 |  | P/A | KS         | IUCN Redlist | CITES appendix | P/A | KS        | IUCN Redlist | CITES appendix | P/A   | KS       | IUCN Red List | CITES appendix |
| Biodivers                       | sity hotspots (name)   |     |            |              |                |     |           |              |                |       |          |               |                |
| 1                               |  |     |            |              |                |     |           |              |                |       |          |               |                |
| 2                               |  |     |            |              |                |     |           |              |                |       |          |               |                |
| 3                               |  |     |            |              |                |     |           |              |                |       |          |               |                |
| Importar<br>stretches<br>(name) | nt aquatic habitats and river<br>s available for fish spawning |     |            |              |                |     |           |              |                |       |          |               |                |
| 1                               |  |     |            |              |                |     |           |              |                |       |          |               |                |
| 2                               |  |     |            |              |                |     |           |              |                |       |          |               |                |
| 3                               |  |     |            |              |                |     |           |              |                |       |          |               |                |
| Biologica<br>(name)             | al corridors and connectivity                                  |     |            |              |                |     |           |              |                |       |          |               |                |
| 1                               |  |     |            |              |                |     |           |              |                |       |          |               |                |
| 2                               |  |     |            |              |                |     |           |              |                |       |          |               |                |
| 3                               |  |     |            |              |                |     |           |              |                |       |          |               |                |
| Importar                        | nt Bird Area (name)  |     |            |              |                |     |           |              |                |       |          |               |                |
| 1                               |  |     |            |              |                |     |           |              |                |       |          |               |                |
| 2                               |  |     |            |              |                |     |           |              |                |       |          |               |                |
| 3                               |  |     |            |              |                |     |           |              |                |       |          |               |                |
| Importar                        | nt Plant Area (name)   |     |            |              |                |     |           |              |                |       |          |               |                |
| 1                               |  |     |            |              |                |     |           |              |                |       |          |               |                |
| 2                               |  |     |            |              |                |     |           |              |                |       |          |               |                |
| 3                               |  |     |            |              |                |     |           |              |                |       |          |               |                |
| Protecte                        | d/Conservation Area (name)                                     |     |            |              |                |     |           |              |                |       |          |               |                |
| 1                               |  |     |            |              |                |     |           |              |                |       |          |               |                |
| 2                               |  |     |            |              |                |     |           |              |                |       |          |               |                |
| 3                               |  |     |            |              |                |     |           |              |                |       |          |               |                |
|                                 |  |     |            |              |                |     |           |              |                |       |          |               |                |

Table 47: Documentation of IPAs in an area of influence

| Study parameter   | Control sites above dam | Diversion reach | Downstream of powerhouse |
|---|-------------------------|-----------------|--------------------------|
| Forest type   |                         |                 |                          |
| List of major plant species<br>(protected, endemic, non-timber forest products) |                         |                 |                          |
| List of IUCN Red List Species   |                         |                 |                          |
| List of species protected under CITES   |                         |                 |                          |
| List of ethnobotanically important plant species                                |                         |                 |                          |
| List of medicinal plants  |                         |                 |                          |
| If any others:  |                         |                 |                          |
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# 6. Ecosystem services

Ecosystem services (ES) refer to the multiple benefits - large and small, direct and indirect - that ecosystems provide to people (MEA, 2005). They play a crucial role in economic, environmental and social well-being, the three pillars of sustainable development (Chaudhary et al., 2018; UNDESA, 2015). River ecosystems provide a broad set of services for no cost in the form of provisioning, supporting, regulating and cultural benefits to human societies (GoN, 2012; MoFSC, 2014). Examples of services are - water for drinking and irrigation; habitat protection; fish as food supply and for recreational fishing and religious rituals; climate stability (MoFE, 2018b; MoFSC, 2014). Ecosystem services include both tangible (e.g., food, timber) and intangible benefits (flood protection, nutrient cycling, waste absorption, climate regulation, soil formation). Improving these ES can safeguard people's health and well-being and help mitigate impacts on livelihood and food security (Ding et al., 2017). However, hydropower projects affect these services, depriving communities of access to clean water for drinking, water for irrigation, fish for food, etc. A comprehensive assessment of environmental and social impacts needs to take ES into consideration. This would help stakeholders understand how a

project may affect important ES as well as how the project's success may depend on certain ES. In an EIA, baseline information should include ecosystem services available in the project's area of influence, and critical ecosystem services that need to be protected, along with their quality, quantity, use/importance to local people, and the availability of alternatives to such services (MoFE, 2018).

There are several methods of valuation and assessment for ecosystem services. The Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services (IPBES) states that different valuation methodologies are appropriate in different policy or decision-making contexts (IPBES, 2016). A 2013 report by the World Resource Institute, titled 'Weaving Ecosystem Services into Impact Assessment: A Step-by-Step Method' provides guidelines on the assessment of ecosystem services in the context of hydropower development (Landsberg et al., 2013). The report outlines six steps for assessing ecosystem services, which are summarized in Table 48.

The ES assessment should be conducted by an interdisciplinary team. The team may include forest, environment, social and other required experts. The team should first delineate the geographical

Table 48: Six steps for the assessment of ecosystem services

| SN | Steps  | Description   |
|----|--|---|
| 1  | Identify relevant ecosystem services   | Identify ecosystem services the project may impact and/or on which the project depends.   |
| 2  | Prioritize relevant ecosystem services   | Prioritize ecosystem services by identifying which of the relevant ecosystem services, if altered, could affect the livelihoods, health, safety, or culture of their beneficiaries or the operational performance of the project. Only priority ecosystem services are carried forward to subsequent steps. All projects that require an ESIA should at minimum undertake Steps 1 and 2 to determine whether any ecosystem services should be prioritized and assessed in the later stages of the ESIA. |
| 3  | Define the scope and information<br>needs of the ecosystem service<br>assessment             | Define the boundaries of and identify indicators for the assessment of impact and dependence assessments to clarify priority ecosystem services data and analysis requirements.   |
| 4  | Establish the baseline for priority ecosystem services                                       | Evaluate the condition of priority ecosystem services in the absence of the project.  |
| 5  | Assess project impacts and dependencies on priority ecosystem services                       | Predict the changes in priority ecosystem services during the life of the project.  |
| 6  | Mitigate impacts and manage<br>dependencies of the project on<br>priority ecosystem services | Identify measures to at least prevent loss of benefits people derive from ecosystems and to ensure planned operational performance where the project depends on ecosystem services.   |

Source: Landsberg, et. al., (2013)

boundaries that fit the needs of the project or the impacted community. Since the project impact depends on time scale, one should consider the type of impact during the EIA process (USAID, 2018).

The data can be generated through direct observation, focus group discussion (FGD), key

informant interview (KII), and household survey (HH). It is also important to specify the site within the project area (control sites including dam, diverted reach, and downstream of the powerhouse) in which the ecosystem services occur, mention the potential scale of impacts, and identify the beneficiaries of each service (Table 49).

**Table 49: Some examples of mitigation measures for impacts caused by hydro-morphological alterations** 

| Impacts                   | Mitigating measures  |
|---------------------------|--|
| Upstream fish migration   | By-pass channel; Fish pass; Catch, transport & release   |
| Downstream fish migration | By-pass channel; Fish pass; fish-friendly turbines   |
| Low flows                 | Optimize river morphology for available flow; determine environmental flows for the river using appropriate simulation model                             |
| Variable flows            | Establish variable discharge (magnitude, frequency, duration, timing and rate of change) as demanded for conserving natural faunal community composition |
| Hydropeaking              | Construct instream/external balancing reservoir; reduce hydropeaking rate; improve river morphology  |
| Impoundment               | Ensure river continuity (by-pass channel to provide additional flowing habitats); reduce storage level   |
| Temperature alteration    | Multiple intakes at different heights in reservoir dam; managing reservoir level   |

# 7. Assessing the impacts

The degree of impact on the biological community depends on the type and location of the proposed hydropower project (MoFE, 2018). Usually, the impacts include habitat fragmentation and degradation, sedimentation load, reduced river baseflow, reduced flow variability (especially reduced size and frequency of floods), poor water quality, land use transformation, geomorphological alteration, greenhouse gas emission from the reservoir, fragmentation of important ecological corridors caused by the reservoir, discontinuity in upstream-downstream river connectivity (Gracey and Verones, 2016). Once the hydropower project comes into operation, reduced river discharge downstream of the dam curtails people's access to drinking water and irrigation, increases erosion due to depletion of sediment load or potentially halts the movement of migratory fish due to the extension of the dewatered river stretch. Therefore, the EIA should describe the potential areas that will be impacted both before and after the construction of the hydropower project (MoFE, 2018).

