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Integrated Water Resources Management in Myanmar

Ecological Status of Rivers, Lakes, and Reservoirs

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Norwegian Institute for Water Research

REPORT

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Summary

This is the final report from output 1 of the IWRM project 2015-2024. The goal of the project was to implement a classification system for the ecological status of rivers and lakes in Myanmar like the EU Water Framework Directive. As the project was ended in 2021 due to the military coup in Myanmar, planned activities could not be finished. This report presents a summary of the ecological surveys and ecological status assessments in selected water bodies in Myanmar achieved within the project. The report should be read in conjunction with the other comprehensive publications from the project. Although the current political situation in Myanmar put a halt to our activities, the reports and scientific papers comprised in this project, in addition to transferred knowledge about freshwater ecology to selected staff and to one PhD student from Myanmar, have led to a set of recommendations that hopefully will be an impetus for future river and lake biomonitoring in Myanmar. As knowledge about the ecology of most of the many water bodies in Myanmar is still poor a much bigger number of freshwater ecologists need to be educated to achieve the goal of classifying their status and to find solutions for their improvement.

Four keywords	Fire emneord
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2. Ecological status	2. Økologisk tilstand
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Integrated Water Resources Management in Myanmar

Ecology of Rivers, Lakes, and Reservoirs

Preface

This report is performed by the Norwegian Institute for Water Research (NIVA), as part of the projects Integrated Water Resources Management – Institutional Building and Training (IWRM) I and II, a cooperation project between Department of Forest, Ministry of Natural Resources and Environmental Conservation (MONREC) and NIVA.

The projects have been part of the Norwegian – Myanmar Bilateral Environment Programme, 2015-2023, being funded by the Norwegian embassy in Yangon. The long-term development goal of the IWRM projects has been to make a significant and positive contribution to the implementation and functioning of an integrated water resources management in Myanmar. As the project ended in 2021 due to the military coup in Myanmar the planned investigations about the ecological status of rivers and lakes and mining activities could not be finished.

The report is written by Andreas Ballot, Marit Mjelde, Tor Erik Eriksen, Johnny Håll, Cathrine Brecke Gundersen and Hans Fredrik Veiteberg Braathen. The report is a summary of ecological surveys in selected rivers, lakes and reservoirs in Myanmar and should be read in conjunction with the other publications about these water bodies.

We thank the Ministry of Natural Resources and Environmental Conservation (MONREC) with underlying agencies, The Department of Forestry, and The Environmental Conservation Department in Myanmar for their support and contributions. Special thanks go to Bo Ni, retired director of Watershed Management Division (Forest Department; FD), Zaw Win Myint – previous director of Watershed Management Division (FD), Thida Swe, May Phoo, Htay Kywae, Nay Ni Kyaw, Toe Toe Aung, Phyo Thet and Swuam Pyaye Aye Aung. We also want to thank, Zaw Lwin Tun and Phyo Wai from the Irrigation and Water Utilization Management Department (IWUMD), retired Sein Tun from the Directorate for Water Resources and Improvement of River Systems (DWIR), and staff from the Forest Department and Irrigation and Water Utilization Management Department at Bago Region.

Oslo, 20.04.2023

Andreas Ballot

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Summary

This is the final report of the ecological water quality status assessment of the project Integrated Water Resources Management – Institutional building and training (IWRM), a collaboration between the Ministry of Natural Resources and Environmental Conservation (MONREC) and the Norwegian Institute for Water Research (NIVA) under the Norwegian – Myanmar Bilateral Environment Programme during phase I and II (2015 – 2023) funded by the Norwegian embassy in Myanmar.

The goal of the project was to implement a classification system for the ecological status of rivers and lakes in Myanmar, similar to the classification system in the EU Water Framework directive. As the project collaboration with Myanmar authorities was ended in 2021 due to the military coup, the planned investigations about the ecological status of rivers and lakes and mining activities could not be fully completed.

The overall aim of this report is to present a summary of the ecological surveys and ecological status assessments in selected rivers, lakes and reservoirs in Myanmar carried out in the IWRM project 2014-2020. The report should be read in conjunction with the other comprehensive publications from the project.

The project included surveys of several biological groups such as macroinvertebrates in rivers, and phytoplankton and aquatic macrophytes in lakes. In addition, physical measurements, analyses of water chemistry, cyanotoxins, and hydromorphology were conducted. A study in some mining areas, with potential environmental and human effects, was included.

The limited dataset collected in Myanmar during the study period until 2020 does not yet enable the implementation of a final classification system for the ecological status of rivers and lakes in Myanmar. However, the initial results show that a modified Norwegian classification system is applicable as a first approach for Myanmar.

Although the current political situation in Myanmar put a halt to the biomonitoring activities, the reports and scientific papers comprised in this project have led to a set of recommendations that hopefully will be an impetus for future river and lake biomonitoring in Myanmar.

The project has transferred knowledge about freshwater ecology to selected MONREC staff and supported doctoral studies of a student from Myanmar. As knowledge about the ecological status of most water bodies in Myanmar is still low, a much larger number of freshwater ecologists need to be trained to achieve the goal of classifying their water bodies status more widely and finding solutions for their improvement.

Sammendrag

Tittel: Integrated Water Resources Management in Myanmar - Ecology of Rivers, Lakes, and Reservoirs
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Forfatter(e): Andreas Ballot, Marit Mjelde, Tor Erik Eriksen, Cathrine Brecke Gundersen,Hans Fredrik Veiteberg Braaten
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Dette er sluttrapporten av den økologisk vannkvalitetsstatusen i prosjektet Integrated Water Resources Management – Institutional building and training (IWRM), et samarbeid mellom Ministry of Natural Resources and Environmental Conservation (MONREC) og Norsk institutt for vannforskning (NIVA) under det bilaterale miljøprogrammet mellom Norge og Myanmar fase I og II (2015 – 2023) finansiert av den norske ambassaden i Myanmar.

Målet med prosjektet var å implementere et klassifiseringssystem for den økologiske tilstanden til elver og innsjøer i Myanmar som ligner på klassifiseringssystemet i EUs vanndirektiv. Ettersom prosjektet ble kansellert i 2021 på grunn av militærkuppet i Myanmar, kunne de planlagte undersøkelsene av den økologiske statusen til elver og innsjøer og gruvedrift ikke fullføres.

Det overordnede målet med denne rapporten er å presentere et sammendrag av de økologiske undersøkelsene og vurderingene av økologisk tilstand i utvalgte elver, innsjøer og vannmagasiner i Myanmar som ble utført i IWRM-prosjektet 2014-2020. Rapporten bør leses i sammenheng med de andre omfattende publikasjonene fra prosjektet.

Prosjektet omfattet undersøkelser av flere biologiske grupper som makroinvertebrater i elver og planteplankton og akvatiske makrofytter i innsjøer. I tillegg ble det gjennomført fysiske målinger, analyser av vannkjemi, cyanotoksiner og hydromorfologi. En studie i noen gruveområder, med potensielle effekter på miljø og mennesker, ble inkludert.

Det begrensede datasettet som er samlet inn i Myanmar i løpet av studieperioden frem til 2020, gjør det ennå ikke mulig å implementere et endelig klassifiseringssystem for den økologiske tilstanden til elver og innsjøer i Myanmar. De første resultatene viser imidlertid at det norske klassifiseringssystemet kan brukes som en første tilnærming til Myanmar.

Selv om den nåværende politiske situasjonen i Myanmar har satt en stopper for overvåkingsaktivitetene, har rapportene og de vitenskapelige artiklene i dette prosjektet ført til et sett med anbefalinger som forhåpentligvis vil være en drivkraft for fremtidig overvåking av elver og innsjøer i Myanmar.

Prosjektet har overført kunnskap om ferskvannsøkologi til utvalgte ansatte ved MONREC og en student fra Myanmar har fullført doktorgraden i ferskvannøkologi. Ettersom kunnskapen om den økologiske tilstanden til de fleste vannforekomstene i Myanmar fortsatt er lav, må et mye større antall ferskvannsøkologer utdannes for å nå målet om å klassifisere tilstanden til vannforekomstene og finne løsninger for å forbedre den.

1 Introduction

1.1 Background and aims

Nature including wildlife, societies and industry are dependent on clean rivers and lakes, groundwater, and bathing waters. Since 2000, the Water Framework Directive has been the main law for water protection in Europe (EU 2000). The EU Water Framework Directive (EU-WFD) has the goals to get polluted waters clean again and to ensure that clean waters are kept clean. It applies to inland, transitional, and coastal surface waters as well as groundwaters. It ensures an integrated approach to water management, respecting the integrity of whole ecosystems, including regulating individual pollutants and setting corresponding regulatory standards. It is based on a river basin district approach to make sure that neighboring countries manage the rivers and other bodies of water they share (EU 2023).

The EU-WFD requires Member States to use their River Basin Management Plans (RBMPs) and Programs of Measures (PoMs) to protect and, where necessary, restore water bodies to reach good status, and to prevent deterioration. Good status means both good chemical and good ecological status. The EU WFD uses an ecosystem-based approach for characterizing and classifying water quality using ecological water quality criteria, an approach designed to protect, preserve, and improve the aquatic environment. The directive requires monitoring of physical-chemical, biological, and hydromorphological water quality elements. According to this directive, all surface water bodies should be classified into one of five normative classes, i.e., high, good, moderate, poor, or bad ecological status.

Myanmar currently lacks systems for evaluating the ecological status of its surface waters including rivers, natural lakes, and man-made reservoirs and dams. However, in 2011 an environmental policy and water legislation reform was initiated in Myanmar with the establishment of the Ministry of Environmental Conservation and Forestry (MOECAF) and with the establishment of the Department of Environmental Protection in 2012. The National Water Resources Committee, established in 2013, adopted in 2014 the National Water Policy (NWRC 2014), the first integrated water policy for the watersheds, rivers, lakes and reservoirs, groundwater aquifers and coastal and marine waters in and around Myanmar, and a policy framework the Myanmar National Water Framework Directive (NWFD). Myanmar's National Water Policy and NWFD state the general objectives of making Myanmar's waters healthier, cleaner and more useful for all purposes, and assessing the ecological and chemical status of its waters.

The objectives of the Myanmar National Water Framework Directive (NWFD) were that Myanmar should become a water efficient nation with well-developed and sustainable water resources based on fully functional integrated water resources management systems within 2020, applying concepts like the EU WFD.

The NWFD presents seven principles for achieving good ecological status for the water quality elements in Myanmar water bodies and river basins, principles which reflects the EU WFD. Among these principles, NWFD Principle (3) is particularly relevant for this report. It states that “The ecological and chemical status of surface waters should be assessed according to the following criteria:
- Physical-chemical quality such as water temperature, pH, conductivity, oxygenation, and nutrients.

- Biological quality (fish, benthic invertebrates, aquatic flora (phytoplankton and macrophytes)
- Hydromorphological quality such as status of riverbanks, riverbank structures, river training works, river continuity or substrate of the riverbed
- Chemical quality that refers to environmental quality standards for river basin specific pollutants."

This situation formed the background for the objectives of the collaboration between the Myanmar Ministry of Natural Resources and Environmental Conservation (MONREC) and NIVA under the IWRM - Integrated Water Resources Management Institutional Building and Training (IWRM) I project (2015-2018), and the IWRM II project (2019-2023) to contribute to the development of a framework for assessing the ecological status of water bodies in Myanmar. The collaborative work was part of the Myanmar Norway Environmental Programme phase I and II funded by the Norwegian embassy in Myanmar.

