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Assessing Ecological Status of Inlay Lake in Myanmar

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Contents

အင်းလေးကန်ရေ၏ ဂေဟစနစ်ဆိုင်ရာအရည်အသွေး အဆင့်အတန်းအား ဆန်းစစ်လေ့လာခြင်း

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ယဉ်ကျေးမှုအမွေအနှစ်များ ကြွယ်ဝမှု၊ သာယာလှပမှုနှင့် ဇီဝမျိုးစုံမျိုးကွဲများ ပေါများမှုတို့ကြောင့် ရှမ်းပြည်နယ်၊ ညောင်ရွှေမြို့နယ်အတွင်းရှိ အင်းလေးကန်သည် နိုင်ငံသားတို့အတွက် အရေးပါသည့် ဒေသတစ်ခုဖြစ်ပါသည်။ အင်းလေးကန်ဒေသသည် လူနှင့် ပတ်ဝန်းကျင် ယှဉ်တွဲနေထိုင်သည့် ပြယုဂ်တစ်ခုဖြစ်သောကြောင့် ယူနက်စကိုမှ လူသားနှင့် ဇီဝအဝန်းဒေသ (MAB) ဟု သတ်မှတ်ခြင်း ခံထားရပါသည်။ သို့သော်လည်း လူဦးရေတိုးပွားလာမှု၊ စိုက်ပျိုးရေးနှင့် ခရီးသွားလာရေးလုပ်ငန်း ဖွံ့ဖြိုးတိုးတက်လာမှု တို့ကြောင့် ကန်၏ ပါတ်ဝန်းကျင်အနေအထားများ ယိုယွင်း လာလျက်ရှိပါသည်။

အင်းလေးကန်၏ဂေဟအဆင့်အတန်း (Ecological Status) ကို သတ်မှတ်ရန်အတွက် ရေ၏ ဂေဟစနစ်ဆိုင်ရာ အရည်အသွေးအား သတ်မှတ်သည့်စံများ ထားရှိရန်လိုအပ်ပါသည်။ ဤသုတေသနစာတမ်းတွင် အင်းလေးကန်၏ ရေ အရည်အသွေးအား ၂၀၁၄ ခုနှစ်မှ ၂၀၁၇ ခုနှစ်အထိ တိုင်းတာစိစစ်ထားရှိမှုကို အခြေခံ၍ ကန်၏ ဂေဟစနစ် ဆိုင်ရာ အရည်အသွေးနှင့်ဆိုင်သည့် စံများအား ဥရောပသမဂ္ဂ၏ ရေသယံဇာတ မူဘောင် (EU Water Framework Directive – EU WFD) ကို အခြေခံ၍ ဆောင်ရွက်ထားမှုကို တင်ပြထားပါသည်။

Assessing Ecological Status of Inlay Lake in Myanmar

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Inlay lake, a freshwater lake located in the Nyaungshwe Township of Taunggyi District of Shan State, is of particular importance to the Myanmar people due to its cultural significance, beauty, and aquatic biodiversity present. The close relationship between people and the lake has been described as a symbiosis, and the lake is accepted as a "Man and the Biosphere Area (MAB)" in 2015. The lake is suffering from environmental effects of increased population and rapid growth in both agriculture and tourism. Assessing the ecological status of the lake requires knowledge of ecological water quality criteria.

This paper is a part of the report on the ecological assessment of Inlay lake under the project ***Integrated water resources management – Institutional building and training***, 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 2015-2018. The paper presents the approach and the methods for ecological status classification according to the EU WFD and provides a preliminary status classification for Inlay Lake based on field work in 2014-2017.

Physical measurements, water and phytoplankton samples and aquatic macrophytes were collected at several sites in different parts of the lake. Inlay lake can be characterized as a mid-altitude, very large and very shallow, calcareous, clear lake, and the nutrient concentration show mesotrophic-semi-eutrophic conditions. Preliminary ecological status for phytoplankton and aquatic macrophyte are suggested based on different indices. Preliminary recommendation for a monitoring programme for Inlay Lake are included.

Assessing Ecological Status of Inlay Lake in Myanmar

1. Introduction

Water quality standards are law or regulations being adopted to enhance water quality and to protect human health and ecosystems. Water quality criteria describe the quality of water that will support a designated use and it may be expressed as either numeric limits or in a narrative statement. Assessing water quality in a water body is relevant from two viewpoints: 1) to describe degree of pollution or degree of human impact, and 2) the suitability of a waterbody for a particular use.

The National Water Resources Committee (Myanmar) adopted in 2014 the National Water Framework Directive (NWFD). The NWFD presents seven principles for achieving good ecological status for the water quality elements in Myanmar water bodies and river basins. The EU Water Framework Directive (EU WFD) uses an ecosystem-based approach for characterizing and classifying water quality through the use of ecological water quality criteria. The EU WFD water quality criteria refer to the same water quality elements, i.e. biological, physical-chemical and hydro-morphological elements.

This paper is a part of the report on the ecological assessment of Inlay lake under the project ***Integrated water resources management – Institutional building and training***, 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 2015-2018. The project aims to make a significant contribution to the implementation of well-functioning Integrated Water Resources Management (IWRM) for inland waters at the national level for Myanmar.

2. Objectives

The main purpose of the paper is to give improved knowledge about aquatic biodiversity and water chemistry in Inlay Lake of Myanmar. Then, selected methods and analyses will be used to develop a sampling and analysis protocol for Inlay Lake, which will also be suitable for other lakes in Myanmar.