#### Impact on biological components

#### TERRESTRIAL AND RIPARIAN ECOSYSTEMS

The EIA should assess the likely impacts of the proposed hydropower project on the ecosystems and their biota. It should quantify the extent of vegetation removal, habitat loss, impact on distribution and abundance of species including any important species on the IUCN Red List (EN, CE, T, NT) and the CITES Appendices, and identify threats to all species and habitats within the area of influence. The assessment should clearly indicate the threat of the proposed project and whether the species are likely to become extinct in the area of

influence or the potential changes in their overall conservation status.

Similarly the proportion of change in the community structure should also be indicated in the assessment report. In case of assessment of forest loss, prescribed procedures by the Ministry shall be followed.

#### IMPACT ON AQUATIC FLORA AND FAUNA

The assessment should evaluate the impact of the proposed hydropower project on specific aquatic flora and fauna within the project's area of influence. Hydropower projects usually alter instream river substrates and flow regimes across space and time. Changes in water quality parameters, in particular water temperature, pH, conductivity, alkalinity, etc. induced by modification of flow regimes should be measured and their effects on aquatic flora and fauna should be assessed.

#### IMPACT ON ECOSYSTEM SERVICES

The EIA should assess the impact of hydropower projects on various types of ecosystem services. Poor water quality and nutrient enrichment due to low river discharge downstream of the dam, and reduced availability of water for domestic, irrigation and industrial purposes, and for cultural and ritual activities are some of the major potential impacts of construction and operation of a hydropower project. Hence, assessment should include both qualitative and quantitative evaluation of services.

A detailed assessment of ecosystem services should follow section 8.5 (Chapter 8) of the Hydropower EIA Manual 2018 (MoFE, 2018).



# 8. Managing impacts

Impacts of hydropower development are diverse and may vary depending on the project type and size, and the sensitivity of the project site. In Nepal, majority of hydropower projects are run-of-river projects with very small inundation areas, and their impact may be less severe than that of large dams. However, aquatic ecosystems and aquatic life are still impacted by changes in river flows and river fragmentation. The ponding effect changes the character of the river (by reducing flow velocity and altering sediment structure, temperature and dissolved oxygen) and lateral connectivity; and the dam acts as a migration barrier; screens/turbines damage fish. The dam also absorbs floods, reducing the size and frequency of floods downstream of the dam and spoiling the habitat (reduced flow, flow pulses, sediment deficits/ flushing).

Run-of-river hydropower projects have relatively small terrestrial footprints and impacts on surrounding environments compared to large dams. However, they have potentially large impacts on aquatic biodiversity as they affect river connectivity, especially when they are built in cascades. The weir/dam acts as a barrier to fish migration and sediment transport. The reduced water flow between intake and tailrace affects river and riparian ecology, if constructed as a diversion scheme.

Reservoir (storage) hydropower projects alter the natural environment by impoundment, resulting in impacts on both terrestrial and aquatic ecosystems and biodiversity. The dam acts as a barrier for fish

migration, flood waters and sediment transport. Significant modification of volume and seasonal patterns of downstream river flows has large impacts on river ecology along the stretch immediately downstream of the dam during ramp-up and ramp-down. Changes also occur in water temperature and quality. The hydroelectric reservoir may add greenhouse gas concentrations to the atmosphere due to the emissions caused by the decomposition of organic matter (Deemer et al., 2016).

Mitigation measures (preventative, compensatory and corrective measures) should be adopted to reduce, avoid, or offset the potential adverse impacts of the proposed hydropower project (Khadka et. al., 2013). Impact management should be carried out according to the mitigation hierarchy, which involves enhancement of beneficial impacts, and avoidance, minimization and/or compensation for adverse impacts (MoFE, 2018). Detailed steps for managing impacts are provided in the Hydropower Environmental Impact Assessment Manual 2018.

Proposed mitigation measures should take the pressure on hydrological changes and ecological impacts into consideration. Some examples are given in Table 49. Mitigation measures should be specific to impacts such as impaired river continuity for fish migration (both upstream and downstream), low flow downstream of the dam, flow pulses downstream of the tailrace relating to hydropeaking, interrupted sediment movement, temperature, etc.



# 9. Reporting

The detailed results of the initial natural values assessment shall be documented in an EIA report to inform the project approval process. The Environment Protection Rules (2020) provides an annotated template which should form the structure of the IEE (Schedule 11)/EIA (Schedule 12) Report. Information requirements for the IEE/

EIA report are summarized in Table 50. All the components discussed in this handbook shall be duly considered and addressed in the IEE/EIA report. Also, follow Table 15 (p. 38) of the Hydropower Environmental Impact Assessment Manual 2018.

Table 50: Information requirements of the IEE/EIA report

| Content   | Minimum information requirements   |
|---|--|
| Name of experts/institutions preparing the report                                 | Mention the names of experts and research assistants with their academic qualifications and experience in the relative field for the respective theme (Hydrology, Micro-biota, Periphyton, Benthic macroinvertebrates, Fish, Macrophytes, Riparian vegetation, etc.)   |
| Procedures adopted for preparing the report                                       | <ul> <li>Literature review, field study and consultations with scientific experts</li> <li>Define the EIA aquatic study area based on the ecology of the area (with an explanation of how they are relevant for the EIAs)</li> <li>Baseline data checklist/questionnaire</li> <li>Field study methodology (Study area and distribution of sampling sites, sample collection method for each study theme)</li> <li>Laboratory analysis method</li> <li>Data analysis</li> </ul>   |
| Existing environmental condition prior to project construction                    | <ul> <li>Physical and chemical environment</li> <li>Biological environment</li> <li>Present a list of species from each taxonomic group for each impact zone within the influence area of the hydropower project</li> <li>Present a fish species list separately and in combined form for each method used</li> <li>Identify and list all habitat types within the project area that may be of ecological, cultural, religious importance and/or provide ecosystem services</li> <li>Present a list of all species with high conservation value, which may include but are not limited to:</li> <li>IUCN Red List - Critically Endangered, Endangered or Vulnerable species</li> <li>Species on the national list of Endangered or Threatened species</li> <li>Endemic or restricted range species, Migratory species</li> <li>Species of cultural or religious importance (e.g., sacred forests)</li> <li>Species that are important for ecosystem functioning (e.g., keystone species)</li> <li>Species that provide ecosystem services to people (e.g., pollinators)</li> </ul> |
| Likely impacts of the project on the environment and proposed protection measures | <ul> <li>Physical and chemical environment</li> <li>Biological environment</li> <li>Physical, chemical and biological parameters should be monitored regularly and reported annually.</li> </ul>   |