The overall aim of this report is to present a summary of the ecological surveys and ecological status assessments in selected rivers, lakes and reservoirs in Myanmar within the IWRM project 2014-2020. The report should be read in conjunction with the other comprehensive publications from the project.

1.2 Biogeographic context of Myanmar

Myanmar is the largest country in South-East Asia, consisting of 676 590 km^2 including mountainous areas, lowlands, deltas, and coastal areas. Mountains rise to more than 5 800 m above sea level in Kachin State in the north, and over 2000 m in Shan, Rakhine and Chin States. The long coastline runs from the Andaman Sea to the east and along the Bay of Bengal to the west (Mjelde et al., 2017).
The climate is seasonal, with a cold season from November to January, followed by a dry season from February to April and then a wet season from May to October. About ninety percent of the annual rainfall is received from mid-May to mid-October, varying geographically, from around 5000 mm in the southern delta area, to 750 mm in the central dry-land area. Although the country has vast water resources, they are both spatially and temporally unevenly distributed following seasonal patterns. The internal total renewable water resources in Myanmar are estimated to be about 1000 km^3 per year. This contains surface water (rivers, lakes and reservoirs) and groundwater (including river base flow) (see references in Mjelde et al. 2017).

In total, there are four major rivers, including the Ayeyarwaddy, Chindwin, Sittaung and Thanlwin River, five river basins where three of these are international basins, and two coastal areas, Rakhine State and Tanintharyi State. The largest international river is Thanlwin, covering about 18% of the territory, while the source of the river is in China. The largest natural lakes are Indawgyi lake (Kachin state) with a surface area of 123 km^2 and Inlay Lake (Shan state) with a surface area of 116 km^2.

As an agriculture-based country, Myanmar has heavily invested in dam construction throughout the country to increase water availability to promote agricultural production and socio-economic development. Because of the relative scarcity of natural lakes in Myanmar, reservoirs are the predominant lake type in many regions and the largest water use category is irrigation (see references in Mjelde et al. 2017)

1.3 Pollution and other risks to good ecological status of water

Typical pollution sources are agriculture, domestic sewage, and industrial wastewater. Industrial wastewater can come from the following industries: textiles, pharmaceuticals, leather, plastics, chemicals, electrical equipment, pulp, and paper mills, and others. Unregulated discharges from point sources can contain high nutrient levels, pesticides or other toxic chemicals and heavy metals that lead to water pollution endangering human health (via contact or ingestion) or wide-scale ecosystem damage (see also Mjelde et al. 2017). The impact on the aquatic environment is determined by chemical type, concentration, timing of release, weather conditions and the type of organism in the discharge area. Deforestation and agricultural practices in catchment areas lead to erosion and increased siltation problems in rivers and lakes. An increasing use of river sand as a source of construction material results in erosion and degradation of riverbanks and riverbeds. In addition, all these activities lead to deterioration of lake and river water quality.

Myanmar has an abundance of geological resources like metals and ores, especially copper, lead, silver, tin, tungsten, zinc, nickel, gold, and iron (Htun et al., 2017) and the minerals marble, jade and ruby. Depending on the minerals and how they are extracted, environmental consequences can be an issue of local, regional, or global concern.

2 Material and methods

2.1 Approach for developing a framework for ecologic status assessment

The project used the EU's Water Framework Directive (WFD) as a conceptual guide for the development of a framework for ecological status assessment adapted to conditions in Myanmar.

According to the EU WFD, ecological status assessment must be 'type specific', i.e., water bodies should be grouped according to their physical and morphological attributes, such as salinity, alkalinity, catchment size or altitude/depth. Such fundamental ecological drivers explain most of the variation among water bodies. A characterisation process that includes preliminary identification and description of water bodies based upon existing geographical information, biological, chemical and physical quality elements, and sometimes expert judgement, is the basis for assigning water body types. In addition, characterisation needs to include identification of the main pressures, a preliminary classification and risk analysis.

The *first step* in the characterisation process is to group all water bodies into a) Lake: body of standing inland surface water, b) River: body of inland water flowing for the most part on the surface of the land, c) Groundwater: all water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil, d) Transitional waters: bodies of surface water in the vicinity of river mouths which are partly saline in character as a result of their proximity to coastal waters but which are substantially influenced by freshwater, e) Coastal water: surface water on the landward side of coastline, every point of which is at a distance of one nautical mile on the seaward side from the nearest point of the baseline from which the breadth of territorial waters is measured, extending where appropriate up to the outer limit of transitional waters, f) Artificial water body: body of surface water created by human activity, or g) Heavily modified water body: body of surface water which as a result of physical alterations. *Second*, the different categorized water bodies need to be identified according to type, this will vary according to such as altitude surface area, depth, and geology (**Table A1a and A1b**).

Considering these water body categories and types, the WFD classification scheme for water quality aims to describe the biological response due to specific pressures, e.g. elevated nutrient concentrations, or hydromorphological alteration. The ecological status is evaluated by assessment methods using selected ***biological quality elements***, including phytoplankton, aquatic macrophytes, phytobenthos, benthic invertebrates, and fish (**Table A2**). Physico-chemical and/or hydro-morphologial parameters are included as supporting elements (**Table A3, A4, A5, A6**). The classification scheme includes five status classes: high, good, moderate, poor, and bad (**Table A7**). 'High status' is defined as the biological, chemical and morphological conditions associated with no or very low human pressure. This condition is the same as or close to the 'reference condition', i.e., the best status achievable. The reference conditions are type-specific, so they differ for different types of rivers, lakes, or coastal waters. Class boundary values have been developed for these supporting elements in the EU WFD but need to be adapted to conditions in Myanmar (see Mjelde et al. 2017 for further description).

In the IWRM project in Myanmar phytoplankton and aquatic macrophytes in lakes and macroinvertebrates in rivers were included. The *phytoplankton* community is composed of microscopic primary producers that respond sensitively to changes in water quality. Changes in phytoplankton composition in lakes along the eutrophication gradient have been well-known for several decades in Europe and North America. For instance, as nutrient concentrations increase, the dominance and abundance of cyanobacteria generally increase, often resulting in dense mono-specific blooms. This makes phytoplankton one of the most relevant biological elements for the assessment of eutrophication in lakes (Poikane et al. 2011, and references herein), and in large, very slow flowing rivers. *Aquatic macrophytes* are floating-leaved or submerged macroscopic plant species with distinct roots and shoots and are considered to be excellent indicators for ecological status assessment of lake ecosystems and slow-flowing rivers because they respond to nutrients, light, toxic contaminants, metals, herbicides, turbidity, and water level change (Poikane et al. 2011, and references herein). *Benthic macroinvertebrates* are organisms that inhabit the bottom of freshwater, they are an integral part within food chains, as well as playing an important role in productivity, nutrient cycling and decomposition, and they are sensitive to organic enrichment, pollution by toxic chemicals, acidification, and abstraction of water.

Physico-chemical water quality elements include several parameters (EU 2000, see also Mjelde et al. 2017). In the IWRM project in Myanmar we included the following parameters, secchi depth, oxygen conductivity, pH, turbidity, suspended solids, alkalinity, calcium, phosphate, total phosphorus, total nitrogen, nitrate, ammonia, potassium, chloride, magnesium, sodium, sulfate and silicate. River-basin specific pollutants are copper, chromium, manganese, iron and arsenic. The EU's priority substances are mercury, cadmium, zinc, nickel and lead.

Other water quality elements: Assessment of coliform bacteria, including the bacterium *Escherichia coli* (*E. coli*), and the biochemical oxygen demand after five days (BOD-5) were undertaken in the Bago River basin. However, measurements of bacteria and BOD-5 were largely unsuccessful owing to a combination of long travelling distances, poor road infrastructure, the warm climate and lack of appropriate laboratory facilities (see Eriksen et al. 2021).

Hydromorphological water quality elements indicate water flow and water level regulations, structure of river or lakebed, and riparian zone. The river hydromorphology was assessed using a modified version of the morphological quality index (MQI; Rinaldi et al. 2013). The version applied here was simplified to test its use in Myanmar and results cannot be compared directly with results obtained with the original MQI method but can give a good indication of the degree of hydromorphological degradation in this area as an impression of its potential use in the future.

Currently, there is no system for ecological classification of rivers and lakes in Myanmar. Future work on developing a classification system for the ecological status of lakes and rivers in Myanmar should include indices and boundaries developed exclusively for Myanmar and based on a large dataset of water bodies in Myanmar. The work presented here represents a small dataset for some lakes and river sections sampled during 2014-2020 as a contribution to the development of Myanmar's classification system.

2.2 Study areas and sampling

2.2.1 Rivers

The Bago Sub-basin and Taunggyi District, in the Salween River Basin were selected to represent freshwater river networks in the lowlands and the uplands areas in Myanmar.

The Bago sub-basin (8-76 m a.s.l., lowland area) was selected as the main case study area for the study of water quality elements in rivers in Myanmar. The sub-basin also represented a pilot case for implementing the river basin administrative approach in Myanmar inspired by the EU WFD (Nesheim et al. 2018). The Bago sub-basin is situated in the southern central part of Myanmar. It includes the Bago River, which flows from the Pegu Yoma mountain range at an elevation of 800 m a.s.l. in the north, running south through meandering sections of more than 331 km before it reaches the Yangon River near Yangon City (Haruyama 2013). The sub-basin is relatively small at 5,359 km^2 and lies between the Sittaung River in the east and the Ayeyarwaddy and Myintmakha Rivers in the west. The Bago sub-basin is connected to the Sittaung River Basin by a 61 km long canal built in 1878 to regulate flooding. The canal is currently an important water supplier for local irrigation.

Before data sampling campaigns, all surface waters were delineated into water bodies to serve as management units for surveys. Based on information from local management authorities and available data, 35 water bodies were assigned to the Bago sub-basin and 26 to the Sittaung sub-basin (**Figure 1**). Sampling campaigns were subsequently initiated to collected novel data on water chemistry, macroinvertebrates, and hydromorphology from the selected water bodies. The Bago River was delineated into six water bodies and tributaries and reservoirs comprised the remaining 29 water bodies. Sampling sites for water chemistry and macroinvertebrate samples and hydromorphological analyses are shown in **Figure 1 and 2**. The sampling campaigns were conducted in different seasons in the years 2016-2020. Riverine macroinvertebrates and environmental data were collected from a total of 48 wadable river sites. Some of the sites were revisited on two or three occasions, such that a total of 64 samples were collected. Thirty-six sites (51 samples) were in the lowland area, with sampling conducted in February and March (dry season), except for one site that was sampled in September (wet season). Macroinvertebrate samples were taken during low flow conditions by kick sampling (see Eriksen et al 2017 for details). Changes in macroinvertebrate composition was analysed in relation to the environmental data collected.

The *Taunggyi District* (886-1057 m a.s.l., highland), covers 24 000 km^2 with a population density of approx. 70 inhabitants per km^2 (Sharma et al. 2020). Sampling was focused on the Inlay Lake catchment and covered all the major tributary rivers to Inlay Lake, situated in the Nyaungshwe township (population density approx. 128 inhabitants per km^2, MOIP 2015) (**Figure 3** and **4**).

Sampling included river macroinvertebrates, physical, chemical, biochemical and bacteriological water body characteristics, habitat characteristics and quality, land use and hydromorphological changes and was carried out in November 2017 to test the general applicability of the lowland findings with regard to a macroinvertebrate-based assessment tool. Thirteen sites (13 samples) were sampled in the cold season (November) in the upland area.