3. Material and Methods

3.1 Study Area

Inlay Lake is situated in Nyaung Shwe township, Taunggyi District, Southern Shan State, in the eastern part of Myanmar (Figure 3.1), and is the second largest natural lake in Myanmar. It is located in 884 meters above sea level in the Balu Chaung valley between the Sinduang (east) and Letmaunggwe, Thandaung and Udaung mountain ranges (west). Today, the length of the lake is about 18 km and the width is 6 km. The lake surface is 116 km^2, however, varying from about 150 km^2 in the rainy season and 100 km^2 in the dry season. It is a shallow lake, where maximum depth varies between approx. 4 m in the dry season and 5-6 m in the rainy season (IID *et al* 2012). The average depth is around 1,5 m in the dry season. In 2014-2015 a maximum depth of 3,7 m was measured (Table 3.1). The volume of Inlay lake is 790 x106 m^3. With a total water inflow of 1132 x 10^6 m^3 per year, the residence time can be estimated to 0,3 years (IID 2012).

Table 3.1. Characteristic data about Inlay lake

Water body	Inlay
State	Shan
type	natural lake
latitude	20,5725
longitude	96,911389
Altitude (m) a.s.l.	884
lake area (km^2)	116
max. depth (m)	3.9*
mean depth (m)	2.44

Figure 3.1. Inlay Lake in Myanmar

(*Source: The overview-map from www.albatros-travel.no and the lake map from google earth*)

The general formation of the lake is Shan Plateau limestone (Akaishi 2006), with limestone, dolomite and sandstone as the main bedrock components (http://www. mappery.com/Myanmar-Burma-Rock-Types-Map). As a result of the dominant limestone in the watershed, Inlay Lake is naturally alkaline, with high calcium content and pH values generally >8. In addition, the bedrock in the Inlay valley is covered by several meters with soil. The soil is mountainous brown and yellow brown, classified as Cambisol and Ferrasols according to FAO classification (MOECAF 2014).

The deforestation in the Inlay lake watershed is large. While open and closed forest cover 16 % and 7 %, respectively, degraded forest covers 30 % of the watershed (MOECAF 2014). Deforestation is expected to be the main reason for the increasing silt load to Inlay lake. The Forest Department of Myanmar has initiated an action plan, including natural forest protection, establishing forest plantation, etc., (MOECAF 2014).

The main business in Inlay Lake is agriculture on the floating gardens. Tomato production from the lake farmers is over 300 tonnes/day in the tomato growing seasons, with annual production about 90,000 tonnes (for two growing seasons) (IID 2012). The floating islands are cultivated approximately 15 years dependent on the floatability of the submerged mattress of vegetation and farmers' practices (Htwe 2015, referring to Than 2007). The farmers use chemical fertilizers, pesticides, and organic fertilizers for the tomato gardens. Win (1996) (cited in Butkus and Su, 2001) derived the loading capacities of eleven pesticides commonly used in tomato cultivation. He reported that the amounts of the pesticides applied far exceed the loading capacity of Inlay Lake for each of these pesticides.

Other business are fisheries, textile industries, weaving, gold- and silver-smith (Akaishi 2006, referring to Ba 2003). FAO (2004) has estimated the annual production of the fisheries in Nyaungshwe township to 550–650 tons. The lake is also important for transporting products around it and into distant townships.

Large volumes of silt as well as water are transported to the lake through the rivers (Table 3.2). Based on the numbers in the table, the total silt inflow from all sub-catchments can be estimated to c. 270,000 tons per year (around 200 g silt per m^3 water), whereas 62 % deposited in deltas, 20 % deposited in marshes and 1% deposited in the lake (Furuichi 2008).

Table 3.2 Inflow and silt load through the main inlet rivers. Data summarised by IID (2012).

These values are slightly different from data from Shan State Irrigation Department (MOECAF 2014)

River	Watershed area km^2	Water inflow 10^6 m^3/yr	Silt flow t/yr	Run-off $m^3/yr/km^2$	Silt load $t/yr/km^2$
Nam Let (Nant Latt) Chaung	1149	505,5	104 000	439 948	91
Negya (Ye Pae) Chaung	250	92,5	19 000	370 000	76
Kalaw (Ka Law) Chaung	742	275,6	56 000	371 430	75
Indein (Nam Bilu) (Upper Belu?) Chaung	813	479,6	98 293	589 914	121
Balu Chaung (outlet river)	3640	332*			

*: outflow

3.2 Water Sampling and Biology Survey

Inlay Lake is dominated by an intensive growth of aquatic macrophytes. Due to this circumstance the program for physico-chemical and biological sampling has been adapted accordingly. As a first comprehensive sampling program for physico-chemical and biological parameters, three transects with 4-5 sampling points each in different parts of the lake were selected (Figure 3.2).

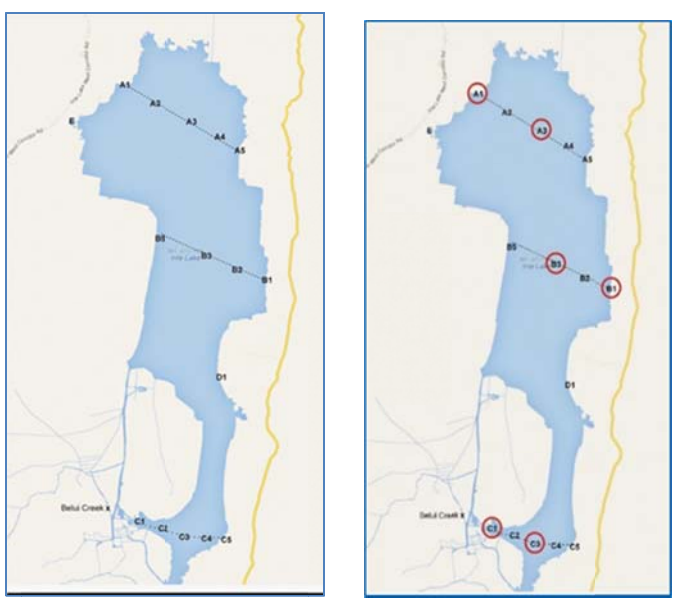


Figure 3.2. Sampling points for comprehensive sampling (left) and reduced set of sampling points for monthly sampling, red circles (right).