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# **Annexes**

# Annex 1: Rapid River Assessment (RRA) Protocol for assessing the river quality status in Mountain region

| River:  | n:          |               | Date/Time:             |                |                   |          |
|---|-------------|---------------|------------------------|----------------|-------------------|----------|
| Site & village:                                 | N:          |               |                        | Surveyor:      |                   |          |
| Temperature water:                              | E:          |               |                        | Altitude (m):  |                   |          |
| pH:   | Conductivit | y:            | 0 <sub>2</sub> (mg/l): |                | O <sub>2</sub> %: |          |
|   |             |               |                        |                |                   |          |
| DECISION SUPPORT TABLE                          |             |               | WATER QUALI            |                |                   |          |
| Multiple choices possible                       |             | I             | II                     | Ш              | IV                | V        |
| Sensory features                                |             | To be ticked, | counted if not it      | n accordance w | ith natural river | type     |
| Non natural turbidity, Suspended solids         |             |               |                        | +              | +                 | ++       |
| Non natural colour                              |             |               | +                      | +              | +                 | ++       |
| Foam  |             |               | +                      | +              | ++                | ++       |
| Odour (water)                                   |             |               | +                      | ++             | ++                | ++       |
| Waste dumping                                   |             |               | +                      | +              | ++                | ++       |
| Ferro-sulphide reduction – (water velocity < 0. | 25 m/s)     | -             |                        |                |                   |          |
| Lower surface of stones (% cover black dots)    |             |               | < 25 %                 | 25-75 %        | 75-100 %          | 100 %    |
| Upper & lower surfaces of stones (% cov. bl     | ack dots)   |               |                        |                | +                 | ++       |
| Ferro-sulphide reduction – (water vel.) 0.25-0. | 75 m/s)     | -             | -                      |                |                   |          |
| Lower surface of stones (% cover black dots)    |             |               |                        | < 50 %         | 50-100 %          | 100 %    |
| Upper & lower surfaces of stones                |             |               |                        |                |                   | +++      |
| Bacteria, fungi, periphyton                     |             |               |                        |                |                   |          |
| Sewage fungi & bacteria (visible to the nake    | ed eyes)    | (-)           | (-)                    | few            | medium            | many +++ |
| Stones with algal vegetation (periphyton) in    | thin layers | ++            | ++                     |                |                   |          |
| % of thick, significant layers of algae         |             | < 25 %        | 25-75 %                | 75-100 %       | 75-100 %          |          |
| Filamentous green algae                         |             | none tofew    | filaments,<br>tufts    | large tufts    | (large) tufts     | Few      |
| Benthic macroinvertebrates                      |             |               |                        |                |                   |          |
| Species richness                                |             | 16-19         | ≥ 20                   | 9-15           | 5-8               | < 5      |
| Dominance of very sensitive organisms (9 to     | o 10)*      | +++           |                        |                |                   |          |
| Dominance of sensitive organisms (7 to 8)*      |             | +             | +++                    | +              |                   |          |
| Dominance of medium tolerant organisms (        | (5 to 6)*   |               |                        | +++            | +                 |          |

#### **DECISION SUPPORT TABLE**

#### WATER QUALITY CLASSES

| Dominance of tolerant organisms (3 to 4)*                     |          |                  |                  | +                | +++             | +         |
|---|----------|------------------|------------------|------------------|-----------------|-----------|
| Dominance of extremely tolerant organisms (1                  | 1 to 2)* |                  |                  |                  |                 | +++       |
| Baetidae- different types                                     |          | 3 or more        | 2 or 3           | 1 or 2           | 1               |           |
| Heptageniidae (Rhithrogena spp.)                              |          | +++              | ++               |                  |                 |           |
| Heptageniidae (Iron spp.)                                     |          | ++               | +++              |                  |                 |           |
| Perlidae  |          | ++               | +                |                  |                 |           |
| Plecoptera  |          | ++               | +                |                  |                 |           |
| Ephemerellidae  |          | +                | ++               | +                |                 |           |
| Rhyacophilidae  |          | +++              | ++               | +                |                 |           |
| Stenopsychidae  |          | +                | ++               |                  |                 |           |
| Hydropsychide (Except <i>Hydropsyche</i> spp. medium to many) |          |                  | +                | +++              | +               |           |
| Elmidae   |          | +                | ++               | +                |                 |           |
| Psephenidae   |          | +                | ++               | ++               |                 |           |
| Euphaeidae  |          | ++               | +                |                  |                 |           |
| Simuliidae  |          | +                | ++               | ++               |                 |           |
| Tabanidae   |          |                  | +                | ++               | ++              |           |
| Bezzia-Group  |          |                  |                  |                  | +               | ++        |
| Chironomidae (with red colour)                                |          |                  | very few         | few              | medium          | +++many** |
| Psychodidae white   |          |                  |                  |                  | +               | +++       |
| Potamidae   |          | +                | ++               | ++               |                 |           |
| Leeches (more than naturally occurring)                       |          | -                | -                | +                | +++             | +         |
| Air-breathing animals, e. g. rat-tail maggots                 |          |                  |                  |                  |                 | +++       |
| Oligochaeta /Tubificidae (mud-worms)                          |          | 0 to very<br>few | few              | few/medium       | medium/<br>many | many**    |
| Physidae (medium to many)                                     |          |                  |                  | +                | ++              |           |
| Planorbidae   |          |                  | ++               | +++              | +               |           |
| Sum of columns  |          |                  |                  |                  |                 |           |
| * check scores in the taxa list on the back page              | 9        | ** abundance     | s may decline to | o 0 if oxygen de | pletes          |           |

| TAXON                                  | TSS | Abd | TAXON                        | TSS | Abd | TAXON              | TSS | Abd |
|--|-----|-----|------------------------------|-----|-----|--------------------|-----|-----|
| Order: Ephemeroptera                   |     |     | Hydroptilidae                | 10  |     | Order: Odonata     |     |     |
| Baetidae                               | 6   |     | Hydrobiosidae                | 10  |     | Gomphidae          | 4   |     |
| Caenidae                               | 4   |     | Ecnomidae                    | 6   |     | Libellulidae       | 5   |     |
| Ephemerellidae                         | 7   |     | Order: Coleoptera            |     |     | Calopterygidae     | 4   |     |
| Ephemerellidae ( <i>Drunel</i> . sp.)  | 10  |     | Hydraenidae                  | 7   |     | Chlorocyphidae     | 5   |     |
| Ephemeridae                            | 6   |     | Hydraenidae (Ochthebius sp.) | 10  |     | Chloroperlidae     | 9   |     |
| Heptageniidae                          | 7   |     | Hydrometridae                | 8   |     | Coenagrionidae     | 5   |     |
| Heptageniidae ( <i>Epeorus</i><br>sp.) | 8   |     | Hydrophilidae                | 6   |     | Corduliidae        | 5   |     |
| Heptageniidae ( <i>Iron</i> sp.)       | 8   |     | Gyrinidae                    | 6   |     | Epiophlebiidae     | 10  |     |
| Hept. (Rhithrogena sp.)                | 9   |     | Dryopidae                    | 5   |     | Euphaeidae         | 8   |     |
| Leptophlebiidae                        | 7   |     | Dytiscidae                   | 4   |     | Protoneuridae      | 5   |     |
| Neoephemeridae                         | 9   |     | Elmidae                      | 8   |     | Order: Megaloptera |     |     |
| Siphlonuridae                          | 10  |     | Psephenidae                  | 7   |     | Corydalidae        | 6   |     |
| Order: Plecoptera                      |     |     | Scirtidae                    | 10  |     | Order: Decapoda    |     |     |
| Nemouridae                             | 9   |     | Noteridae                    | 4   |     | Potamidae          | 7   |     |
| Perlidae                               | 8   |     | Order: Hemiptera             |     |     | Palaemonidae       | 4   |     |
| Perlodidae                             | 9   |     | Ranatridae                   | 4   |     | Order: Tricladida  |     |     |
| Peltoperlidae                          | 10  |     | Gerridae                     | 4   |     | Planariidae        | 9   |     |
| Taeniopterygidae                       | 10  |     | Notonectidae                 | 3   |     | Class: Oligochaeta |     |     |
| Leuctridae                             | 10  |     | Naucoridae                   | 4   |     | Tubificidae        | 1   |     |
| Capniidae                              | 10  |     | Nepidae                      | 4   |     | Class: Clitellata  |     |     |
| Order: Trichoptera                     |     |     | Micronecta                   | 4   |     | Salifidae          | 3   |     |
| Limnocentropodidae                     | 9   |     | Aphelocheiridae              | 7   |     | Class: Mollusca    |     |     |
| Philopotamidae                         | 7   |     | Corixidae                    | 4   |     | Physidae           | 2   |     |
| Odontoceridae                          | 5   |     | Veliidae                     | 5   |     | Corbiculidae       | 4   |     |
| Brachycentridae                        | 7   |     |                              |     |     | Planorbidae        | 4   |     |
| Glossosomatidae                        | 7   |     | Order: Diptera               |     |     | Pleuroceridae      | 4   |     |
| Goeridae                               | 9   |     | Culicidae                    | 2   |     | Lymnaeidae         | 6   |     |
| Lepidostomatidae                       | 7   |     | Tabanidae                    | 2   |     | Bithyniidae        | 5   |     |
| Leptoceridae                           | 6   |     | Stratiomyidae                | 5   |     | Sphaeriidae        | 5   |     |
| Limnephilidae                          | 9   |     | Tipulidae                    | 8   |     | Thiaridae          | 4   |     |
| Glossiphoniidae                        | 4   |     | Simuliidae                   | 7   |     |                    |     |     |
| Helicopsychidae                        | 10  |     | Athericidae                  | 10  |     |                    |     |     |
| Rhyacophilidae                         | 8   |     | Muscidae                     | 2   |     |                    |     |     |
| Psychomyiidae                          | 6   |     | Limoniidae                   | 8   |     |                    |     |     |
| Stenopsychidae                         | 8   |     | Psychodidae (white)          | 1   |     |                    |     |     |
| Polycentropodidae                      | 7   |     | Bezzia-Group                 | 2   |     |                    |     |     |
| Hydropsychidae                         | 4   |     | Blephariceridae              | 10  |     |                    |     |     |
| Uenoidae                               | 9   |     | Chironomidae red             | 1   |     |                    |     |     |
|  |     |     | Chironomidae not red         | 5   |     |                    |     |     |