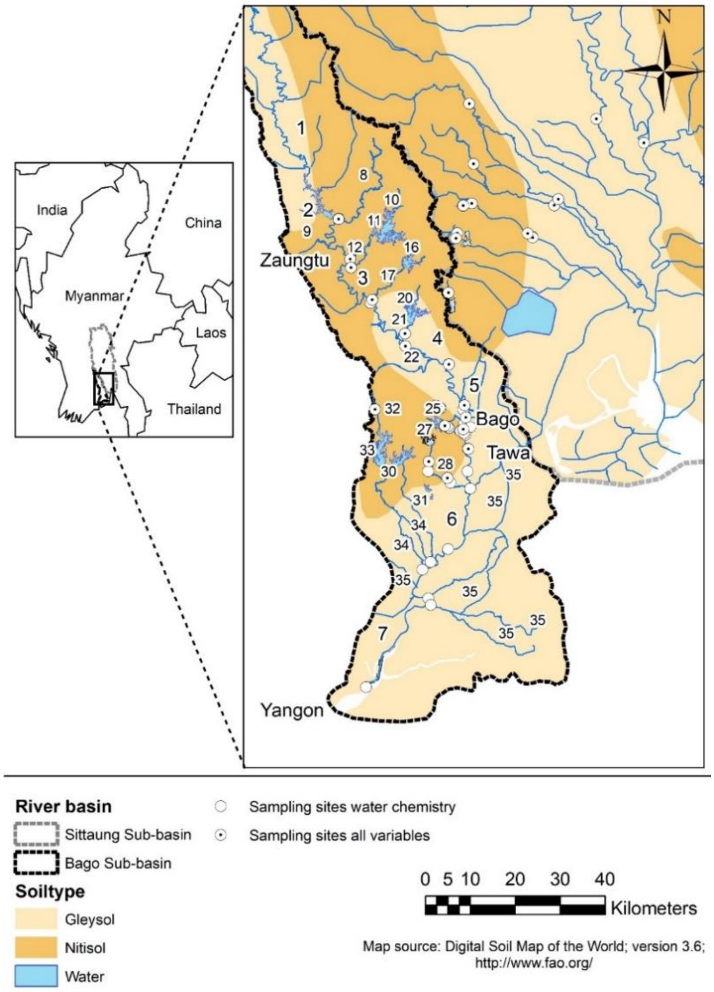

Figure 1. River sampling sites in the Sittaung River Basin which comprises the Sittaung and Bago sub-basins. River water bodies are shown by numbers. The Bago River was delineated into 6 water bodies and tributaries while reservoirs comprised the remaining 29 water bodies. Sampling sites for water chemistry, macroinvertebrate samples and hydromorphological analyses are shown.

Figure 2. Tributary to Bago River (left) and Mazin Chaung in Bago centre (right). Photos: T.E. Eriksen.

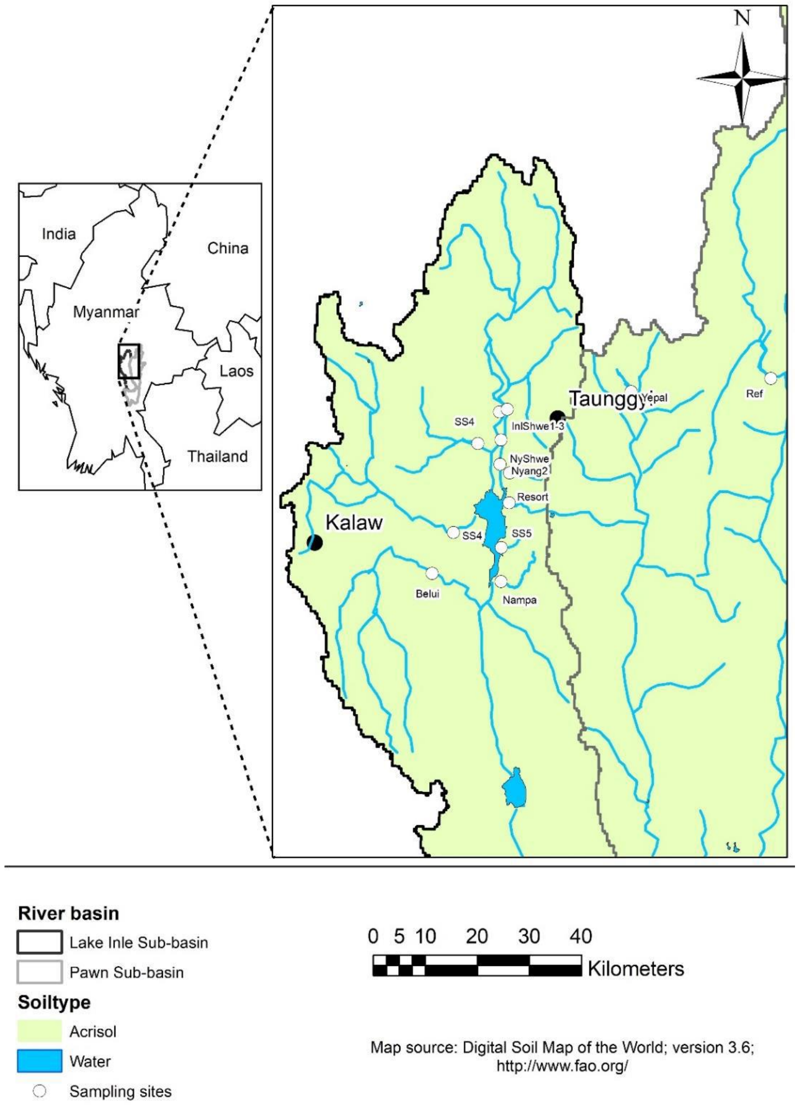

Figure 4. Map showing the location of sampling sites and main soil types in the upland area. The Salween River Basin is comprised of several sub-basins, including the Inlay Lake and Pawn.

Figure 4. Two nameless tributaries to Inlay Lake. Photos: T. E. Eriksen.

2.2.2 Lakes and reservoirs

As for rivers, the aim of this project part was to contribute to the development of a classification system for the ecological status of lakes in Myanmar, like that implemented in the EU Water Framework Directive (EU 2000). It is to note that due to the relatively short and abruptly stopped project period only a relatively small number of water bodies could be investigated. For the development of a reliable classification system, data from a much higher number of lakes surveyed in different seasons and different areas would be necessary. However, testing the Norwegian classification system in Indawgyi Lake and Inlay Lake, the largest and second largest natural lakes in Myanmar (Ballot et al., 2018, Mjelde et al. 2018), gave reasonable results that can be a basis for further development and adaptation of the system to the subtropical and tropical conditions in Myanmar, as soon as political changes allow it.

Altogether 17 lakes and reservoirs were selected in different regions in Myanmar and investigated once or multiple times at one or several sampling points in the period 2014 -2020 (**Table 1, Figure 6**). The investigations comprised physical-chemical parameters (e.g., temperature, pH, oxygen, conductivity, turbidity, ammonium, total nitrogen, total phosphorous, soluble reactive phosphorus, total organic carbon, calcium, and silicate) and biological parameters (phytoplankton and aquatic macrophyte abundance and composition) (as recommended by Mjelde et al., 2017). In addition, the presence of cyanobacteria and cyanotoxins was investigated. Water samples were analysed for the presence of hepatoxic cyanotoxins: microcystins and cylindrospermopsins, and neurotoxic saxitoxins and anatoxins and for the isolation and culturing of potential toxin producing cyanobacteria. The water samples and the cultured cyanobacterial strains were investigated with ELISA and liquid chromatography–mass spectrometry (LC–MS).

All analyses were conducted at the Water Quality Laboratory in the Forest Research Institute, Yezin, Myanmar (see chapter 2.3) or at the Norwegian Institute for Water Research, Norway.

Table 1. Lakes and reservoirs in Myanmar investigated in 2014-2020.

Lake	**State/Region/ Division**	**Latitude**	**Longitude**	**Altitude** m	[1]**Lake area** km^2	**Lake type**
Inlay Lake	Shan State	20,563046	96,918640	884	[2]116	Natural
Sakar Inn	Shan State	20,169411	96,932716	884	3	Natural
Pekon Lake	Shan State	19,879100	97,032623	884	134	Reservoir
Indawgyi Lake	Kachin State	25,116667	96,316667	170	123	Natural
Meiktila Lake, North	Mandalay Region	20,886560	95,852966	230	4,8	Reservoir
Meiktila Lake, South	Mandalay Region	20,863464	95,854511	230	4,3	Reservoir
Yezin dam	Mandalay Region	19,855852	96,276798	128	6,4	Reservoir
Nga Laik Dam	Mandalay Region	19,861665	96,005058	163	5,5	Reservoir
Moeyingyi Reservoir	Bago Region	17,570721	96,596947	10	15	Reservoir
Taung Thaman Lake, North	Mandalay Region	21,900833	96,060556	61	3	Reservoir
Kantawgyi lake, South	Mandalay Region	21,936389	96,065833	66	1,8	Reservoir
Pyu Kan Lake	Mandalay Region	21,768056	95,891111	102	2	Reservoir
Khu Le Inn	Mandalay Region	22,592222	95,980000	76	2,5	Reservoir
Sunye In Tank	Mandalay Region	21,679722	96,230000	91	4	Reservoir
Pauk In	Mandalay Region	21,326944	95,048056	55	0,15	Natural
Kyet Mauk Taung Dam	Mandalay Region	20,812222	95,250833	279	4,5	Reservoir
Wethtigan lake	Magwe Division	20,575833	94,641111	66	1,7	Natural

***1**: Lake area can vary considerable between wet and dry season. **2**: Inlay Lake area is reduced, and open water was in 2014 measured to 46* km^2.

Figure 5. Lakes and reservoirs investigated in Myanmar in the period 2014-2020 (overview map from www.albatross-travel.no).

Figure 6. Macrophyte harvesting at Inlay Lake (left) and water chemistry sampling at Indawgyi Lake (right). Photos: A. Ballot and M. Mjelde.

2.2.3 Additional study sites at mining areas

In the IWRM project phase II, monitoring was planned for six relevant mining sites, each representing different geographical areas, different mining activities, and different potential environmental and human effects (**Table 2**). Bago was selected as a reference site with little or no known pollution.

Table 2. Overview of sampling sites and activities in areas* affected by mining.

Lake/river system*	Catchment activity	Sampling activity	Samples collected
Shwegyin	Gold mining	Sampling February 2020	Water, sediment (surface), fish
Indawgyi	Gold (small and medium scale) and jade mining (large scale)	Initial assessment in November 2017	Water, sediment (core and surface), fish, rice
Moehti Moemi	Gold mining (large scale, mining activity shut down)	Initial assessment in November 2019	Water
Mawchi	Lead mining	n.a.	-
Monywa	Copper mining (large scale)	n.a.	-
Tanintharyi	Gold mining	n.a.	-
Bago	No known sources (reference station)	Sampling November 2016	Water

***** *Due to the global Covid-19 pandemic situation, and later the changed political status of Myanmar, field work was only initiated for Shwegyin, Indawgyi, Moehti Moemi and Bago with field campaign dates indicated in the table.*

The *Shwegyin area* is located on the western edge of the Kayah-Karen/Tenasserim Moist Forest, a region listed by WWF as one of the world’s 200 most significant eco-regions due to the level of biodiversity (Olson and Dinerstein, 2002). The mining occurs along the Shwegyin and Mawtama rivers. *Indawgyi* Lake Wildlife Sanctuary, located in Mohnyin Township, Kachin State, is one of five Ramsar protected areas in Myanmar (i.e., an area protected by the Framework for Conservation of Wetlands). The selection of sampling locations was focused on Artisanal and Small-Scale Gold Mining (ASGM)-affected streams and unaffected streams (sampling of water and sediments). In the *Moehti Moemi* mining area sampling was difficult due to an ongoing conflict concerning the present and the previously operating company. Only local staff was allowed in the area, and water samples were only collected from two stations thought to be affected by runoff from previous mining activity. *Bago* was included as a reference site thought to have no or little influence from mining activity. For a full detailed description of sampling and sampling sites in Bago, we refer to Eriksen et al. (2021). In the *Mawchi, Monywa and Tanintharyi* areas fieldwork could not be conducted due to Covid 19 pandemic and changed political status in Myanmar.