All 14 sampling points were investigated in November 2014, and February and November 2015, for water chemistry, phytoplankton and aquatic macrophytes. In addition, 3 more points were sampled for aquatic macrophytes (D, E1 and E2). At a reduced number of six sampling points (see Figure 3.2), phytoplankton and physico-chemical parameters was monthly sampling from March 2015 until December 2015 and from January 2017 to until now.

Additionally, water samples for physio-chemical parameters were sampled in the inflowing river Belui (Belu) in November 2014, and February and November 2015. In November 2015, water samples from two additional inflowing rivers, Nei Gyar (Ye Pae) and Tham Daung (Nant Latt), and from the outlet river, were also sampled.

3.3 Field and analysis methods

3.3.1. Physical measurement and water chemistry

All sample and analyse methods are in according to suggested methods in Mjelde *et al*. (2017). The measurements and water samples were taken at approx. 20 cm water depth at selected localities in the lake. The water samples were preserved in the field with 4M H_2SO_4 for nutrient analysis (Total P, Ortho phosphorous, Nitrate-Nitrite, Total Nitrogen, etc.) or not preserved for analysis of Turbidity, Total Alkalinity, Color, Calcium and other cations. These samples were analysed at NIVA and Water Quality Laboratory in FRI, Yezin. In Table 3.3-3.8, boundaries for selected physico-chemical parameters in different lake types in Norway are depicted (Direktoratsgruppen 2015). These boundaries will be used to assess the physico-chemical status of Inlay lake and the inlet and outlet rivers.

Table 3.3. Boundaries for Secchi depth in different lake types in Norway.

Altitude	Type	high	good	moderate	poor	bad
Lowland	siliceous, clear, shallow	>6	4-6	2-4	1-2	<1
Lowland	siliceous, clear, deep	>8	5-8	3-5	1,5-3	<1,5
Lowland	siliceous, humus-rich	>4	3-4	1,5-3	0,7-1,5	<0,7
Lowland	calcareous, clear	>4	3-4	1,5-3	0,7-1,5	<0,7
Lowland	calcareous, humus-rich	>3	2-3	1-2	0,5-1	<0,5
Forest	siliceous, clear	>8	6-8	3-6	1,5-3	<1,5
Forest	siliceous, humus-rich	>5	3,5-5	1,7-3,5	0,8-1,7	<0,8
Mountains	siliceous, humus-rich	>9	7-9	3,5-7	1,7-3,5	<1,7

Table 3.4. Boundaries for total phosphorous (TP) in different lake types in Norway.

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 3.5. Boundaries for total nitrogen (TN) in different lake and river types in Norway.

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 3.6. Boundaries for total phosphorous (TP) in different rivers types in Norway.

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 3.7. Boundaries for ammonium (NH_4+NH_3) and free ammonia (NH_3) in lakes and rivers in Norway.

Water type	Parameter	high	good	moderate	poor	bad
All types	free ammonia (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.

3.3.2. Phytoplankton

The abundance and composition of phytoplankton are important indicators for the ecological status of standing water bodies. The group of phytoplankton comprises microscopic prokaryotic cyanobacteria and eukaryotic algae. They are freely floating organisms, which move mainly with water currents. The highest biodiversity of phytoplankton organisms is often observed under lower nutrient concentrations. Increasing nutrient concentrations often lead to a decrease in phytoplankton biodiversity and an increase in biomass of some adapted phytoplankton taxa. At eutrophic conditions very often blooms of one or a few phytoplankton taxa can be observed. In lakes and reservoirs, the spatial variation of phytoplankton can be very variable vertically and horizontally. In many cases the vertical variation is higher than the horizontal variation. However, a higher variability in horizontal distribution of phytoplankton taxa and their biomasses has often been observed (patchiness).

The knowledge about phytoplankton in Asia and especially in Myanmar is scarce. However, several phytoplankton organisms are found both in tropical and temperate regions. This allows a determination of many species with standard literature from Europe and North America (e.g. Büdel *et al*. 1978-2015, Croasdale 1983, Huber-Pestalozzi 1969, Komárek *et al*. 1983, Prescott *et al* 1977, 1981, 1982, Skuja 1949). Several taxa, however, can only be determined to genus or family level so far.

Field method

Qualitative and quantitative water samples for phytoplankton composition and biomass were taken at the selected sites in Inlay lake. All samples were fixed with Formaldehyde (for qualitative analysis) or acidic Lugol's solution (for quantitative analysis), stored in the dark and later analysed at NIVA using inverted and compound microscopy.

Analysis methods

The species are identified to species or genus level, using selected identification keys (see references). Additionally, genetic methods are used for the identification of some uncertain taxa.

Trophic indices

Several parameters are used to characterize the ecological status of lakes with phytoplankton: chlorophyll a, total bio-volume of phytoplankton, Phytoplankton Trophic Index (PTI) and biomass of cyanobacteria. Phytoplankton composition and biomass reacts very sensitive against an increase in nutrients, especially nitrogen and phosphorous. In a weak eutrophication process the phytoplankton biomass increases and the phytoplankton composition changes. In a strong eutrophication process the phytoplankton diversity will be reduced to some species which often develop blooms. In many cases cyanobacteria are responsible for such blooms. A number of cyanobacterial species is also known to be able to produce toxic compounds which pose a risk for the health of humans and animals. The four indices which are developed for phytoplankton combine all the changes and are well correlated to total phosphorous in lakes. Chlorophyll- a is the most important pigment involved in the photosynthesis of phytoplankton and can be used as a proxy for phytoplankton biomass.

The phytoplankton Trophic index (PTI) describes the increase of tolerant species (often nuisance algae or cyanobacteria) and the reduction of sensitive taxa along the phosphorus gradient. The index is based on a modification of Ptacnik *et al.* (2009). It sums up the indicator value for each taxon in a sample in relation to the proportion of each taxon in the sample. The indicator value for each taxon can vary from 1 to 5. The index value for lakes can vary between 1,5 and 4,0. The maximum volume for cyanobacteria (Cyanomax) describes the presence of unwanted cyanobacteria.

$$\mathrm{PTI}=\frac{\sum_{j=1}^{n} a_j s_j}{\sum_{j=1}^{n} a_j}$$

Cyanobacteria are associated with eutrophication in lakes. They can produce high biomasses and are potential toxin producers. Their presence can limit the use of lakes as drinking water source for recreation and other purposes. This index reflects an unwanted disturbance of the phytoplankton community and is linked to risk levels of WHO (1999).