### **Annex 2: Physical Habitat Assessment Protocol**

(Modified from Clapcott, 2015)

| Site Information                              |           |  |                                |  |           |                  |           |   |         |                         |       |  |
|---|-----------|--|--------------------------------|--|-----------|------------------|-----------|---|---------|-------------------------|-------|--|
| River name:                                   |           | Site co  | de:                            | Dat  | e:        | •••••            |           | Time                                    | e:      |                         |       |  |
| Non vegetated width (Left): m Non             |           |  | Non vegetated width (Right): m |  |           |                  |           | Bank alterations: Embankment ☐ Yes ☐ No |         |                         |       |  |
| Habitat Assessment Score                      |           |  |                                |  |           |                  |           |   |         |                         |       |  |
| Habitat parameter                             | Condition | Condition category (Visual estimation except no. 10) |                                |  |           |                  |           |   |         |                         | Score |  |
| 1. Deposited                                  | The perce | entage of the ri                                     | verbe                          | ed covered by fine   | sedimer   | nt               |           | 1                                       |         |                         |       |  |
| sediment                                      | 0         | 5  | 10                             | 15   | 20        | 30               | 40        | 50                                      | 60      | ≥60                     |       |  |
| Score   | 10        | 9  | 8                              | 7  | 6         | 5                | 4         | 3                                       | 2       | 1                       |       |  |
| 2.Substrate<br>embeddedness and<br>compaction |           | entage of riverbedded and                            | Slig                           | ubstrates emdedd<br>htly embedded<br>I mostly loose,<br>e compaction | Firmly    | embed<br>oderate | ded       | Heavil<br>tightly                       | •       | edded and<br>ed<br>> 80 |       |  |
| Score   | 10        | 9  | 8                              | 7  | 6         | 5                | 4         | 3                                       | 2       | 1                       |       |  |
|   |           | -  | -                              | •  | -         |                  | ļ ·       |   | _       | -                       |       |  |
| 3.Macroinvertebrate habitat diversity         |           |  |                                | trate types such a<br>phyton. Presence o                             |           |                  |           |   |         | ou, leaves,             |       |  |
|   | < 5       | 5  | 5                              | 4  | 4         | 3                | 3         | 2                                       | 2       | 1                       |       |  |
| Score   | 10        | 9  | 8                              | 7  | 6         | 5                | 4         | 3                                       | 2       | 1                       |       |  |
| 4. Macroinvertebrate habitat abundance        | The perce | entage of subs<br>clear of filamen                   | trate<br>tous                  | favourable for EPT<br>algae/macrophyte                               | colonis   | ation, e         | .g., flow | ing wat                                 | er over | gravel-                 |       |  |
|   | 95        | 75   | 70                             | 60   | 50        | 40               | 30        | 25                                      | 15      | 5                       |       |  |
| Score   | 10        | 9  | 8                              | 7  | 6         | 5                | 4         | 3                                       | 2       | 1                       |       |  |
| 5. Fish cover diversity                       | encroach  |  | mac                            | trate types such a<br>rophytes, boulders                             |           |                  |           |   |         |                         |       |  |
|   | <5        | 5  | 5                              | 4  | 4         | 3                | 3         | 2                                       | 2       | 1                       |       |  |
| Score   | 10        | 9  | 8                              | 7  | 6         | 5                | 4         | 3                                       | 2       | 1                       |       |  |
| 6. Fish cover abundance                       | The perce | entage of fish o                                     | over                           | available.   |           |                  |           |   |         |                         |       |  |
| abulidance                                    | 95        | 75   | 60                             | 50   | 40        | 30               | 20        | 10                                      | 5       | 0                       |       |  |
| Score   | 10        | 9  | 8                              | 7  | 6         | 5                | 4         | 3                                       | 2       | 1                       |       |  |
| 7. Hydraulic hetereogeneity                   |           |  |                                | nponents such as p<br>liter. Presence of de                          |           |                  |           | / run, ra <sub>l</sub>                  | pid, ca | scade/                  |       |  |
|   | <5        | 5  | 4                              | 4  | 3         | 3                | 2         | 2                                       | 2       | 1                       |       |  |
| Score   | 10        | 9  | 8                              | 7  | 6         | 5                | 4         | 3                                       | 2       | 1                       |       |  |
| 8. Bank Erosion                               |           | entage of the ri<br>of the bank or                   |                                | ank recently/active<br>k pugging.                                    | ely erodi | ng due           | to scoul  | ring at t                               | he wat  | er line,                |       |  |
| Left bank                                     | 0         | < 5  | 5                              | 15   | 25        | 35               | 50        | 65                                      | 75      | > 75                    |       |  |
| Score   | 10        | 9  | 8                              | 7  | 6         | 5                | 4         | 3                                       | 2       | 1                       |       |  |
| Right bank                                    | 0         | < 5  | 5                              | 15   | 25        | 35               | 50        | 65                                      | 75      | > 75                    |       |  |
| Score   | 10        | 9  | 8                              | 7  | 6         | 5                | 4         | 3                                       | 2       | 1                       |       |  |
| Average score (Left and Right banks)          | 10        | 9  | 8                              | 7  | 6         | 5                | 4         | 3                                       | 2       | 1                       |       |  |

| 9. Bank vegetation                   | The matu   | The maturity, diversity and naturalness of bank vegetation. |  |  |  |  |          |   |        |        |
|--------------------------------------|--|---|--|--|--|--|----------|---|--------|--------|
| Left bank                            | Mature native<br>trees with diverse and<br>intact mature shrubs,<br>sparse tree<br>understorey |   | Regenerating native<br>or<br>flaxes/sedges/<br>tussock > dense<br>exotic |  | Mature shrubs,<br>sparse tree<br>cover > young<br>exotic, long grass |  |          | Heavily grazed or bare/<br>impervious ground. |        |        |
| Score                                | 10   | 9   | 8  | 7  | 6  | 5  | 4        | 3   | 2      | 1      |
| Right bank                           | Mature native<br>trees with diverse and<br>intact mature shrubs,<br>sparse tree<br>understorey |   | or<br>flax<br>tus  | Regenerating native<br>or<br>flaxes/sedges/<br>tussock > dense<br>exotic |  | Mature shrubs,<br>sparse tree<br>cover > young<br>exotic, long grass |          | Heavily grazed or bare/<br>impervious ground. |        |        |
| Score                                | 10   | 9   | 8  | 7  | 6  | 5  | 4        | 3   | 2      | 1      |
| Average score (Left and Right banks) | 10   | 9   | 8  | 7  | 6  | 5  | 4        | 3   | 2      | 1      |
| 10. Riparian width                   | The width  | (m) of the ripa   | arian  | buffer constrained   | by vege  | etation,   | fence or | other s                                       | tructu | re(s). |
| Left bank                            | ≥ 30   | 15  | 10   | 7  | 5  | 4  | 3        | 2   | 1      | 0      |
| Score                                | 10   | 9   | 8  | 7  | 6  | 5  | 4        | 3   | 2      | 1      |
| Right bank                           | ≥ 30   | 15  | 10   | 7  | 5  | 4  | 3        | 2   | 1      | 0      |
| Score                                | 10   | 9   | 8  | 7  | 6  | 5  | 4        | 3   | 2      | 1      |
| Average score (Left and Right banks) | 10   | 9   | 8  | 7  | 6  | 5  | 4        | 3   | 2      | 1      |
| Total Score                          |  |   |  |  |  |  |          |   |        |        |