2.3 Analysis of water quality elements

NIVA´s laboratories and Myanmar´s national water quality laboratories have been used for the analyses of water samples in the IWRM project. NIVA laboratory performs services within the areas of chemical analysis, ecotoxicological testing and biology. NIVA has broad and long-established experience within method development, consulting and problem-solving within these areas and within laboratory quality assurance. The laboratories are equipped with advanced modern instruments for the delivery of high-quality custom analyses. NIVA performs routine determinations of chemical and biological water quality parameters and metals in both fresh and marine waters. Most methods are accredited according to NS-EN ISO/IEC 17025, under registration Test 009.

As part of the IWRM Myanmar´s national water quality laboratories at the Forest Research Institute/Yezin were rehabilitated to meet current requirements for health, environment, and safety.

Instruments for the analysis of physical and chemical and biological parameters, bacteria were installed, and training sessions were organized as part of the IWRM project (2015-2018). The laboratory was constructed and established in the period 2018-2020 as part of the IWRM II project. The laboratory has modern facilities to handle water, biota, and sediment samples. It has several temperature regulated rooms and equipment to store samples for long and short periods. It is equipped with instruments for physical and chemical parameters (e.g., pH, nutrients, and ions) and for heavy metal analyses (As, Pb, Cd, Cu, Cr, Ni, Zn, Hg). Instruments for the determination of biological oxygen demand (BOD5), bacterial analyses, ELISA) and phytoplankton analyses are also in place. The new laboratory was used for the physical-chemical measurements and analyses of chemical and biological water samples from rivers and lakes in the IRWM project.

3 Results and discussion

3.1 Ecological status in selected rivers

In the Bago sub-basin the dominant pressures on rivers were urban land use, inputs of untreated sewage, in-stream and riparian garbage littering, run-off from agricultural fields and plantations, and physical habitat degradation. Water chemistry data indicated inputs of sediments and nutrients to degraded streams, but no obvious metal pollution. Hydromorphological alterations (MQI index) indicated high perturbation in urban areas and to lesser extent in less populated areas. River reaches draining degraded catchments with agriculture and settlements had elevated concentrations of nutrients (phosphorous and nitrogen) and notable oxygen stress. **Table 3** depicts water quality criteria for nutrients in gleysol soil streams (calcium <4 mg/l) and nitisol soil streams (calcium 4-20 mg/l). The established class boundaries are based on a limited dataset and will probably need revision as more data become available.

Table 3. Water quality criteria for nutrients in rivers proposed for gleysol soil streams (calcium <4 mg/l) and nitisol soil streams (calcium 4-20 mg/l). Status classes are expressed as *high* (H), *good* (G), *moderate* (M), *poor* (P) and *bad* (B).

Gleysol soils	**River typology: <200 m a.s.l., calcium <4 mg/l**					
	Reference	**H**	**G**	**M**	**P**	**B**
Total phosphorus (µg P/l)	6	11	17	**30**	60	> 60
Total nitrogen (µg N(l)	200	325	475	**775**	1350	> 1350
Ammonia (NH4+NH3 µg N/l)	10	10	30	**60**	100	160

Nitisol soils	**River typology: <200 m a.s.l., calcium 4-20 mg/l**					
	Reference	**H**	**G**	**M**	**P**	**B**
Total phosphorus (µg P/l)	9	15	25	**38**	65	> 65
Total nitrogen (µg N/l)	275	425	675	**950**	1425	> 1425
Ammonia (NH4+NH3 µg N/l)	10	10	30	**60**	100	160

A preliminary status classification based on phosphorus concentrations in the Bago River and its tributaries is depicted in **Figure 7**. Similar types of stressors were observed in the Salween River Basin in the upland area.

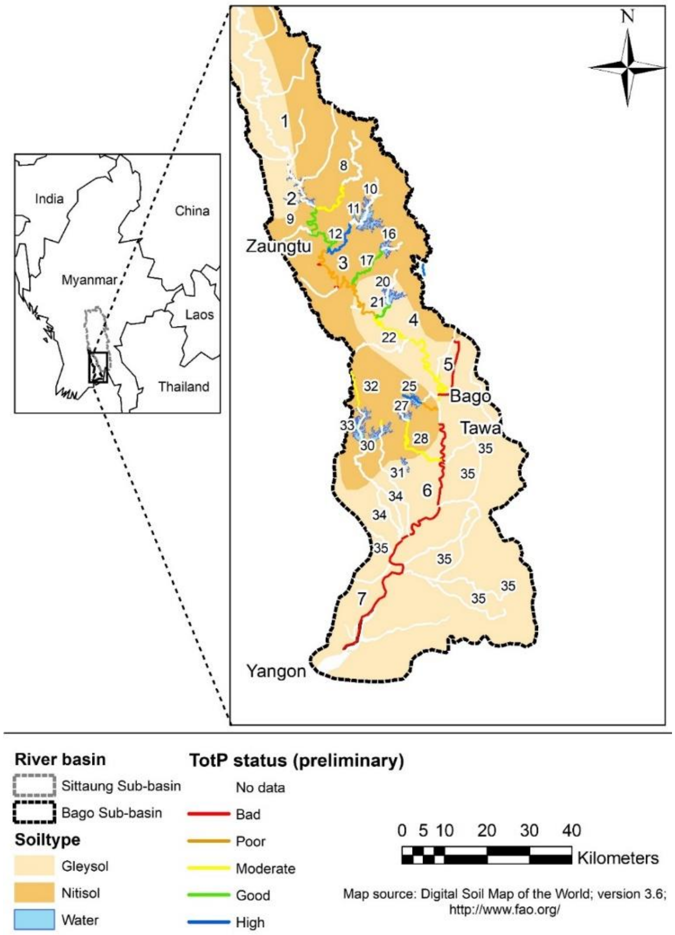

Figure 7. A preliminary assessment of total phosphorous (Tot P) concentrations in the Bago River and its tributaries. Status class boundaries used are based on a limited dataset and may need revision.

The use of riverine macroinvertebrates was effective to detect cumulative stress associated with urban and agriculture landscapes. Pollution by nutrients (nitrogen and phosphorous) and sewage was prominent in some parts of the river network. This was common to river reaches draining degraded catchments with a high proportion of agriculture and urban activities. Several assemblage attributes showed responses to impacts, including sensitivity, diversity, and heterogeneity. The use of multiple assemblage attributes, expressed as *multimetrics*, was most effective for detecting cumulative impacts (Eriksen 2022). Impacted river sites had volatile oxygen regimes with notable oxygen deficit. The highest deficits took place during darkness when there was no light available for oxygen production (photosynthesis) by algae and macrophytes to compensate for oxygen consumed by biological communities (respiration). Non-impacted sites had relatively stable oxygen concentrations and low oxygens stress. Respiration studies of selected, common riverine macroinvertebrates (laboratory studies) showed that all taxa investigated were to some extent able to regulate their respiration when placed under oxygen stress. The oxy-regulation capacity of macroinvertebrate assemblages in the river network was inversely related to diel oxygen stress (minimum percent oxygen concentrations), where taxonomic richness (EPTCO) and pollution sensitivity (ASPT metric) also declined sharply. These findings suggest that tropical lowland river systems are highly sensitive to pollution by nutrients and organic matter leading to substantial impacts on ectotherm community composition and ecosystem functioning.

In the Bago sub-basin, the hydromorphology across the river network ranged from pristine rivers with no evidence of modifications, to very degraded river reaches. Overall, most river reaches assessed showed relatively little hydromorphological alternation. The main pressures of rivers in terms of hydromorphology are the presence of dams upstream, embankments and extensive loss of riparian vegetation. The least degraded rivers are found in the upper part of the river networks. In and around Bago City, most river reaches have been physically modified to some degree and the most impacted rivers are found here (**Figure 8**). However, even in populated areas, river reaches can be found that are still in an acceptable condition regarding hydromorphological alternations.

Figure 8. Hydromorphological alternations in Bago (Sittaung River catchment). Photos: T. E. Eriksen.

When MQI class boundaries developed in Europe are applied to the Bago River dataset, 76 % of the reaches assessed were either in high or good status class. Only nine reaches had moderate, poor, or bad hydromorphological status class (**Figure 9**). These results should be interpreted with caution, as both the method and the class boundaries are not designed for use in Myanmar. Nevertheless, the findings suggest that the impact of hydromorphological degradation in many river reaches is at a level where it will have a limited negative effect on the ecological status. In about 24% of the river sections, the hydromorphology is likely to be negatively affected, so that mitigation measures, such as physical restoration, should be considered in the future.

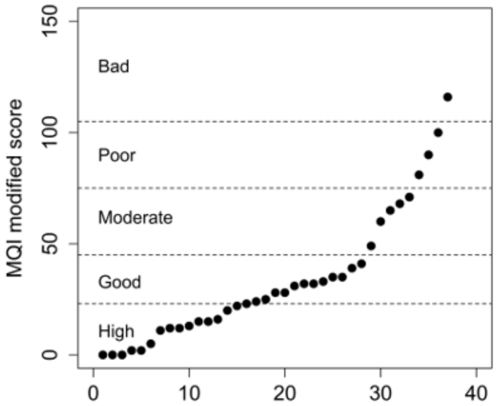

Figure 9. MQI (modified) scores assessing hydro-morphological degradation at 37 river reaches in the Bago Sub-basin (in ascending order i.e., increasing degree of hydromorphological degradation). MQI (modified) range from 0 (pristine) to 150 (extremely impacted). Class boundaries the original MQI system are: (1) high, 0 ≤ MQI ≤ 23; (2) good, 23 ≤ 45; (3) moderate, 45 ≤ 75; (4) poor, 75 ≤ 105; (5) bad, 105 ≤ 150. The results are preliminary and may need revision.

3.2 Ecology studies in lakes

3.2.1 Physico-chemical conditions

The 17 investigated lakes and reservoirs in Myanmar are characterized by a high variability in physico-chemical parameters **(Table 4)**.

Table 4. Variability in physico-chemical parameters in studied lakes. Average values from the period 2014-2020.