WHO defines different risk levels. The thresholds are 4 000, 20 000 and 100 000 cells/ml (WHO 1999). These values are converted to biovolume thresholds of 0,2, 1 and 5 mm^3/l (or mg/l) and multiplied with a cell volume (based on spherical cells like those from *Microcystis* with a cell diameter of 4,5 µm (Hillebrand *et al.* 1999).

Table 3.8. Class boundaries for phytoplankton-indices in Norwegian lakes. 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

3.3.3. Aquatic macrophytes

A simple definition of aquatic macrophytes is plants growing in or close to the water. They can be divided into semi-aquatic plants (i.e. emergent plants, helophytes) and aquatic macrophytes (hydrophytes), i.e. submerged plants or plants with floating leaves. In this study we only include aquatic macrophytes (hydrophytes), i.e. species in the lifeform groups *isoetids, elodeids, nymphaeids, lemnids*, and *charophytes* (Mjelde, in prep.).

Field method

The surveys of aquatic macrophytes in Inlay lake took place in November 2014, and February and November 2015. The survey included 17 different localities in the lake (see Figure 3.1 and Table 3.1). At each locality the plants were recorded using an aqua scope and collected by dredging from the boat (casting rake). The abundances of the species are scored by a semi-quantitative scale, where 1 = rare, 2 = scattered, 3 = common, 4 = locally dominant and 5 = dominant. The lake is very shallow, and the aquatic macrophytes are covering the whole depth gradient.

Analyse method

All species are identified to species levels, using the floras and identification keys suggested below. Most of the identification was done in the field. However, a few specimens of each species are collected and dried. This herbarium collection is used for identification using microscope and for genetic analysis.

Flora and identification keys

In the Asian region, some aquatic macrophyte genera are very variable without satisfactory taxonomic treatment. In addition, several genera have been cultivated for a long time, e.g. among the *Nymphaea* species, which may confuse the taxonomic identification. For species identification, we have used the keys in standard floras for the region, i.e. Cook 1996, in addition to updated or more specialized taxonomic work, e.g. Wiegleb 1990, Wiegleb & Kaplan 1998, Ito *et al*. 2014, Triest 1988, La-Ongsri-2008, in addition to different internet-sites like Flora of China (http//www.efloras.org) and Encyclopedia of life (http//eol.org). The *Chara*-species are identified based on Wood & Imahori 1965. However, for some difficult genera, additional genetic analysis are needed as an identification supplement.

Trophic index

Coverage and species richness of macrophytes decrease with increasing enrichment of lakes (Phillips, *et al*., 1978, Rørslett, 1991). The enrichment causes a change from the submerged isoetids or charophytes, via elodeids, to floating leaved or free-floating species, and in the end to phytoplankton. The decrease in submerged macrophyte cover and species diversity are mainly due to shading by phytoplankton, or epiphytic algae, or competition for nutrients (see Mjelde and Faafeng, 1997, with references).

For assessing ecological status of aquatic macrophytes in Inlay lake, we have used the Norwegian trophic index (Mjelde *et al*., in prep.) The index is based on the relationship between species sensitive to eutrophication and species that are tolerant to this impact.

$$TI_C = \frac{N_S - N_T}{N} \times 100$$

N_S is the number of sensitive species in the lake, while N_T is the number of tolerant species. N is the total number of all aquatic macrophyte species.

The index-value can vary between +100, if all present species are sensitive, and -100, if they are tolerant. The index calculates one value for each lake, however, for larger lakes index-values for different parts of the lake should be considered. The different species of aquatic macrophytes have various distribution patterns, and most of the species found in temperate regions in Northern Europe are rare or no-existing in the tropical regions, and vice versa. Therefore, the Norwegian list of sensitive and tolerant species is not suitable for Myanmar lakes. Species sensitivity has to be established exclusively for Myanmar or for South-eastern Asia. As a start, Mjelde *et al* (2017) suggested a preliminary list the list of sensitive and tolerant species, see Table 3.9. The list is an important basis for calculating the trophic index and give a correct ecological status.

Table 3.9. Preliminary eutrophication sensitivity for aquatic macrophytes in Myanmar.

See explanation in Mjelde *et al* 2017. S=sensitive, T=tolerant, I=indifferent.

Latin names	Preliminary sensitivity Myanmar species		Latin names	Preliminary sensitivity Myanmar species
ELODEIDS			***NYMPHAEIDS***	
Ceratophyllum demersum	T		*Euryale ferox*	S
Hydrilla verticillata	S		*Nelumbo nucifera*	I
Limnophila sessiflora	I		*Nymphaea cyanea*	I
Myriophyllum spicatum	T		*Nymphaea nouchali*	I
Myriophyllum verticillatum	T		*Nymphaea pubescens*	I
Najas indica	I		*Nymphaea rubra*	I
Najas minor	I		*Nymphoides indica*	T
Nechamandra alternifolia	T		*Nymphoides hydrophylla*	T
Potamogeton crispus	I		*Nymphoides cordata*	T
Potamogeton lucens	S		*Ottelia alismoides*	I
Potamogeton nodosus	I		*Ottelia ovalifolia*	I
Potamogeton pusillus	I		*Trapa natans v. bispinosa*	T
Potamogeton nodosus-hybrid?	-		*Trapa natans v. natans*	T
Potamogeton sp.	-		***LEMNIDS***	
Stuckenia pectinata	T		*Azolla pinnata*	T
Utricularia aurea	S		*Eichornia crassipes*	T
Utricularia australis	S		*Lemna trisulca*	I
Utricularia punctata	S		*Pistia stratiotes*	T
Utricularia stellaris	S		*Spirodela polyrhizza*	I
Utricularia sp	S		*Salvinia cucullata*	T
Vallisneria spiralis	I		*Salvinia natans*	T
			CHAROPHYTES	
			Chara sp. zeylandica	S

Table 3.10 shows the class boundaries for the TIc-index in Norwegian lakes. These boundaries are used as examples only, and may give a wrong result for Myanmar lakes. **Therefore, boundaries exclusively for Myanmar lakes have to be developed as soon as more data are available.**

Table 3.10. Class boundaries for the aquatic macrophyte TIc-index in Norwegian lakes. H=high, G=good, M=moderate, P=poor, B=bad.