#### **Total Score**

Sketch of the river reach

## Annex 3: Measurement of water quality parameters for reservoir samples

| Site information                        |                   |                        |       |    |
|---|-------------------|------------------------|-------|----|
| River name: Site of                     | ode: Date         | э:                     | Time: |    |
| Length of reservoir (m):                |                   | Width of reservoir (m) | ):    |    |
| Site features                           |                   |                        |       |    |
| Sites/parameters                        | X1                | X2                     | Х3    | X4 |
| Water temperature ( °C)                 |                   |                        |       |    |
| Conductivity (µS/cm)                    |                   |                        |       |    |
| DO (mg/L)                               |                   |                        |       |    |
| DO (% saturation)                       |                   |                        |       |    |
| Turbidity (NTU)                         |                   |                        |       |    |
| Tota Nitrogen (mg/L)                    |                   |                        |       |    |
| Total Phosphorus (mg/L)                 |                   |                        |       |    |
| Secchi depth (m)                        |                   |                        |       |    |
| Depth (m)                               |                   |                        |       |    |
| Sketch of a reservoir with distribution | of sampling sites |                        |       |    |
|   |                   |                        |       |    |
|   |                   |                        |       |    |
|   |                   |                        |       |    |
|   |                   |                        |       |    |

## Annex 4: List of phytoplankton commonly found in the rivers of Nepal

| Class   | Genus   |  |  |  |  |  |
|---|---|--|--|--|--|--|
| Chlorophyceae   | Actinastrum, Ankistrodesmus, Chlorella, Chlamydomonas, Cladophora, Closteridium, Coelestrum, Closterium, Cosmarium, Draparnaldia, Gonatozygon, Hydrodictyon, Microspora, Mougeotia, Oedogonium, Pediastrum, Desmidium, Scenedesmus, Spirogyra, Tetraspora, Ulothrix, Volvox, Zygnema. |  |  |  |  |  |
| Cyanophyceae  | Aphanizomenon, Anabena, Gomphosphaeria, Nodularia, Nostoc, Oscillatoria, Merismopedia, Microcystis, Spirulina, Rivularia.   |  |  |  |  |  |
| Bacillariophyceae   | Achnanthes, Amphora, Asterionella, Cocconies, Cyclotella, Cymbella, Diatoms, Diatoma, Epithemia, Fragillaria, Gomphonema, Gyrosigma, Melosiragranulate, Navicula, Nitzschia, Synedra, Tabellaria  |  |  |  |  |  |
| Dinophyceae   | Ceratium  |  |  |  |  |  |
| Xanthophyceae   | Tribonema   |  |  |  |  |  |
| Euglenophyceae  | Euglena, Peridium   |  |  |  |  |  |
| Sources: Malik and Bharti, 2012; Mahaseth, 2017; Mehta and Kushwaha, 2016 |   |  |  |  |  |  |

## Annex 5: List of zooplankton commonly present in rivers

| Class       | Genus  |
|-------------|--|
| Crustacea   | Cyclops spp., Cyprus spp., Diaphanosoma spp., Daphnia spp., Diaptomus spp. |
| Eurotatoria | Asplanchna spp., Keratella spp.  |
| Monogononta | Brachionus spp.  |

## Annex 6: List of native fish in the 'threatened' category.

| Order          | Family         | Latin name  | Local name                               | IUCN |
|----------------|----------------|---|--|------|
| Anguilliformes | Anguillidae    | Anguilla bengalensis (Gray, 1831)                 | Raj Bam, Rem                             | NT   |
|                |                | Neoanguilla nepalensis (Shrestha, 2008)           |  | NE   |
|                | Moringuidae    | Moringua raitaborua (Hamilton,1822)               | Bam                                      | NE   |
| Beloniformes   | Hemirhamphidae | Hyporhamphus limbatus (Valenciennes, 1847)        |  | LC   |
|                | Belonidae      | Xenentodon cancila (Hamilton, 1822)               | Kauwa machha, Chuchhe bam,<br>Kabai, Sui | LC   |
| Clupeiformes   | Clupeidae      | Gudusia chapra (Hamilton, 1822)                   | Suiya, Suia                              | LC   |
|                |                | Gudusia variegata (Day, 1870)                     | Suiya, Suia                              | LC   |
|                | Engraulidae    | Setipinna phasa (Hamilton, 1822)                  | Gankabau, Phasi                          | LC   |
| Cypriniformes  | Cyprinidae     | Bangana dero (Hamilton, 1822)                     | Gardi, Gurdi, Bangsa, Kalabans           | LC   |
|                |                | Bangana ariza (Hamilton, 1807)                    | Rewa                                     | LC   |
|                |                | Chagunius chagunio (Hamilton, 1822)               | Patharchatti, Kasree, Chaguni, Rewa      | LC   |
|                |                | Cirrhinus mrigala (Hamilton, 1822)                | Mrigal, Naini                            | LC   |
|                |                | Cirrhinus reba (Hamilton, 1822)                   | Mrigal, Rewa                             | LC   |
|                |                | Crossocheilus latius (Hamilton, 1822)             | Dhurla, Gauma, Mate Buduna, Lohari       | LC   |
|                |                | Cyprinion semiplotum (McClelland, 1839)           | Chepti, Khurpe                           | VU   |
|                |                | Gibelion catla (Hamilton, 1822)                   | Bhakur, Catla, Vakur                     | LC   |
|                |                | Labeo angra (Hamilton, 1822)                      | Thed, Kalanch, Thaid                     | LC   |
|                |                | Labeo bata (Hamilton, 1822)                       | Bata, Rohu                               | LC   |
|                |                | Labeo boga (Hamilton, 1822)                       | Boga, Tikauli                            | LC   |
|                |                | Labeo caeruleus (Day, 1877)                       | Bishari, Roi                             | NE   |
|                |                | Labeo calbasu (Hamilton, 1822)                    | Kalonch, Kalbasu, Karnoch                | LC   |
|                |                | Labeo dyocheilus (McClelland, 1839)               | Kalanch, Gardi, Gurdi                    | LC   |
|                |                | Labeo fimbriatus (Bloch, 1795)                    | Boi, Gurdi                               | LC   |
|                |                | Labeo gonius (Hamilton, 1822)                     | Kursa, Karsa, Gurdi                      | LC   |
|                |                | Labeo pangusia (Hamilton,1822)                    | Kalaacha, Termassa                       | NT   |
|                |                | Labeo rohita (Hamilton, 1822)                     | Rohu                                     | LC   |
|                |                | Neolissochilus hexagonolepis<br>(McCelland, 1839) | Katle, Vadalke                           | NT   |
|                |                | Oreichthys cosuatis (Skyes, 1939)                 | Patharchatti                             | LC   |
|                |                | Osteobrama cotio (Hamilton, 1822)                 | Gurda                                    | LC   |
|                |                | Osteobrama neilli (Day, 1873)                     | Gurda                                    | LC   |
|                |                | Pethia conchonius (Hamilton, 1822)                | Pothi, Sidre, Pothia Sidre               | LC   |
|                |                | Pethia gelius (Hamilton, 1822)                    | Pothi                                    | LC   |
|                |                | Pethia guganio (Hamilton, 1822)                   | Tilke Pothi                              | LC   |
|                |                | Pethia phutunio (Hamilton, 1822)                  | Pothi                                    | LC   |