No	Lake	temp. °C	Cond. µS/cm	pH *	Ca mg/l	turb FNU	TOC mg C/l	TP µg P/l	PO4 µg P/l	TN µg N/l	NO3 µg N/l	NH4 µg N/l	Silicate µg/l
1	Inlay Lake	24,7	368	8,3	48,9	0,6	5,1	17	3,6	479	34	40	6991
2	Sakar Inn	21,4	381	7,8	-	-	3,9	7	2	430	24	36	3120
3	Pekon Lake	-	-	-	45,5	-	5,5	9	1	440	4	20	10467
4	Indawgyi Lake	31,1	123	9,2	9,0	1,2	-	7	1	532	2	20	-
5	Meiktila Lake, North	27,1	700	8,9	17,3	13,3	4,1	18	4	413	8,4	19	4888
6	Meiktila Lake, South	27,0	617	9,1	13,7	2,7	3,9	14	2	446	5	17,0	4985
7	Yezin dam	27,7	82	8,5	8,0	-	5,1	21	4	402	5	18	21933
8	Nga Laik Dam	-	-	-	21,9	6,7	-	20	-	510	-	-	-
9	Moeyingyi Reservoir	30,8	24	6,9	1,3	-	8,1	50	13	446	25	29	25233
10	Taung Taman Lake, North	28,1	756	8,1	24,7	50,4	19,3	2010	1615	11450	2	6600	32100
11	Kantawgyi lake, South	28,9	703	8,5	31,1	7,2	4,5	188	122	860	5	188	27100
12	Pyu Kan Lake	27,3	229	8,7	17,8	7,9	2,2	45	14	500	140	<2	-
13	Khu Le Inn	27,8	187	9,5	10,3	1,3	5,4	26	7	565	3	47	1090
14	Sunye In Tank	28,3	394	8,1	21,3	1,8	6,9	22	4	575	2,0	54	2180
15	Pauk In	27,6	1248	8,7	23,6	47,0	10,3	190	53	2000	<2	102	-
16	Kyetmauk Taung Dam	27,4	601	8,7	29,9	7,4	4,7	19	7	1130	366	59	15000
17	Wethtigan lake	28,0	516	8,2	31,3	0,8	5,2	9,0	4,5	585	3	98	11700

3.2.2 Phytoplankton and aquatic macrophytes

Species composition and richness

Up to 269 different phytoplankton taxa belonging to different groups were found in the lakes and reservoirs in Myanmar (**Figure 10**). Especially the clear natural Inlay Lake was characterised by a high phytoplankton diversity, while the diversity was much lower in the turbid reservoirs. Diatoms (Bacillariophyta), green algae (Chlorophyta/Charophyta), golden algae (Chrysophyceae) and Dinophyta were more abundant in the clearer lakes and cyanobacteria were only present with low biomasses (**Figure 12**). The turbid lakes and reservoirs were in contrast dominated by cyanobacteria and the other phytoplankton groups were abundant in lower percentages only (e.g., Ballot et al. 2020, Swe et al. 2021b, Mjelde & Ballot 2016, Mjelde et al. 2018, and unpublished data).

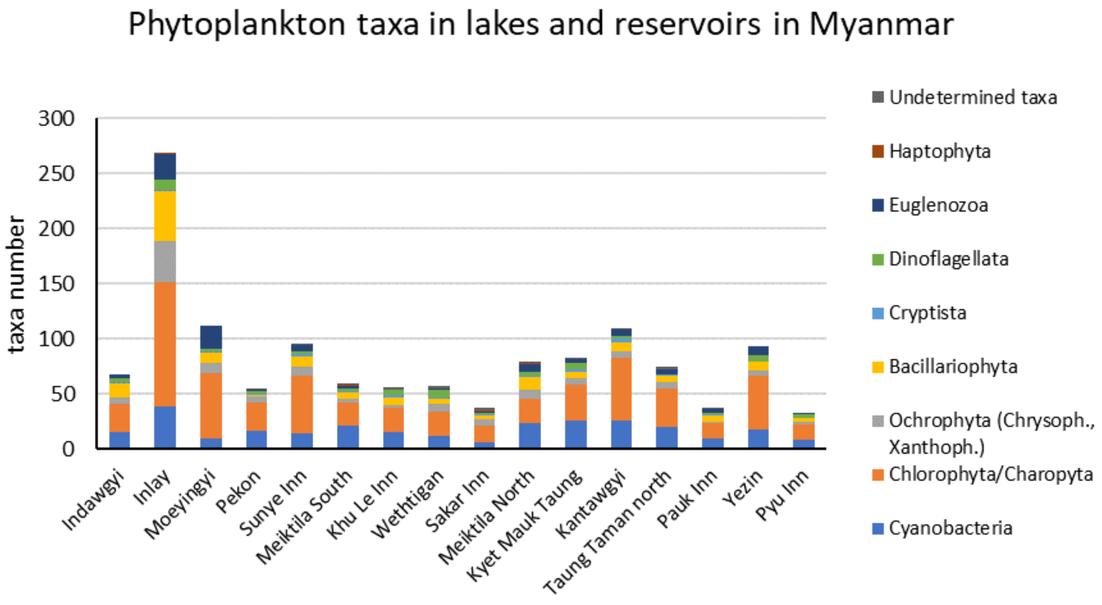

Figure 10. Number of phytoplankton taxa in 16 lakes and reservoirs in Myanmar.

Altogether, 44 species (including hybrids) of aquatic macrophytes (submerged, floating leaved and free-floating species) were recorded in the lakes (Ballot et al. 2018, Mjelde & Ballot 2016, Mjelde & Wathne 2015, Mjelde et al. 2018, Mjelde et al. 2020, Swe et al., 2021, and unpublished data) (**Figure 11**). Highest biodiversity was found in the two largest natural lakes, Inlay Lake (27 species, Swe et al., 2021) and Indawgyi Lake (21 species, Mjelde et al., 2018a), and in Moeyingyi Reservoir (18 species, Mjelde & Wathne 2015, Mjelde et al., 2016). The hypereutrophic Kantawgyi and Taung Taman lakes in the middle of Mandalay city typically had very low biodiversity, dominated by free-floating species (unpublished data) (**Figure 13**).

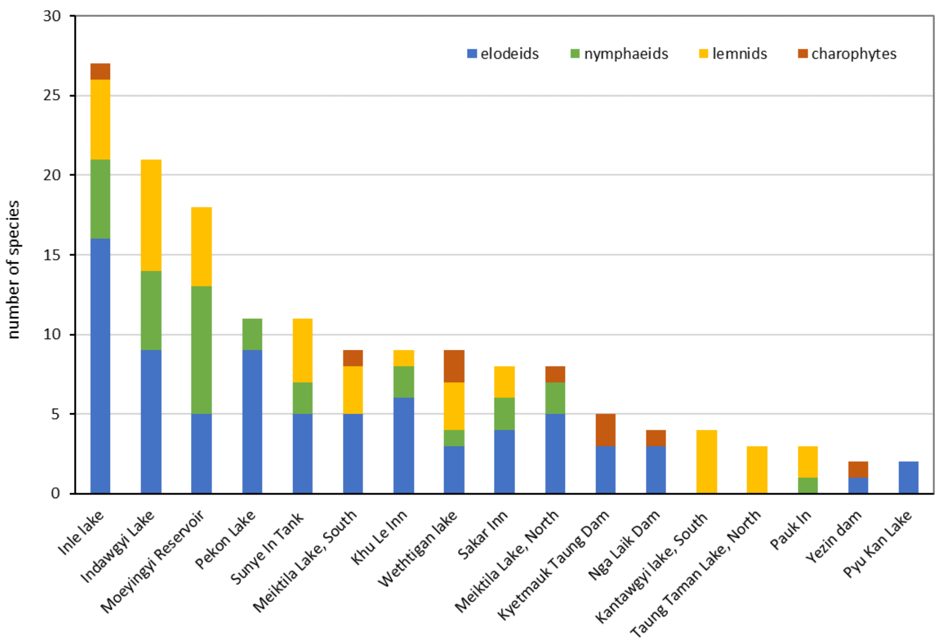

Figure 11. Number of aquatic macrophytes in 17 lakes and reservoirs in Myanmar.

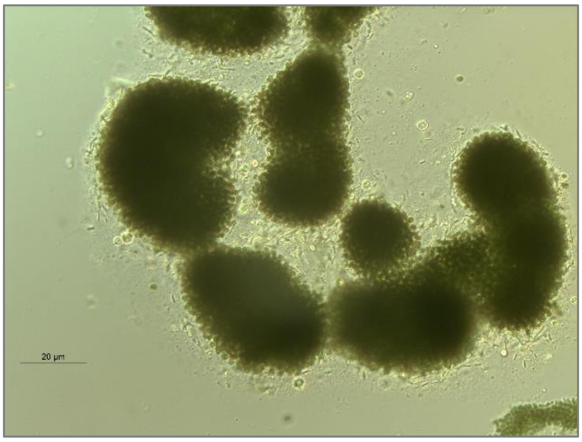

Figure 12. *Microcystis* a common cyano-bacterium in Indawgyi Lake and Inlay Lake. Photo: A. Ballot

Figure 13. Two of the dominating submerged species in Inlay Lake; *Nechamandra alternifolia* (upper left) and *Potamogeton lucens* (upper right). The floating-leaved *Euryale ferox* (lower, left) was only recorded in Indawgyi Lake. The invasive *Eichhornia crassipes* (lower, right) was the most common macrophyte in lakes and reservoirs in Myanmar. Photos: A. Ballot and M. Mjelde.

Interactions between phytoplankton and macrophytes
The macrophyte composition and abundance varied between the lakes. For instance, shallow natural lakes like Inlay Lake, Sunye In Tank and Wethtigan Lake are characterized by a dominance of aquatic macrophytes covering most parts of the lake bottom and clear water. The phytoplankton biomasses in these lakes are relatively low because most of the phosphorous and nitrogen is taken up and stored in the macrophyte biomass and not available for phytoplankton growth (Swe et al. 2021a, and unpublished data). Cyanobacteria are found in these lakes only in small numbers. Although microcystin producing cyanobacterium *Microcystis* (**Figure 12**) has been observed in Inlay Lake the abundance is very low (Swe et al. 2021a). Indawgyi Lake, a relatively deep natural in Myanmar differs considerably from Inlay Lake. It is a lake also with luxury aquatic macrophytes, however growth limited to the relatively small littoral zone. Here *Microcystis* at times is observed with high biomasses (Mjelde et al. 2018). Like Indawgyi Lake several of the deeper reservoirs (e.g., Yezin Dam, Kyet Mauk Taung Dam), are dominated by phytoplankton growth. These dams are exposed to higher water level fluctuations which limits the growth of aquatic macrophytes additionally. In these reservoirs, toxin producing cyanobacteria *Raphidiopsis* and *Microcystis* were observed during the project period (Ballot et al. 2020, unpublished data). In Yezin Dam non-toxin producing *Dolichospermum* was responsible for the highest cyanobacterial biomasses (Swe et al. 2021b). Due to the increased phytoplankton growth the water is also relatively turbid in these reservoirs.

Other shallow reservoirs are Meiktila Lake, Taung Thaman Lake and Kantawgyi Lake. Taung Thaman lake is severely affected by wastewater from industrial areas situated close to the lake and heavy blooms of cyanobacteria are observed at times. We observed blooms of *Arthrospira* (*Limnospira*) and of potentially cylindrospermopsin producing *Raphidiopsis* in this lake, while aquatic macrophytes were almost absent due to the high pollution of the lake (unpublished data). In parts of Meiktila lake the water was turbid and like in Yezin Dam the cylindrospermopsin producing cyanobacterium *Raphidiopsis* and microcystin producing cyanobacterium *Microcystis* were observed. Meiktila Lake is a very old reservoir and was exposed to sedimentation of erosion material from the catchment. In the northern lake a belt of aquatic macrophytes (dominated by *Potamogeton* spp. and *Nelumbo nucifera*) seem to have a kind of filtering function. The water north of the belt is therefore clearer than south of the belt (Ballot et al. 2020). Despite large water level regulations, the very shallow Moeyingyi Reservoir had low phytoplankton biomass, while both species richness and abundance of aquatic macrophytes were high (Mjelde & Ballot 2016).