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

As recommended by Mjelde *et al* (2017), we have tested metrics based the relative abundance of the lifeform groups charophytes and lemnids, in addition to the relative abundance of the sensitive elodeid *Potamogeton lucens* (Table 3.11). The average of all metrics and localities gives a number 1-5, where 5= high status, 4= good status, 3= moderate status, 2=poor status and 1= bad status. The boundaries are examples, and have to be tested with available data from Myanmar lakes.

In Inlay lake, high coverage of submerged macrophytes seem prevent massive growth of phytoplankton and especially nuisance cyanobacteria. A metric based, therefore, on submerged macrophyte coverage were also included.

Table 3.11. Suggested abundance index, with possible metrics for assessing ecological status for aquatic macrophytes.

metric	High (5)	Good (4)	Moderate (3)	Poor (2)	Bad (1)
RA: Potamogeton lucens [2]	3	4-5	2	1	0
RA: charophytes [2]	4-5	3	2	1	0
RA: lemnids [2]	0	1-2	3	4	5
Submerged macrophyte coverage [1]	5	3-4	2	1	0

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

2: semi-quantitative score

4. Results and Discussions

4.1 Identification of water bodies and typology

Based on the morphological data and water chemistry data (Table 2.1 and Table 4.2), Inlay Lake can be characterized as a **mid-altitude, very large and very shallow, calcareous, clear lake** (Table 4.1).

Table 4.1. Characteristic data for the investigated lakes (estimated lake areas)

Water body	**State**	**type**	**Altitude m.a.sl.**	**Lake Area km^2**	**Max. depth, m**	**Mean depth, m**	**Calcium mg Ca/l**	**TOC mg/l**
Inlay	Shan state	natural lake	884	116	3,9*	2.44*	48,8	4,8

*based on the data measured in November 2017

4.2 Water chemistry Status

Inlay Lake is a shallow lake with inflow from 4 large rivers. The water is clear; with turbidity variations between 4,5 and 5,7 FNU (Table 4.2). However, some of the inflowing rivers have higher turbidity (Table 4.3). The lake is a calcareous lake, with average calcium value at 49 mg Ca/l. With average colour values at 17 mg Pt/l it can be characterized as a clear lake. The nutrient content in Inlay Lake show mesotrophic-semi-eutrophic conditions (Salas and Martino 1991), however, see discussion in next chapter. Both phosphorous and nitrogen are generally higher in the investigated inlet rivers (Table 4.3 and 4.4).

The inflowing rivers transport total suspended solids (TSS), which includes inorganic and organic material, into the lake. The ranges measured in this study varied between 149 g/m^3 in Belui river and 48 g/m^3 in Nay Gyar. The loads are a little bit lower than the transport of 200 g silt/m^3 water described by IID (2012).

Table 4.2. Physical chemical data from Inlay Lake 2014-2015, 2017 (min, max and mean values).

Period 2014-2015	Water temp. °C	pH	Conductivity µS/cm	Turbidity FNU	Oxygen mg / l	Oxygen %	Silicate µg/l	TOC mg C/l
Min	20.30	7.33	286	0.54	1.3	16.0	1920	1.20
Max	28.00	9.43	491	6.64	14.0	185.2	13400	10.70
Mean	**24.67**	**8.23**	**369**	**2.34**	**7.2**	**95.8**	**6989**	**5.08**

Table 4.2. cont.

Period 2014-2015	Calcium mg Ca/l	Colour mg Pt/l	Tot-P/L µg P/l	PO4-P µg P/l	Tot-N/L µg N/l	NH4-N µg N/l	NO3-N+NO2-N µg N/l	Cl mg/l	SO4 mg/l
Min	46.7	16.7	3	1.0	290.0	26.0	3.0	6.4	2.9
Max	50.4	16.7	122	15.0	810.0	75.0	286.0	6.4	3.4
Mean	**48.6**	**16.7**	**17.1**	**3.6**	**478.3**	**40.2**	**33.8**	**6.4**	**3.2**

Table 4.3. Physical-chemical data from Belui (Belu) river 2014-2015 (min, max and mean values).

Period	Water temp., °C	pH	Conductivity µS/cm	Turbidity FNU	LOI mg/l	TSS mg/l	Oxygen mg O_2/ l	Oxygen %	Silicate µg/l	TOC mg C/l
Min	21.70	8.19	352	39	129	149	7.3	96.6	7590	0.6
Max	25.20	8.36	483	39	129	149	7.8	99.9	11400	1.4
Mean	**23.6**	**8.28**	**407**	**39**	**129**	**149**	**7.6**	**98.3**	**9495**	**1.0**

TSS = total suspended solids, LOI = loss of ignition

Table 4.3. cont.

Period 2014-2015	Calcium mg Ca/l	Colour mg Pt/l	Tot-P/L µg P/l	PO4-P µg P/l	Tot-N/L µg N/l	NH4-N µg N/l	NO3-N+NO2-N µg N/l	Cl mg/l	SO4 mg/l
Min	51.5	3	3	18	635	19	485	2.0	2.8
Max	51.5	3	122	57	690	30	550	2.0	2.8
Mean	**51.5**	**3**	**17.1**	**38**	**663**	**25**	**518**	**2.0**	**2.8**

Table 4.4. Physical chemical data from the inlet rivers Tham Daung (Nant Latt) and Nei Gyar (Ye Pae), and the Inlay outlet river (23. November 2015).