| Order | Family | Latin name                                 | Local name   | IUC |
|-------|--------|--|--|-----|
|       |        | Puntius chola (Hamilton, 1822)             | Sidhre, Pothiya  | LC  |
|       |        | Puntius sophore (Hamilton, 1822)           | Pothi,Pate Sidhra, Chanda pothi                          | LC  |
|       |        | Puntius terio (Hamilton, 1822)             | Pothi  | LC  |
|       |        | Puntius ticto (Hamilton, 1822)             | Tite Pothi, Sidre  | LC  |
|       |        | Systomus clavatus (McCelland, 1839)        | Bada Pothi, Pothia                                       | NT  |
|       |        | Systomus sarana (Hamilton,1822)            | Thub Pothi, Kande, Bhitte, Bada<br>Pothi, Thulo pothi    | LC  |
|       |        | Schismatorhynchus nukta (Hamilton, 1822)   |  | EN  |
|       |        | Semiplotus modestus (Day, 1870)            |  | DD  |
|       |        | Tor chelyniodes (McClelland, 1845)         | Karange, Halude  | VU  |
|       |        | Tor mosal (Hamilton, 1822)                 | Mahseer, Ratar   | NE  |
|       |        | Tor putitora (Hamilton, 1822)              | Sahar/Mahaseer, Pahale Mahseer,<br>Mansar/Ratar          | EN  |
|       |        | Tor tor (Hamilton, 1822)                   | Sahar, Falame Sahar                                      | DD  |
|       |        | Chela cachius (Hamilton, 1822)             | Chane  | LC  |
|       |        | Laubuka laubuca (Hamilton, 1822)           | Chalwa, Deduwa,  | LC  |
|       |        | Salmostoma acinaces (Valenciennes, 1844)   | Nam sehara   | LC  |
|       |        | Salmostoma bacaila (Hamilton, 1822)        | Chelwa, Chela, Darai, Galphulani                         | LC  |
|       |        | Salmostoma phulo (Hamilton, 1822)          |  | LC  |
|       |        | Securicula gora (Hamilton, 1822)           | Gora-Chela, Chilwa, Dariai                               | LC  |
|       |        | Amblyphryngodon microlepis (Bleeker, 1853) | Mada, Dhawai   | LC  |
|       |        | Amblyphryngodon mola (Hamilton, 1822)      | Mada, Dhawai   | LC  |
|       |        | Aspidoparia jaya (Hamilton, 1822)          |  | LC  |
|       |        | Cabdio morar (Hamilton, 1822)              | Chakale, Bhegna, Harda, Karangi                          | LC  |
|       |        | Barilius barila (Hamilton, 1822)           | Faketa, Chahale, Karo                                    | LC  |
|       |        | Barilius bendelisis (Hamilton, 1822)       | Chiple Faketa, Gurdere, Khasree,<br>Chala, Gudari,Gudasi | LC  |
|       |        | Barilius modestus (Day, 1872)              | Chiple faketa  | NE  |
|       |        | Barilius radiolatus (Gunther, 1868)        | Chala, Faketa  | DD  |
|       |        | Barilius shacra (Hamilton,1822)            | Fakate   | LC  |
|       |        | Barilius vagra (Hamilton,1822)             | Lam Faketa, Fakate                                       | LC  |
|       |        | Opsarius barna (Hamilton,1822)             | Putti, Faketa, Pati, Pattaure,<br>Titerkane, Faketa      | LC  |
|       |        | Opsarius tileo (Hamilton,1822)             | Faketa, Goha   | LC  |
|       |        | Danio rerio (Hamilton, 1822)               | Zebra machha, Bhitte machha,<br>Chitharpothi             | LC  |
|       |        | Devario aequipinnatus (McClelland, 1839)   | Bhitti, Chitharpothi                                     | DD  |
|       |        | Danio dangila (Hamilton, 1822)             | Nepti, Pothi   | LC  |
|       |        | Devario devario (Hamilton, 1822)           | Chithari pothi, Bhitti                                   | LC  |
|       |        | Esomus danrica (Hamilton, 1822)            | Dedhawa, Darai   | LC  |
|       |        | Megarasbora elanga (Hamilton, 1822)        | Dedhaura   | LC  |
|       |        | Rasbora daniconius (Hamilton,1822)         | Dedua, Dhera, Dedhaura                                   | LC  |

| Order | Family          | Latin name  | Local name   | IUCN |
|-------|-----------------|---|--|------|
|       |                 | Raiamas bola (Hamilton, 1822)                       | Bola, Bhola, Chiplae, Faketa, Butte,<br>Chala,Goha | LC   |
|       |                 | Raiamas guttatus (Day, 1870)                        | Thople Bola  | LC   |
|       |                 | Diptychus maculatus (Steindachner, 1866)            | River trout  | NE   |
|       |                 | Schizothorax esocinus (Heckel, 1838)                | Thunde Asala, Asala                                | NE   |
|       |                 | Schizothoraichthys curvifrons (Heckel, 1838)        | Chuche Asala                                       | NE   |
|       |                 | Schizothoraichthys labiatus<br>(McClelland,1842)    | Chuche Asala                                       | NE   |
|       |                 | Schizothorax macrophthalmus<br>(Terashima, 1984)    |  | LC   |
|       |                 | Schizopyge niger (Heckel, 1838)                     | Kalo Tilke   | NE   |
|       |                 | Schizothoraichthys progastus<br>(McClelland, 1839)  | Chuche Asla  | LC   |
|       |                 | Schizothorax molesworthi (Chaudhuri, 1913)          | Sunaula Asala, Lede Asla                           | DD   |
|       |                 | Schizothorax plagiostomus (Heckel, 1838)            | Buchhe Asala, Sun Asla, Snow trout                 | NE   |
|       |                 | Schizothorax nepalensis (Terashima, 1984)           | Tikhe Asla, Asala                                  | CR   |
|       |                 | Schizothorax raraensis (Terashima, 1984)            | Rara Asla  | CR   |
|       |                 | Schizothorax richardsonii (Gray, 1832)              | Asla, Buche Asla, Budhe Asla                       | VU   |
|       |                 | Garra annandalei (Hora, 1921)                       | Buduna, Lohari, Lahare Buduna                      | LC   |
|       |                 | Garra gotyla (Gray, 1830)                           | Buduna, Dhumke Buduna                              | LC   |
|       |                 | Garra lamta (Hamilton, 1822)                        | Mate Buduna, Patther Chatti                        | LC   |
|       |                 | Garra lissorhynchus (McClelland, 1842)              | Buduna   | LC   |
|       |                 | Garra mullaya (Skyes, 1839)                         | Mate Buduna, Khurpe Buduna                         | LC   |
|       |                 | Garra nasuta (McClelland, 1838)                     |  | LC   |
|       |                 | Garra nepalensis (Rayamajhi & Arunachalam, 2017 )   |  | NE   |
|       |                 | Garra rupecula (McClelland, 1839)                   | Buduna   | NT   |
|       | Psilorhynchidae | Psilorhynchus balitora (Hamilton, 1822)             | Titari   | LC   |
|       |                 | Psilorhynchus homaloptera (Hora & Mukerji, 1935)    | Patharchati  | LC   |
|       |                 | Psilorhynchus nudithoracicus (Tilak & Husain, 1980) |  | LC   |
|       |                 | Psilorhynchus nepalensis (Conwey & Mayden, 2008)    |  | LC   |
|       |                 | Psilorhynchus pseudecheneis (Menon & Datta, 1964)   | Tite machha, Titae, Raigadelo                      | LC   |
|       |                 | Psilorhynchus sucatio (Hamilton, 1822)              | Titae  | LC   |
|       | Balitoridae     | Balitora brucei (Gray, 1830)                        | Tita kabri   | NT   |
|       |                 | Balitora eddsi (Conwey & Mayden, 2010)              |  | LC   |
|       |                 | Homaloptera bilineata (Blyth, 1860)                 | Patherchatti                                       | DD   |
|       | Nemacheilidae   | Acanthocobotis botia (Hamilton, 1822)               | Pate Gadela, Baghe                                 | LC   |
|       |                 | Aborichthys elongatus (Hora, 1921)                  |  | LC   |
|       |                 | Nemacheilus corica (Hamilton, 1822)                 | Raigadero, Gadelo                                  | LC   |