Our surveys indicate the importance of the submerged aquatic macrophytes in inhibiting phytoplankton and especially cyanobacterial biomasses, and thereby maintaining a clear water state in several Myanmar lakes.

Preliminary assessments of ecological status
During the study period (2015-2020), the suitability of the Norwegian ecological classification system for *phytoplankton* in lakes could be tested for Indawgyi Lake and Inlay Lake, the two largest natural lakes in Myanmar. The classification system gave a reasonable status classification for these two lakes (Ballot et al. 2018, Mjelde et al. 2018). Overall, the ecological status of both lakes was classified as moderate to poor regarding the composition and biomass of the phytoplankton (**Figure 14**). However, it should be kept in mind that the ecological status calculated for the two lakes is based on very little data and only gives an initial indication of the status. Boundaries need to be assessed and further developed based on additional data from lakes in Myanmar, feedback from Myanmar experts and comparison with other available assessment systems.

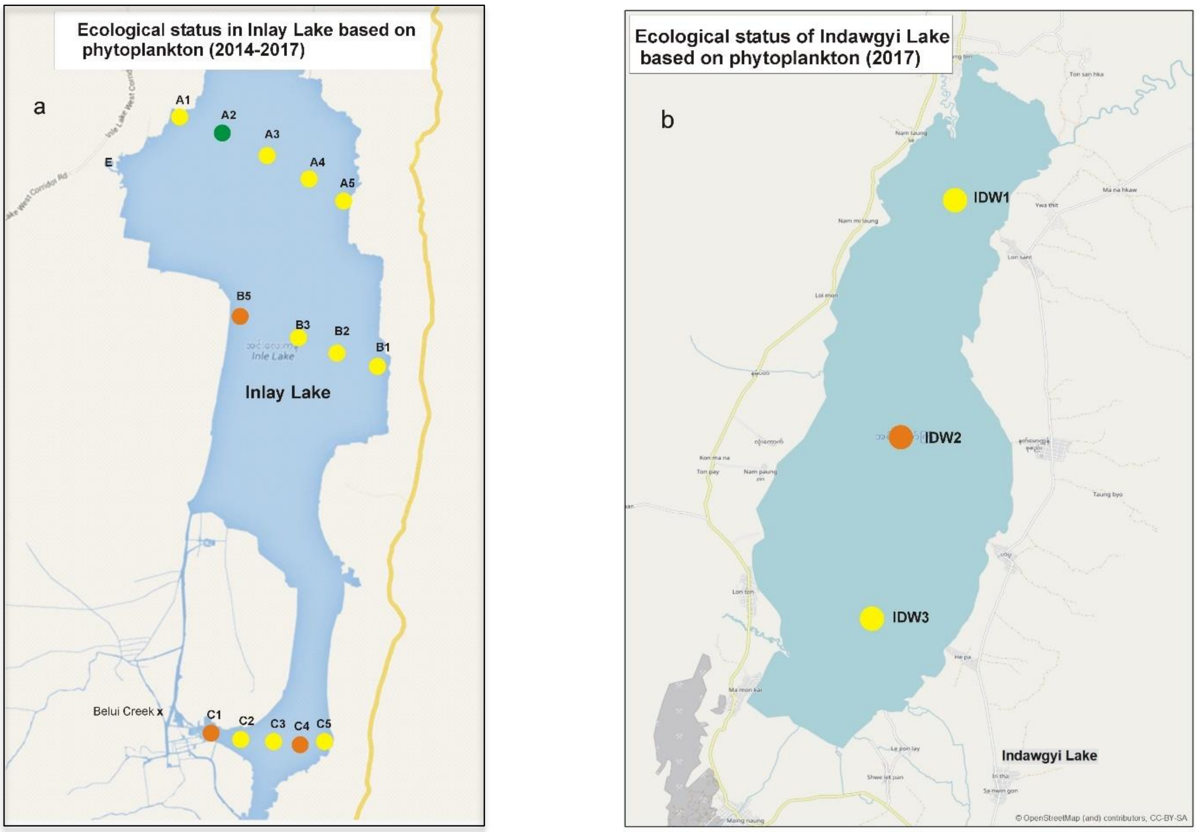

Figure 14. Ecological status of Inlay Lake based on phytoplankton data from Inlay Lake 2014-2017 and Indawgyi Lake 2017, modified from Ballot et al. (2018) and Mjelde et al (2018). The dots represent the worst calculated status at each sampling point. Green = good, yellow= moderate, orange = poor.

As a first approach to assess ecological status for *aquatic macrophytes* in Myanmar lakes, we tested the Norwegian trophic index (TIc) in Inlay Lake and Indawgyi Lake. The index is based on the relationship between species sensitive to eutrophication and species that are tolerant to this impact (Hellsten et al., 2014, Penning et al., 2008). Species sensitivities must be established exclusively for Myanmar or for South-Eastern Asia. As a start, a preliminary list of Myanmar sensitive and tolerant species was suggested, based on expert judgement and literature survey from Asian countries (list from Ballot et al. 2018, see **Table A8)** The list is an important basis for the calculation of the trophic index and for a correct assessment of the ecological status it needs to be corrected and updated as soon as more data is available from Myanmar. Boundaries for Myanmar are not developed. Therefore, the same boundaries that were set for the Norwegian lake types were used (**Table A9**). These also have to be developed for Myanmar as soon as more data are available.

The TIc index indicated poor condition in both lakes (**Table 5**), i.e., the aquatic macrophytes were dominated by tolerant species (Ballot et al., 2018, Mjelde et al. 2018). These results seem to fit very well with the general impression of the status of the lakes. However, the indices and boundaries must be evaluated when more data from Myanmar lakes are available.

In addition, different calculations of a relative abundance index (RA index) were tested, i.e., relative abundance between the free-floating species (lemnids), which are tolerant to eutrophication, and the abundance of more sensitive species, such as charophytes and other submerged species (Ballot et al., 2018, Mjelde et al. 2018, and **A10, A11**). This index gave moderate status in Inlay and poor in Indawgyi (**Table 5**), however slightly different calculation method was used.

Macrophytes cover, particularly in shallow lakes, are important for maintaining the clear water state. In Inlay Lake, high coverage of submerged macrophytes seems to prevent massive growth of phytoplankton and especially nuisance cyanobacteria (Swe et al. 2021a). We therefore included a metric based on submerged macrophyte coverage (SMC) in this lake, which gave good status in the lake (**Table 5**).

The distribution of aquatic macrophytes in different lake types in Myanmar is poorly known, and no agreement of sensitivities for the species appearing in lakes exist. We therefore think that the Submerged cover index (SMC-index) and the Relative abundance index (RA index) would be good alternatives to the eutrophication index (TIc) and should be further developed in Myanmar. When enough data to do the sensitivity analysis for Myanmar species are achieved, we suggest developing a TIc index for Myanmar.

Table 5. Ecological status of aquatic macrophytes in Inlay Lake and Indawgyi Lake, using suggested indices. Green=good, yellow= moderate and orange = poor status.

		TIc-index		**RA index***		**SMC index**	
Lake	**Period**	**value**	**status**	**value**	**status**	**value**	**status**
Inlay Lake	November 2015	-21.1	poor	2.4	moderate	4.1	good
Indawgyi Lake	November 2017	-27.3	poor	2.5	poor	-	-

*: Slightly different calculation method in the 2 lakes (see Ballot et al 2018 and Mjelde et al. 2018)

3.3 Human health issues in relation to water and biota in selected catchments

Measurements of bacteria and BOD-5 were largely unsuccessful owing to a combination of long travelling distances, poor road infrastructure, the warm climate and lack of appropriate laboratory facilities (see Eriksen et al. 2021). Our results however showed that *E. coli* was present in urban streams in the Bago City.

In Myanmar, there is little knowledge about the distribution and impact of harmful cyanobacteria. The investigations in the IWRM project, however, confirmed the presence of cyanobacterial blooms dominated by members of the cyanobacterial taxa *Arthrospira*, *Dolichospermum*, *Microcystis* or *Raphidiopsis* in several lakes and reservoirs in Myanmar. Hepatotoxic microcystins (MC) produced by the cyanobacterium *Microcystis* were detected in e.g., Inlay Lake, Indawgyi Lake, Meiktila Lake, Yezin Dam, Kyet Mauk Taung Reservoir, Sunye In Tank, Kantawgyi Lake (Ballot et al. 2018, Mjelde et al. 2018, Swe et al. 2021a, Swe et al. 2021b, Ballot et al. 2020, and unpublished data). For example, in *Microcystis* strains from Yezin Dam up to 22 microcystin variants and in *Microcystis* strains from Meiktila Lake up to 52 microcystin variants were detected. Hepatotoxic cylindrospermopsin and deoxycylindrospermopsin produced by the cyanobacterium *Raphidiopsis* were confirmed in Meiktila Lake and Yezin Dam. Potentially cylindrospermopsins (CYNs) producing cyanobacteria were also observed in Taung Thaman Lake and Kyet Mauk Taung Reservoir (unpublished data). The toxin concentration observed were still below the guideline values set by the WHO (WHO 2020). However, a change in the cyanobacterial composition and an increase in toxin concentrations causing harmful effects on human beings and animals cannot be excluded in the future. Serious acute and chronic human and animal health problems, in some cases even mortalities, have been related to the presence of cyanotoxins. Several studies have concluded that cyanotoxins may be transferred through aquatic food webs and thus have effects on higher trophic levels, including humans. Thus, in Myanmar, blooms of potential toxin-producing cyanobacteria should receive increased attention when developing in drinking water supplies and inland waters used for irrigation, fishing, watering of animals and recreational activities. It can be assumed that potential toxin-producing cyanobacteria and hepato- and neurotoxins are widely distributed in Myanmar water bodies with deleterious effects on human and animal health.

3.4 Contamination with mercury and other heavy metals at the selected mining sites

Myanmar has widespread gold mining activities (Connette et al., 2016; Osawa and Hatsukawa, 2015; Papworth et al., 2017). Gold mining on a small-scale is one of the major challenges to the world due to the use of mercury (Hg) in the gold extraction process (Pirrone et al., 2010, Veiga et al., 2006, UNEP, 2014). Mercury is a toxic element whose organic forms, such Methylmercury (MeHg), can bioaccumulate in food chains, and have potentially harmful effects for organisms and humans (Scheulhammer et al., 2007; WHO, 1991; Zahir et al., 2005). Additionally, ASGM are often associated with environmental contamination, negative health effects and environmental damage of other metals in addition to Hg, including arsenic, cobalt, lead, manganese, and zinc (Obiri et al., 2016; Ogola et al., 2002; Pavilonis et al., 2017). Mercury concentrations were investigated at three selected sites with mining activities, Indawgyi Lake, Shwegyin and Moehti Moemi.

Indawgyi Lake
At Indawgyi Lake, sediment depth profile revealed relatively low concentrations of Hg (<100 µg/kg). There is not much data from Indawgyi Lake or Myanmar in general for comparison, but the concentration in our surface sediment sample (74.8 µg/kg) is similar to levels in a previous study (Kernan et al., 2015). Mercury concentrations do not change much throughout the core and there was no distinct peak as is commonly seen in other places in the world for lakes where the main source of Hg is long-range transport. This indicates that the sediment in Indawgyi Lake mostly originates from the particle rich inlet rivers in the south of the lake. When comparing sediment concentrations in streams assumed to be influenced by ASGM with those influenced by other sources, there were no significant differences.