River	Water temp., °C	pH	Conductivity µS/cm	Turbidity FNU	LOI mg/l	TSS mg/l	Oxygen mg O_2/ l	Oxygen %	Silicate µg/l	TOC mg C/l
Tham Daung	24.0	8.19	483	-	54	61	-	-	9800	0.98
Nei Gyar	22.5	7.57	485	-	39	48	-	-	10600	4.7
Inlay outlet	24.1	7.61	367	-	-	-	-	-	11700	5

Table 4.4. cont.

River	Calcium mg Ca/l	Colour mg Pt/l	Tot-P/L µg P/l	PO4-P µg P/l	Tot-N/L µg N/l	NH4-N µg N/l	NO3-N+NO2-N µg N/l	Cl mg/l	SO4 mg/l
Tham Daung	-	-	27	14	620	14	500	-	-
Nei Gyar	-	-	42	20	560	60	130	-	-
Inlay outlet	-	-	23	8	475	40	20	-	-

4.2.1. Chemical classification

The parameters ammonium (NH_4), total nitrogen (TN) and total phosphorous (TP) were used for the chemical classification of Inlay Lake and selected inlet rivers.

Ammonium

Inlay lake has in most parts good chemical status according to the ammonium concentrations measured in 2014 and 2015. Only sampling point A4 was characterized by moderate ammonium concentrations (Figure 4.1). The four inflowing rivers are also characterized by good or even very good status. In Nei Gyar river (Ye Pae), in the North of Inlay lake, the ammonium concentration was at the boundary between good and moderate status.

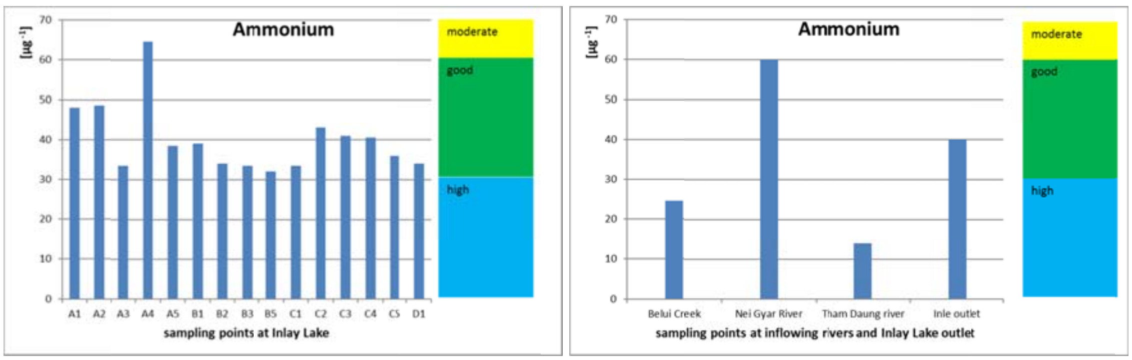


Figure 4.1. Classification of Inlay lake, tributaries Belui (Belu), Tham Daung (Nant Latt) and Nei Gyar (Ye Pae), and outlet river, using average ammonium concentrations (sampling points see Figure 3.1). The status is based on boundaries in Table 3.7

Total nitrogen

The parameter total nitrogen (TN) shows a similar picture (Figure 4.2). The sampling points A3, B3 and C3 located in the lake centre are characterized by a very good or good status. The other sampling points which are located close to the shore showed higher TN-concentrations, but are still in good status. This reflects clearly the influence of fertilizers and wastewater from the floating garden and villages. It can be assumed that most of the nutrients are taken up by the aquatic macrophytes which densely cover most parts of the lake bottom. This suggests, that most of the nutrients are not available for the growth of phytoplankton. All three inflowing rivers are a source for TN in Inlay lake. The TN-concentrations are slightly higher than those measured in Inlay lake. However, the concentrations measured are in a range which characterize the three investigated rivers as still being in a good status.

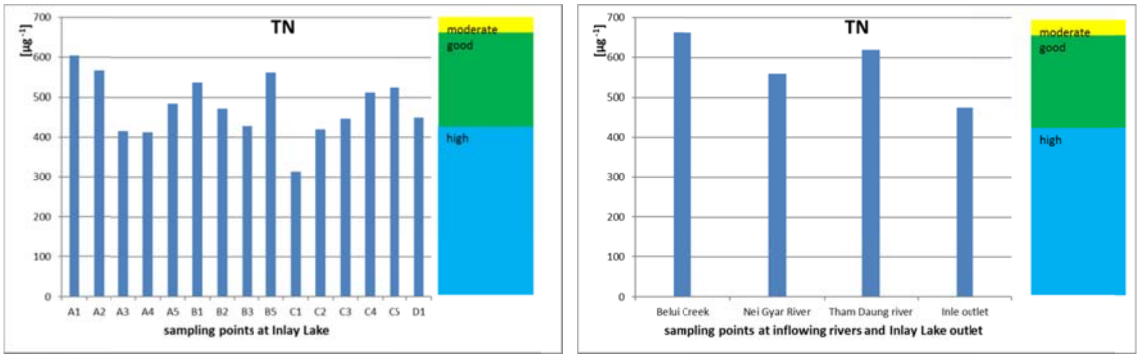


Figure 4.2. Classification of Inlay Lake, tributaries Belui (Belu), Tham Daung (Nant Latt) and Nei Gyar (Ye Pae), and outlet river using average total nitrogen (TN)-concentrations (sampling points see Figure 3.1). The status is based on boundaries in Table 3.5

Total phosphorus

The parameter total phosphorous (TP) depicts best the ecological status of Inlay lake (Figure 4.3). The sampling points A2-4 and B2-3 in the lake are characterized by very good and good status. All sampling points close to the shore and the sampling points in the C transect are characterized by a moderate to very poor status regarding TP. Reasons for the high TP-concentrations are the influence of the floating gardens and the domestic waste water from the villages especially in the southern part of the lake. It is also most likely that higher amounts of TP are stored in the sediments of Inlay lake and in the large stands of aquatic macrophytes which cover the lake bottom.