| Order              | Family        | Latin name  | Local name  | IUCN |
|--------------------|---------------|---|---|------|
|                    |               | Schistura beavani (Gunther, 1868)                                     | Gadaula, Kholse, Gadero, Dharkee,<br>Gadero               | LC   |
|                    |               | Schistura devdevi (Hora, 1935)  | Gadera, Garolla   | NT   |
|                    |               | Schistura himachalensis (Menon, 1987)                                 | Gadela  | NE   |
|                    |               | Schistura horai (Menon, 1952)   | Gadela, Suli Gadero                                       | NE   |
|                    |               | Schistura multifasciata (Day, 1878)                                   | Gadelo  | LC   |
|                    |               | Schistura prashadi (Hora, 1921)                                       | Gadela, Dum Gadera  | VU   |
|                    |               | Schistura rupecula (McClelland, 1838)                                 | Bhotee Gadelo   | LC   |
|                    |               | Schistura savona (Hamilton, 1822)                                     | Gadela  | LC   |
|                    |               | Schistura scaturigina (McClelland, 1839)                              | Gadela, Khole Gadero                                      | LC   |
|                    |               | Schistura sikamaiensis (Hora, 1921)                                   | Gadela  | LC   |
|                    |               | Schistura zonata (McClelland, 1839)                                   | Gadela, Khole gadela                                      | DD   |
|                    |               | Schistura fasciata (Lokeshwar & Viishwanath, 2011)                    | Gadela  | NE   |
|                    |               | Physoschistura elongata (Sen & Nalbant, 1982)                         | Siyae, Suiree   | VU   |
|                    |               | Turcinoemacheilus himalaya (Conwey,<br>Edds, shrestha & Mayden, 2011) |   | NE   |
|                    | Cobitidae     | Canthophrys gongota (Hamilton, 1822)                                  | Latai, Goira, Baluwari                                    | LC   |
|                    |               | Lepidocephalichthys guntea (Hamilton, 1822)                           | Lata, Nakata, Goira, Kande Gainche,<br>Sim, Gadera, Ghara | LC   |
|                    |               | Lepidocephalichthys annandalei<br>(Chaudhuri, 1912)                   | Goira   | DD   |
|                    |               | Lepidocephalichthys goalparensis (Pillai<br>& Yazdani, 1976)          | Lata, Makhibutte Gadera                                   | LC   |
|                    |               | Neoeucirrhichthys maydelli (Bănărescu<br>& Nalbant, 1968)             |   | LC   |
|                    |               | Pangio pangia (Hamilton, 1822)  |   | LC   |
|                    | Botiidae      | Botia almorhae (Gray, 1831)   | Baghi, Baghuwa  | LC   |
|                    |               | Botia dario (Hamilton, 1822)  | Baghawa, Bothn  | LC   |
|                    |               | Botia geto (Hamilton, 1822)   | Baghawa, Bothn  | LC   |
|                    |               | Botia lohachata (Chaudhuri, 1912)                                     | Baghi, Getu   | NE   |
|                    |               | Botia histrionica (Blyth, 1860)                                       | Baghi   | LC   |
| Cyprinodontiformes | Aplocheilidae | Aplocheilus panchax (Hamilton, 1822)                                  | Tikauli, Tikuli   | LC   |
| Mugiliformes       | Mugilidae     | Rhinomugil corsula (Hamilton, 1822)                                   | Karsula   | LC   |
|                    |               | Sicamugil cascasia (Hamilton, 1822)                                   | Ladhiya   | LC   |
| Osteoglossiformes  | Notopetridae  | Chitala chitala (Hamilton, 1822)                                      | Moi, Patara, Vuna, Chitala                                | NT   |
|                    |               | Notopterus notopterus (Pallas, 1769)                                  | Lepsi, Golhai, Patara                                     | LC   |
| Perciformes        | Ambassidae    | Chanda nama (Hamilton, 1822)  | Nata, Chanerbijuwa  | LC   |
|                    | Ambassidae    | Parambassis baculis (Hamilton, 1822)                                  | Chanari   | LC   |
|                    | Ambassidae    | Parambassis lala (Hamilton, 1822)                                     | Cahnerbijuwa  | NT   |
|                    | Ambassidae    | Parambassis ranga (Hamilton, 1822)                                    | Cahnerbijuwa, Chanari                                     | LC   |
|                    | Anabantidae   | Anabas cobojius (Hamilton, 1822)                                      | Kabai   | DD   |
|                    |               | Anabas testudineus (Bloch, 1792)                                      | Kabai   | DD   |
|                    | Badidae       | Badis badis (Hamilton, 1822)  | Pasari, Khesalei  | LC   |

| Order        | Family         | Latin name                                      | Local name                                  | IUCN |
|--------------|----------------|---|---|------|
|              | Channidae      | Channa barca (Hamilton, 1822)                   | Snakehead                                   | DD   |
|              |                | Channa gachua (Hamilton, 1822)                  | Bhoti, Hile                                 | LC   |
|              |                | Channa marulius (Hamilton, 1822)                | Saur, Saura, Bhaura                         | LC   |
|              |                | Channa orientalis (Bloch & Schneider, 1801)     | Bhoti, Garahi, Ghau nya , Chenga            | NE   |
|              |                | Channa punctatus (Bloch, 1793)                  | Bhote, Garai, Helae                         | LC   |
|              |                | Channa stewartii (Playfair, 1867)               | Hile, Charangi                              | LC   |
|              |                | Channa striata (Bloch, 1793)                    | Helae, Saura                                | LC   |
|              | Gobiidae       | Caragobius burmanicus (Hora, 1926)              |   | NE   |
|              | Nandidae       | Nandus nandus (Hamilton, 1822)                  | Dalahai, Dhala, Dewan, Dhoke                | LC   |
|              | Osphronemidae  | Trichogaster faciatus (Bloch & Schneider, 1801) | Katara, Khesara, Kotari, Vansari            | LC   |
|              |                | Trichogaster Ialius (Hamilton, 1822)            | Kotari                                      | LC   |
|              |                | Trichogaster chuna (Hamilton, 1822)             | Kotari                                      | LC   |
|              |                | Ctenops nobilis (McClelland, 1845)              |   | NT   |
|              |                | Glossogobius giuris (Hamilton, 1822)            | Bulla, Vulvule, Bulle                       | LC   |
|              | Sciaenidae     | Daysciaena albida (Cuvier, 1830)                | Bhola                                       | NE   |
|              |                | Johnius coitor (Hamilton, 1822)                 | Bhola                                       | LC   |
| Siluriformes | Amblycipitidae | Amblyceps mangois (Hamilton, 1822)              | Pichhi, Bokshi Macho, Baljung               | LC   |
|              | Ailiidae       | Ailia coila (Hamilton, 1822)                    | Patasi, Patangu, Patsi                      | NT   |
|              |                | Clupisoma garua (Hamilton, 1822)                | Jalkapoor, Baikha                           | LC   |
|              |                | Clupisoma montanum (Hora, 1937)                 | Jalkapoor                                   | LC   |
|              | Bargidae       | Sperata aor (Hamilton, 1822)                    | Kanti                                       | LC   |
|              |                | Sperata seengala (Skyes, 1839)                  | Seenghari, Sujaha                           | LC   |
|              |                | Batasio batasio (Hamilton, 1822)                | Batasio                                     | LC   |
|              |                | Batasio macronotus (Ng & Edds, 2004)            | Batasio                                     | DD   |
|              |                | Batasio tengana (Hamilton, 1822)                |   | LC   |
|              |                | Hemibagrus mendona (Hamilton, 1822)             | Belauni                                     | LC   |
|              |                | Mystus bleekeri (Day, 1877)                     | Tenger, Tengra                              | LC   |
|              |                | Mystus cavasius (Hamilton, 1822)                | Tenger, Tengra                              | LC   |
|              |                | Mystus gulio (Hamilton, 1822)                   | Tengra                                      | LC   |
|              |                | Mystus tengara (Hamilton, 1822)                 | Tengri, Tenger                              | LC   |
|              |                | Mystus vittatus (Bloch, 1794)                   | Tenger, Kanti                               | LC   |
|              |                | Rita rita (Hamilton, 1822)                      | Rita, Chona, Belaunda, Kurkuree,<br>Kirkire | LC   |
|              | Chacidae       | Chaca chaca (Hamilton, 1822)                    | Pauwa, Pauna,                               | LC   |
|              | Clariidae      | Clarias batrachus (Hamilton, 1822)              | Mungri, Mangur, Mungar                      | LC   |
|              | Erethistidae   | Conta conta (Hamilton, 1822)                    |   | DD   |
|              |                | Erethistes pussilus (Müller & Troschel, 1849)   | Bhoomi, Kata Kanti                          | LC   |
|              |                | Erethistoides montana (Hora, 1950)              | Dantkirra                                   | DD   |
|              |                | Erethistoides ascita (Ng & Edds, 2005)          |   | DD   |
|              |                | Erethistoides cavatura (Ng & Edds, 2005)        |   | DD   |