Aqueous total Hg concentrations showed large variations, varying three orders of magnitude from minimum (0.9 ng/L, the lake itself) to maximum concentrations (235 ng/L, river inlet influenced by mining activities). Generally, the measured Hg concentrations in this study are quite low, compared to Osawa and Hatsukawa (2015) who measuring Hg concentrations at levels 1000 times higher (81 µg/g) in other areas in Myanmar affected by ASGM. Low dissolved phase Hg concentrations were detected in all samples collected during the 2017 field campaign, suggesting that high Hg concentrations are due to particulate matter (as observed during fieldwork). As with the sediment samples, the water samples suggest that sedimentation (i.e. high particle loading) from the watershed is a much bigger problem for Indawgyi Lake than Hg itself. The high concentrations are due to high inorganic Hg levels and are probably related to natural particles rather than upstream use of Hg in ASGM.

Concentrations of the organic MeHg were low (below detection limit 0.02 ng/L in all stream samples). The water from a well in Mine Naung village had low concentrations of total Hg (1.2 ng/L) and the gold shop activity does not seem to affect the local water source.

In total, 12 fish (Tilapia) from Indawgyi Lake were collected from local markets to perform an initial assessment of the Hg risk from fish consumption. The Hg concentrations in the fish were generally low, below 0.01 mg/kg. However, some higher values are found (Kernan et al., 2015). Combined with a short life-span and a vegetarian diet, the high water temperature and the lake's high nutrient levels (Mjelde et al., 2018), this means that the Tilapia in Indawgyi Lake probably accumulate Hg to a limited extent.

Shwegyin
As for the uppermost sediment in the streams around Indawgyi, the sediment samples from Shwegyin also showed low Hg concentrations. Highest concentrations were found in the samples from streams Kyawk Sin Win (37.4 µg/kg) and Chaung Wa (33.1 µg/kg), located upstream from Shwegyin were ASGM and forestry are potential sources. Additionally, 35 fish were collected from a local fisherman. With a few exceptions fish were small and concentrations low, only two samples had concentrations exceeding the limit value set by FAO/WHO for Hg levels in fish used for human consumption (FAO, 1995). It is probably the high particle content that poses the greatest mining-related environmental threat to the river system. Since the 1990s, the area has been industrialized and exploitation of the gold deposits increased rapidly.

Moehti Moemi
In the Moehti Moemi mining area, sampling was difficult due to an ongoing conflict. Water samples were only taken at two stations believed to be affected by wastewater from past mining activities. In general, the concentrations of the measured parameters at the reference station were lower than at the two stations within the mining area. Most striking were the MeHg concentrations, which were very high in both mining stations (> 1 ng/L). In the reference station, MeHg concentrations were below the detection limit.

Bago
Water samples analysed in the Bago system indicated sediment and nutrient inputs, but not obvious metal pollution. Compared with the other sites investigated for effects from mining activities, Bago is suitable as a reference station (when considering water data).

4 Concluding remarks

This is the final report from outcome 1 (Ecological water quality status assessment) of the Integrated Water Resources Management – Institutional Building and Training (IWRM) projects I and II, a collaboration between the Ministry of Natural Resources and Environmental Conservation (MONREC) and the Norwegian Institute for Water Research (NIVA) under the Norwegian – Myanmar Bilateral Environment Programme phase I and II (2015 – 2023). As the project collaboration ended in 2021 due to the military coup in Myanmar the planned investigations about the ecological status of rivers and lakes and mining activities could not be fully completed. The limited dataset which has been collected in Myanmar during the study period until 2020 does not yet enable the implementation of a final classification systems for the ecological status of rivers and lakes in Myanmar. The first results indicate, however, that the use of European classification systems for rivers and lakes achieve reasonable results when applied to lakes and rivers in Myanmar. This could be shown for two river catchments the Sittaung and Bago sub-basins and for the two biggest natural lakes Indawgyi Lake and Inlay Lake in Myanmar.

Although data of 15 additional lakes have been collected and partly analysed a higher number of river catchments and lakes in different areas in Myanmar need to be investigated to adapt the European classification systems to the different conditions in Myanmar.

In the European Water Framework Directive (EU WFD), that served as inspiration for the Myanmar NWFD, ecological status assessments of rivers and lakes are largely based on the outcome of bioassessments. Environmental conditions are assessed by the five status classes: high, good, moderate, poor, and bad. Water bodies that do not achieve at least good status are legally obliged to be restored to this state, i.e., allowing for only minor deviation from natural states. The effectiveness and wide applicability of such approaches have considerable value for detecting and diagnosing human-induced perturbations on rivers and lakes, including those in Myanmar. Given the gross pollution of rivers and lakes in the study area, along with the importance of healthy surface waters for a large majority of the Myanmar population, citizen science projects would probably be much appreciated by locals and could further expand biomonitoring interests. Citizen science projects, largely founded on voluntary work from local stakeholders, should be supervised by a coming generation of trained water ecologists in Myanmar, that eventually allows for more advanced freshwater studies.

It is ultimately the management authorities in Myanmar that will need to expand their approaches to cover the whole country, sensu the Myanmar NWFD. Experiences from the two selected river study areas (Sittaung and Salween River Basins) and the selected 17 lakes and reservoirs across Myanmar should be expanded to other areas in Myanmar. However, the investigation of more rivers and lakes is needed to implement a nation-wide water framework directive, with legally binding actions for water quality, like in the EU WFD. Substantial capacity building is still required in Myanmar, there being a need for local personnel trained to conduct the river and lake characterizations, monitoring, and assessments. There is also a need for more well-equipped laboratory facilities, and experts in taxonomy and ecology. Such capacity takes time to build and thus requires a strong political will to support the activities in a long-term perspective. Although the current political situation in Myanmar put a halt to our biomonitoring activities, the reports and scientific papers comprised in this project have led to a set of recommendations that hopefully will be an impetus for future river and lake biomonitoring in Myanmar.

The project has transferred knowledge about freshwater ecology to selected staff from the FRI and other local staff and enabled a doctoral degree to a student from Myanmar. As the knowledge about the ecological status of most of the many water bodies in Myanmar is still poor a much bigger number of freshwater ecologists need to be educated to achieve the goal of classifying their status and to find solutions for their improvement.

5 Project publications and theses

The project resulted in several reports, scientific publications, manuals, one master thesis and two PhD theses.

Reports

Ballot, A., Mjelde, M., Swe, T. 2018. Integrated Water Resources Management in Myanmar. Assessing ecological status in Inlay Lake. NIVA-report 7301-2018.

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Mjelde, M., Ballot, A., Swe, T. 2018a. Conservation of biodiversity and improved management of protected areas in Myanmar. Aquatic macrophytes and phytoplankton in Indawgyi Lake. NIVA-report 7253-2018.

Mjelde, M., Ballot, A., Swe, T., Eriksen, T.E., Nesheim, I., Aung, T.T. 2017. Integrated Water Resources Management in Myanmar. Water usage and introduction to water quality criteria for lakes and rivers in Myanmar. NIVA-report 7163-2017.

Mjelde, M., Wathne, B.M. 2015. Report from: Introductory Study in Moeyingyi reservoir and Indawgyi Lake. NIVA, 15. June 2015.

Scientific publications

Ballot, A., Swe, T., Mjelde, M., Cerasino, L., Hostyeva, V., Miles, C.O. 2020. Cylindrospermopsin- and deoxycylindrospermopsin-producing Raphidiopsis raciborskii and microcystin-producing Microcystis spp. in Meiktila Lake, Myanmar. Toxins 12(4), 232.

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Eriksen, T. E.; Jacobsen, D.; Demars, B.O.L.; Brittain, J. E.; Søli, G.; Friberg, N. 2021. Effects of pollution-induced changes in oxygen conditions scaling up from individuals to ecosystems in a tropical river network. Science of the Total Environment (2021) 151958.

Mjelde, M., Swe, T., Langangen, A., Ballot, A. 2020. A contribution to the knowledge of Charophytes in Myanmar; morphological and genetic identification and ecology notes. Botany Letters DOI: 10.1080/23818107.2020.1847189.

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Swe, T., Miles, C.O., Cerasino, L., Mjelde, M., Kleiven, S., Ballot, A. 2021b. Diversity of cyanobacteria and cyanotoxins in Yezin Dam, Myanmar. Limnologica 90, 125901.

Manuals

Mjelde, M., Ballot, A., Swe, T. 2018. Aquatic macrophytes in lakes in Myanmar 2014-2020. Field survey and identification. NIVA-report in preparation.

Mjelde, M., Ballot, A. 2023. Field survey methods in lakes, reservoirs and rivers in Myanmar (including field protocol). NIVA-report in preparation.

Theses

One masters and two PhD candidates were able to finish their studies during the project period.

1. Mathias Brink Kjeldgaard: Anthropogenic impact on fish communities and trophic relations in streams in Myanmar. Master Thesis University of Copenhagen 2021.

2. Thida Swe: The Ecology of Phytoplankton with focus on Cyanobacteria and Aquatic Macrophytes in selected Lakes and Reservoirs of Myanmar. Forest Research Institute, Myanmar and University of South-Eastern Norway, Norway. PhD thesis February 2023.

3. Tor Erik Eriksen: A macroinvertebrate-based biomonitoring tool for diagnosing environmental conditions of rivers in Myanmar – a novel approach in a biodiversity hotspot. PhD thesis University of Oslo, Norway. May 2022

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Eriksen T.E. 2022. A macroinvertebrate-based biomonitoring tool for diagnosing environmental conditions of rivers in Myanmar – a novel approach in a biodiversity hotspot. PhD thesis University of Oslo, Norway. May 2022

Eriksen, T. E.; Friberg, N.; Brittain, J. E; Søli, G.; Ballot, A.; Årstein-Eriksen, E.; Blakseth, T. A.; Braaten, H. F. V. 2021. Ecological condition, biodiversity and major environmental challenges in a tropical river network in the Bago District in South-central Myanmar. First insights to the unknown. Limnologica 2021 86, 125835

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6 Appendix

Table A1a. Numeric ranges applied for the most used type factors for **lakes** in the EU WFD (ETC/ICM, 2015).

Type factor	Categories	Numeric ranges for Europe
Altitude	lowland mid-altitude highland	<200 masl 200-800 masl >800 masl
Surface area	very small small medium large very large	<0,5 km^2 0,5-1 km^2 1-10 km^2 10-100 km^2 >100 km^2
Mean water depth	very shallow shallow deep	<3 m 3-15 m >15 m
Geology	siliceous calcareous organic/humic mixed	alkalinity: <1 mEq/l, calcium: <20 mg Ca/l and colour: <30 mg Pt/l alkalinity: >1 mEq/l, calcium: >20 mg Ca/l and colour: <30 mg Pt/l colour: >30 mg Pt/l any

Table A1b. Numeric ranges applied for the most used type factors for **rivers** in the EU WFD (ETC/ICM, 2015).

Type factor	Categories	Numeric ranges for Europe
Altitude	lowland mid-altitude highland	<200 masl 200-800 masl >800 masl
Catchment size (upstream area)	very small small medium large very large	<10 km^2 10-100 km^2 100-1000 km^2 1000-10 000 km^2 >10 000 km^2
Geology	siliceous calcareous organic/humic mixed	alkalinity: <1 mEq/l, calcium: <20 mg Ca/l and colour: <30 mg Pt/l alkalinity: >1 mEq/l, calcium: >20 mg Ca/l and colour: <30 mg Pt/l colour: >30 mg Pt/l any

Table A2. Water quality criteria to assess the ecological status in lakes and rivers.