The inflowing rivers are transporting TP into the lake. All investigated rivers are characterized by high TP-concentrations characterizing them in a moderate to bad status. The high TP values originate from erosion and use of fertilizers in the catchment area and wastewater from settlements.

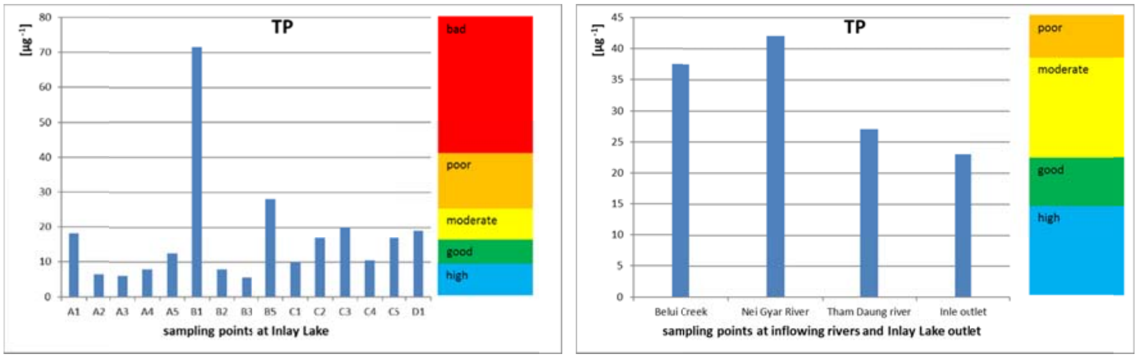


Figure 4.3. Classification of Inlay Lake, tributaries Belui (Belu), Tham Daung (Nant Latt) and Nei Gyar (Ye Pae), and outlet river using average total phosphorus (TP)-concentrations (sampling points see Fig. 3.1). The status is based on boundaries in Table 3.4 and 3.6

4.3. Phytoplankton

4.3.1. Species diversity and abundance

The phytoplankton composition and biomass are influenced by the availability of nutrients, especially phosphorous and nitrogen compounds. The three sampling points A3, B3 and C3, located in the centre of the three selected transects, were analysed for phytoplankton composition and its abundance. During the three field sampling episodes in November 2014, February 2015 and November 2015 altogether 140 phytoplankton taxa were identified at the three sampling locations A3, B3, and C3. The phytoplankton taxa and their abundance based on a semi-quantitative scale are depicted in Appendix B. As number of taxa could be determined to genus level only, the number of taxa present in Inlay lake is supposed to be higher. Furthermore, the additional sampling points in the A, B and C transect, which will be analysed in a later stage, will most likely increase the number of taxa in Inlay lake. The phytoplankton biomass ranged from 0,44 to 1,85 mg/l, which indicate good to moderate status of the Inlay lake phytoplankton, see Figure 4.4.

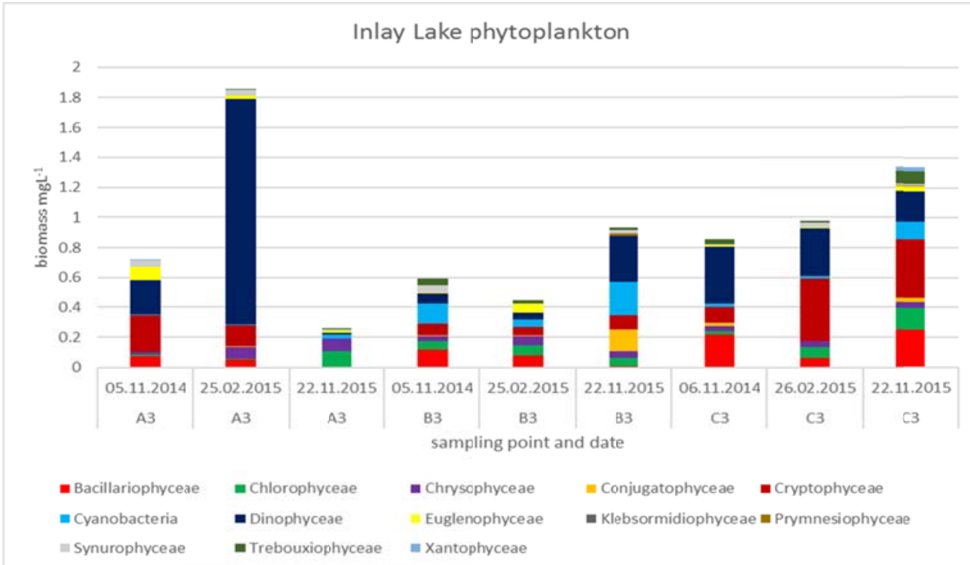


Figure 4.4. Phytoplankton composition and biomass at three sampling points and sampling locations in Inlay Lake in 2014 and 2015.

At the stations A3 and C3, diatoms (Bacillariophyceae), Cryptophyceae and Euglenophyceae were the dominating groups. Green algae (Chlorophyceae) were found at B3 and C3 in relative higher amounts. Cyanobacteria were present at all locations but higher biomasses were found only at the stations B3 and C3. However, the biomass of Cyanobacteria was always in a range still indicating good water quality. It is to note that the cyanobacterial species *Microcystis aeruginosa* was found in low amounts at all three sampling points. Using enzyme linked immunosorbent assay (ELISA), hepatotoxic microcystins were identified in cultures *of M. aeruginosa* isolated from Inlay lake. Figure 4.5 shows *Microcystis aeruginosa,* isolated from Inlay lake. The nutrient concentrations found in Inlay Lake in 2014 and 2015 suggest that a more extensive growth of phytoplankton, and in particular potential toxic cyanobacteria like *M. aeruginosa*, (Figure 4.5) can occur.