| Order | Family           | Latin name   | Local name                   | IUCN |
|-------|------------------|--|------------------------------|------|
|       |                  | Hara hara (Hamilton, 1822)   | Panahi, Tinkana, Datari      | LC   |
|       |                  | Hara jerdoni (Day,1870)  | Panahi, Tinkana, Datari      | LC   |
|       |                  | Pseudolauvia assula (Ng & Conwey, 2013)  |                              | NE   |
|       |                  | Pseudolaguvia kapuri (Tilak & Husain,<br>1975)                                 | Kirkire, Tinkanatiya, Datari | LC   |
|       |                  | Pseudolauvia nepalensis (Rayamajhi,<br>Arunachalam & Usharamalakshmi,<br>2016) |                              | NE   |
|       |                  | Pseudolaguvia ribeiroi (Hora, 1921)  | Tinkanatiya, Bistuiya        | LC   |
|       | Heteropneustidae | Heteropneustes fossilis (Bloch, 1794)  | Singhi                       | LC   |
|       | Olyridae         | Olyra longicaudata (McClelland, 1842)  |                              | LC   |
|       | Pangasiidae      | Pangasius pangusius (Hamilton, 1822)   | Jalkapoor, Patasi            | LC   |
|       | Schilbeidae      | Eutropiichthys goongwaree (Skyes, 1839)  | Bachawa                      | DD   |
|       |                  | Eutropiichthys murius (Hamilton, 1822)   | Jalkapoor, Muriys Vacha      | LC   |
|       |                  | Eutropiichthys vacha (Hamilton, 1822)  | Bachawa, Bachora, Cherki     | LC   |
|       |                  | Pachypterus atherinoides (Bloch, 1794)   | Patasi, Potasi, Jalkapur     | LC   |
|       |                  | Silonia silondia (Hamilton, 1822)  |                              | LC   |
|       | Siluridae        | Ompok bimaculatus (Bloch, 1794)  | Pabata, Nauni, Papta         | NT   |
|       |                  | Ompok pabda (Hamilton, 1822)   | Pabda, Badaari               | NT   |
|       |                  | Ompok pabo (Hamilton, 1822)  | Pabda                        | NT   |
|       |                  | Wallago attu (Bloch & Schneider, 1801)   | Bohari, Padni                | NT   |
|       | Sisoridae        | Bagarius bagarius (Hamilton, 1822)   | Gonch                        | NT   |
|       |                  | Bagarius yarrelli (Skyes, 1839)  | Gonch                        | NT   |
|       |                  | Coraglanis kishinouyei (Kimura, 1934)  | catfish                      | NE   |
|       |                  | Parachiloglanis hodgarti (Hora, 1923)  | Telcapre, Tilkabri           | LC   |
|       |                  | Exostoma labiatum (McClelland, 1842)   |                              | LC   |
|       |                  | Gagata cenia (Hamilton, 1822)  | Tikthigogta, Padana, Ganfak  | LC   |
|       |                  | Gagata gagata (Hamilton, 1822)   |                              | LC   |
|       |                  | Gagata sexualis (Tilak, 1970)  | Buhani, Tengana              | LC   |
|       |                  | Glyptosternon maculatum (Regan, 1905)  | Capre                        | LC   |
|       |                  | Glyptosternon reticulatum (McClelland, 1842)                                   | Capre                        | NE   |
|       |                  | Glyptothorax alaknandi (Tilak, 1969)   | Kapre                        | LC   |
|       |                  | Glyptothorax annandalei (Hora, 1923)   | Kapre                        | LC   |
|       |                  | Glyptothorax botius (Hamilton, 1822)   | Telcapre                     | LC   |
|       |                  | Glyptothorax cavia (Hamilton, 1822)  | Kapree, Vedro                | LC   |
|       |                  | Glyptothorax conirostris (Steindachner, 1867)                                  |                              | DD   |
|       |                  | Glyptothorax garhwali (Tilak, 1969)  | Capre                        | LC   |
|       |                  | Glyptothorax gracilis (Gunther, 1864)  | Capre                        | DD   |
|       |                  | Glyptothorax indicus (Talwar, 1991)  | Capre                        | LC   |
|       |                  | Glyptothorax kashmirensis (Hora, 1923)   |                              | CR   |

| Order               | Family               | Latin name                                    | Local name                                   | IUCN |
|---------------------|----------------------|---|--|------|
|                     |                      | Glyptothorax pectinopterus (McClelland, 1842) | Karsingha, Capre                             | LC   |
|                     |                      | Glyptothorax telchitta (Hamilton, 1822)       | Telchitta, Telcapre, Kotel                   | LC   |
|                     |                      | Glyptothorax trilineatus (Blyth, 1860)        | Kabre, Kafre, Kavre                          | LC   |
|                     |                      | Myersglanis blythi (Day, 1870)                | Tengana, Tilkabre                            | DD   |
|                     |                      | Nangra assamensis (Sen & Biswas,<br>1994)     | Nangra, Befuni                               | LC   |
|                     |                      | Nangra nangra (Hamilton, 1822)                | Befuni                                       | LC   |
|                     |                      | Gogangra viridescens (Hamilton, 1822)         | Katenga                                      | LC   |
|                     |                      | Pseudecheneis eddsi (Ng 2006)                 | Kabre, Gotel                                 | DD   |
|                     |                      | Pseudecheneis crassicaudata (Ng & Edds, 2005) | Kabre  | DD   |
|                     |                      | Pseudecheneis serracula (Ng & Edds, 2005)     | Kabre  | LC   |
|                     |                      | Pseudecheneis sulcata (McClelland, 1842)      | Kabre, Kabri                                 | LC   |
|                     |                      | Sisor rhabdophorus (Hamilton, 1822)           | Kirkiree, Bistuiyya, Sing Puchhare<br>Machho | LC   |
|                     |                      | Sisor rheophilus (Ng, 2003)                   | Kirkiree, Sing, Puchhare Machho              | DD   |
| Synbranchiformes    | Synbranchidae        | Monopterus cuchia (Hamilton, 1822)            | Andho Bam, Anali, Anahi                      | LC   |
|                     | Mastacembelidae      | Macrognathus aculeatus (Bloch, 1786)          | Gainchi, Bamsemti                            | NE   |
|                     |                      | Macrognathus aral (Bloch & Schneider, 1801)   | Gainchi                                      | LC   |
|                     |                      | Mastacembelus armatus (Leceped, 1800)         | Chusi bam, Chuche Bam, Garchi                | LC   |
|                     |                      | Macrognathus lineatomaculatus (Britz, 2010)   |  | DD   |
|                     |                      | Macrognathus pancalus (Hamilton, 1822)        | Kath gainchi, Bami, Kathgainchi              | LC   |
|                     |                      | Macrognathus zebrinus (Blyth, 1858)           | Bam, Bamali                                  | LC   |
| NT - Near Threatene | d, NE – Near Endange | red, LC – Least Concern, VU – Vulnerable, I   | EN – Endangered, DD – Data Deficit           |      |