	LAKES	RIVERS
Biological quality elements		
Phytoplankton: - chlorophyll a (µg/l) - Total algal biomass (mg/l) - Species composition - Cyanobacterial biomass (mg/l)	+ + + + +	- - - - -
Aquatic macrophytes: - abundance - species composition	 + +	 (+) (+)
Periphyton: - abundance - species composition	 (+) (+)	 + +
Macroinvertebrates (bottom fauna) - abundance - species composition - Indicator organisms:	 (+) (+) Amphipod *Gammarus lacustris*, Tadpole shrimps, noble crayfish	 + + Freshwater pearl mussel, noble crayfish
Fish - Abundance	 +	 +
Physico-chemical quality elements		
Secchi depth (m)	+	-
Oxygen (close to bottom) (mg/l)	+	+
Total phosphorous (µg/l)	+	+
Ammonium (NH4 + NH3) (mg/l)	+	+
Total nitrogen (µg/l)	+	+
pH	+	+
ANC (acid neutralizing capacity) (µekv/l)	+	+
LAL (labile aluminium) (µg/l)	+	+
Concentration of quantitative significant micropollutants (heavy metals and organic micropollutants)	+	+
Hydromorphology: - Water level variations - Water flow regulations	 + 	 + +

Table A3. Boundaries for total phosphorous (TP) in different lake types in **Norway** (used for lakes in Myanmar) (from Direktoratsgruppa 2015).

Altitude	Type	high	good	moderate	poor	bad
Lowland	siliceous, clear, shallow	1-7	7-11	11-20	20-40	>40
Lowland	siliceous, clear, deep	1-4	4-9	9-16	16-38	>38
Lowland	siliceous, humus-rich	1-11	11-16	16-30	30-55	>55
Lowland	calcareous, clear	1-10	10-17	17-26	26-42	>42
Lowland	calcareous, humus-rich	1-13	13-20	20-39	39-65	>65
Forest	siliceous, clear	1-5	5-10	10-17	17-36	>36
Forest	siliceous, humus-rich	1-9	9-13	13-24	24-45	>45
Forest	calcareous clear	1-7	7-11	11-20	20-40	>83
Mountains	siliceous, clear	1-3	3-5	5-11	11-20	>40
Mountains	siliceous, humus-rich	1-5	5-10	10-17	17-36	>36

Table A4. Boundaries for total nitrogen (TN) in different lake and river types in **Norway** (used for lakes in Myanmar) (from Direktoratsgruppa 2015).

Altitude	Type	high	good	moderate	poor	bad
Lowland	siliceous, clear, shallow	1-325	325-475	475-775	775-1350	>1350
Lowland	siliceous, clear, deep	1-200	200-400	400-650	650-1300	>1300
Lowland	siliceous, humus-rich	1-475	475-650	650-1075	1075-1755	>1755
Lowland	calcareous, clear	1-425	425-675	675-950	950-1425	>1425
Lowland	calcareous, humus-rich	1-550	550-775	775-1325	1325-2025	>2025
Forest	siliceous, clear	1-250	250-425	425-675	675-1250	>1250
Forest	siliceous humus-rich	1-400	400-550	550-900	900-1500	>1500
Forest	calcareous humus -rich	1-475	475-650	650-1075	1075-1755	>1755
Mountains	siliceous, clear	1-175	175-250	250-475	475-775	>775
Mountains	siliceous humus-rich	1-250	250-425	425-675	675-1250	>1250

Table A5. Boundaries for total phosphorous (TP) in different rivers types in **Norway** (used for lakes in Myanmar) (from Direktoratsgruppa 2015).

Altitude	Type	high	good	moderate	poor	bad
Lowland	siliceous, clear, shallow	1-11	11-17	17-30	30-60	>60
Lowland	siliceous, humus-rich	1-17	17-24	24-45	45-83	>83
Lowland	calcareous, clear	1-15	15-25	25-38	38-65	>65
Lowland	calcareous, humus-rich	1-20	20-29	29-58	58-98	>98
Forest	siliceous, clear	1-8	8-15	15-25	25-55	>55
Forest	siliceous, humus-rich	1-14	14-20	20-36	36-68	>68
Forest	calcareous humus -rich	1-17	17-24	24-45	45-83	>83
Mountains	siliceous, clear	1-5	5-8	8-17	17-30	>30
Mountains	siliceous humus-rich	1-8	8-15	15-25	25-55	>55

Table A6. Boundaries for ammonium (NH_4+NH_3) and free ammonia (NH_3) in lakes and rivers in **Norway** (from Direktoratsgruppa 2015).

Watertype	Parameter	high	good	moderate	poor	bad
All types	free ammoniac (NH_3)	1-5	5-10	10-15	15-25	>25
All types	Total ammonium (NH_3+NH_4)	10-30	30-60	60-100	100-160	>160

* only valid for pH > 8 and temp. > 25 ^{0}C.

Table A7. Class boundaries for phytoplankton-indices in **Norwegian lakes** (used for lakes in Myanmar). H=high, G=good, M=moderate, P=poor, B=bad.

Lake-Type	Class	chlorophyll µg/l	Biovolume mg/l	PTI	Cyanomax mg/l
Lowland, calcareous, clear, shallow	**H**	<6	<0,64	<2,26	<0,16
	G	6-9	0,64-1,04	2,26-2,43	1,00
	M	9-18	1,04-2,35	2,43-2,60	1,00-2,00
	P	18-36	2,35-5,33	2,60-2,86	2,00-5,00
	B	>36	>5,33	2,86-4,0	>5,00
Lowland, siliceous, clear, shallow or Forest, calcareous, clear, shallow	**H**	<4	<0,40	<2.17	<0,16
	G	4-6	0,40-0,64	2,17-2,34	0,16-1,00
	M	6-13	0,64-1,60	2,34-2,51	1,00-2,00
	P	13-27	1,60-3,79	2,51-2,69	2,00-5,00
	B	>27	>3,79	2,69-4,0	>5,00
Lowland, siliceous, clear, deep	**H**	<2	<0,18	<2,09	<0,16
	G	2-4	0,18-0,40	2,09-2,26	0,16-1,00
	M	4-7	0,40-0,77	2,26-2,43	1,00-2,00
	P	7-15	0,77-1,90	2,43-2,60	2,00-5,00
	B	>15	>1,90	2,60-4,0	>5,00
Lowland, siliceous, humus-rich, shallow or Forest, calcareous, humus-rich, shallow	**H**	<5,4	<0,60	<2,26	<0,16
	G	5,4-9	0,60-1,00	2,26-2,43	0,16-1,00
	M	9-16	1,00-2,00	2,43-2,60	1,00-2,00
	P	16-32	2,00-4,60	2,60-2,86	2,00-5,00
	B	>32	>4,60	2,86-4,0	>5,00
Lowland, siliceous, clear, shallow or deep Forest, siliceous, clear, shallow or deep	**H**	<2	<0,18	<2,00	<0-0,16
	G	2-4	0,18-0,40	2,00-2,17	0,16-1,00
	M	4-7	0,40-0,77	2,17-2,34	1,00-2,00
	P	7-15	0,77-1,90	2,34-2,51	2,00-5,00
	B	>15	>1,90	2,51-4,0	>5,00
Lowland or forest, siliceous, humus-rich, shallow	**H**	<4	<0,40	<2,17	<0,16
	G	4-6	0,40-0,64	2,17-2,34	0,16-1,00
	M	6-12	0,64-1,46	2,34-2,51	1,00-2,00
	P	12-25	1,46-3,46	2,51-2,69	2,00-5,00
	B	>25	>3,46	2,69-4,0	>5,00
Lowland, calcareous, humus-rich, shallow	**H**	<7	<0,77	<2,39	<0,16
	G	7-10,5	0,77-1,24	2,39-2,56	0,16-1,00
	M	10,5-20	1,24-2,66	2,56-2,73	1,00-2,00
	P	20-40	2,66-6,03	2,73-3,07	2,00-5,00
	B	>40	>6,03	3,07-4,0	>5,00

Table A8. Suggested eutrophication sensitivity for aquatic macrophytes identified through our investigations in Myanmar lakes (from Ballot et al 2018). The background for the sensitivity is explained in Mjelde et al (2017). S=sensitive, T=tolerant, I=indifferent.

Latin names	Preliminary sensitivity
ELODEIDS	
Ceratophyllum demersum	T
Hydrilla verticillata	S
Limnophila sessiflora	I
Myriophyllum spicatum	T
Myriophyllum verticillatum	T
Najas indica	I
Najas minor	I
Nechamandra alternifolia	T
Potamogeton crispus	I
Potamogeton lucens	S
Potamogeton nodosus	I
Potamogeton pusillus	I
Potamogeton nodosus-hybrid?	-
Potamogeton sp.	-
Stuckenia pectinata	T
Utricularia aurea	S
Utricularia australis	S
Utricularia punctata	S
Utricularia stellaris	S
Utricularia sp	S
Vallisneria spiralis	I

Latin names	Preliminary sensitivity
NYMPHAEIDS	
Euryale ferox	S
Nelumbo nucifera	I
Nymphaea cyanea	I
Nymphaea nouchali	I
Nymphaea pubescens	I
Nymphaea rubra	I
Nymphoides indica	T
Nymphoides hydrophylla	T
Nymphoides cordata	T
Ottelia alismoides	I
Ottelia ovalifolia	I
Trapa natans v. bispinosa	T
Trapa natans v. natans	T
LEMNIDS	
Azolla pinnata	T
Eichornia crassipes	T
Lemna trisulca	I
Pistia stratiotes	T
Spirodela polyrhizza	I
Salvinia cucullate	T
Salvinia natans	T
CHAROPHYTES	
Chara sp. zeylandica	S

Table A9. Class boundaries for the aquatic macrophyte TIc-index in **Norwegian** lakes. H=high, G=good, M=moderate, P=poor, B=bad (from Direktoratsgruppa 2015).

Lake type		Calsium mg Ca/l	Colour mg Pt/l	reference value	H/G	G/M	M/P	P/B
001	Very low alkalinity, clear	<1	<30	95	92	55	40	15
002	Very low alkalinity, humic	<1	>30	78	71	55	40	15
101	Low alkalinity, clear	1-4	<30	79	75	55	40	15
102	Low alkalinity, humic	1-4	>30	78	71	55	40	15
201	Moderate alkalinity, clear	4-20	<30	74	66	30	5	-35
202	Moderate alkalinity, humic	4-20	>30	69	67	30	5	-35
301	High alkalinity, clear	>20	<30	75	63	30	5	-35
302	High alkalinity, humic	>20	>30	73	63	30	5	-35

Table A10. Suggested abundance index, with possible metrics for assessing ecological status for aquatic macrophytes, tested in Inlay Lake.

Indices and metrics	High (5)	Good (4)	Moderate (3)	Poor (2)	Bad (1)
RA: relative abundance index					
- *Potamogeton lucens* [1]	3	4-5	2	1	0
-charophytes [1]	4-5	3	2	1	0
-lemnids [1]	0	1-2	3	4	5

RA: relative abundance, 1: one or more species at each locality with given semi-quantitative score,
2: average semi-quantitative score

Table A11. Relative abundance metrics for lemnids and for submerged species, with suggested boundaries, tested in Indawgyi Lake. The average of both metrics and all localities gives a number 1-5, where 5= high status, 4= good status, 3= moderate status, 2=poor status and 1= bad status.

Metrics/Ecological Class	High (5)	Good (4)	Moderate (3)	Poor (2)	Bad (1)
Coverage of lemnids [2]	0	1-2	3	4	5
Coverage of submerged species[2]	3	4-5	2	1	0

2: using average of highest semi-quantitative scores at each locality

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