Inlay lake, however, is a very shallow and clear lake with a water depth not exceeding 4 m. These conditions support a strong growth of aquatic macrophytes. The macrophytes compete with phytoplankton for available nutrients and are so far preventing a massive growth of phyto-plankton and especially nuisance cyanobacteria. A complete removal of aquatic macrophytes from Inlay lake would probably lead to an increased growth of phytoplankton and have very negative effects for the water quality of the lake.

Figure 4.5. Colony of the microcystin-producing cyanobacterium *Microcystis aeruginosa* isolated from Inlay Lake.

4.3.2. Ecological status of Inlay lake based on phytoplankton

In Figure 4.6 the ecological status of Inlay lake in the years 2014 and 2015 is depicted. The analysis of phytoplankton composition and biomass and the calculation of the phytoplankton trophic index PTI shows clearly that in November 2014 and in February 2015 Inlay lake was classified as being in a good status regarding phytoplankton at all three central sampling stations A3, B3 and C3. In November 2015, however, Inlay lake was evaluated as being in a moderate status according to phytoplankton biomass and composition and the calculated PTI index. This clearly shows a deterioration of the water quality of Inlay lake in 2015. It is to note that the other sampling points are still under evaluation and the results will be integrated in the final report.

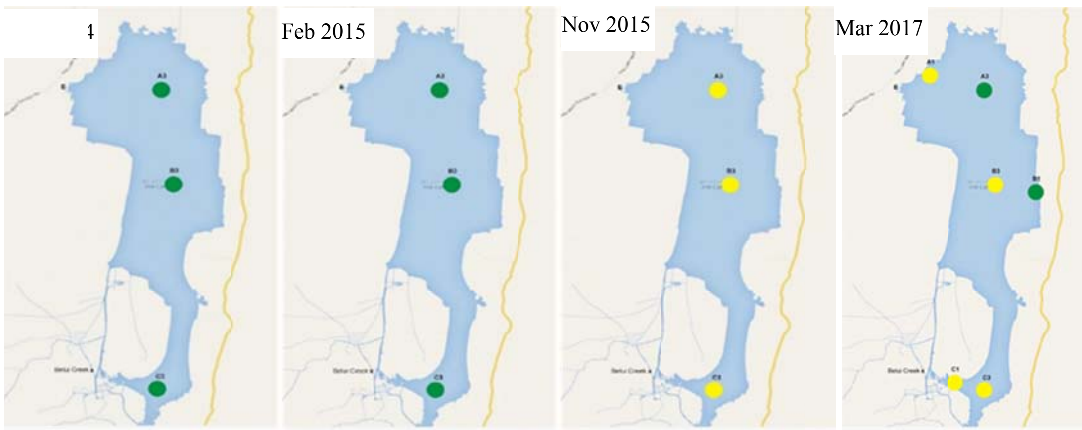


Figure 4.6. Ecological status of Inlay Lake in 2014 -2017 determined using phytoplankton biomass, PTI index and cyanobacteria biomass The evaluation is based on Table 3.1 using the lake type: Lowland, calcareous, clear, shallow. Green =good status, yellow= moderate status.

4.4. Aquatic macrophytes

4.4.1. Species diversity and abundance

The species diversity of aquatic macrophytes is high in Inlay lake, compared to other lakes in Europe and Asia of similar size and type. In 2014-2015, a total number of 25 species of aquatic macrophytes are recorded in the lake. Among these, 13 elodeids, 6 nymphaeids, 5 lemnids and one charophyte were identified. Species frequency and abundance differed from season to season, and from year to year. However, in both years and seasons, the elodeids *Nechamandra alternifolia* and *Potamogeton lucens,* and the lemnid *Eichornia crassipes* dominated the aquatic macrophyte vegetation (Figure 4.7).

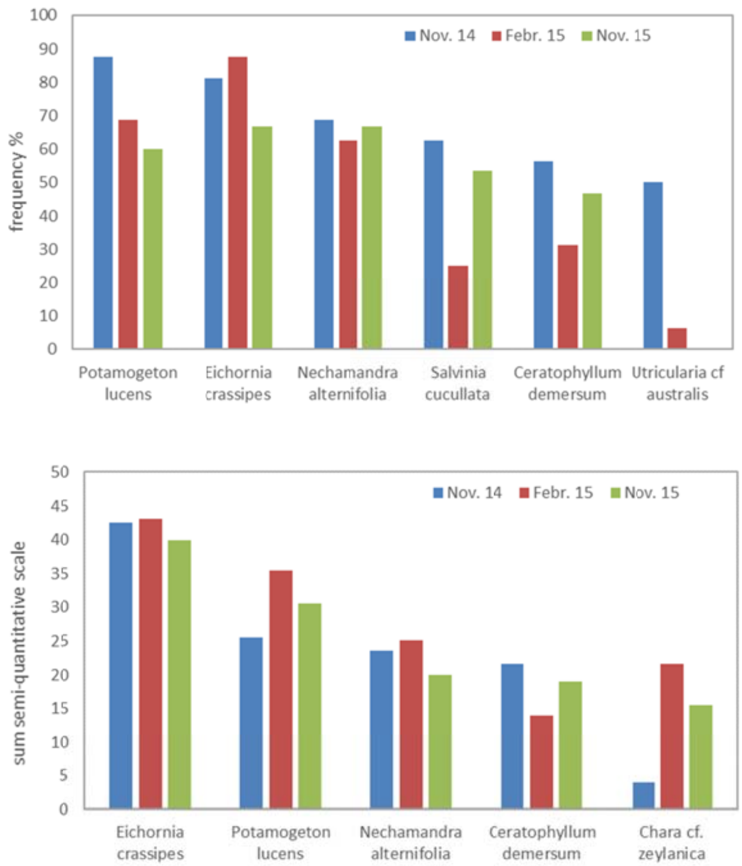


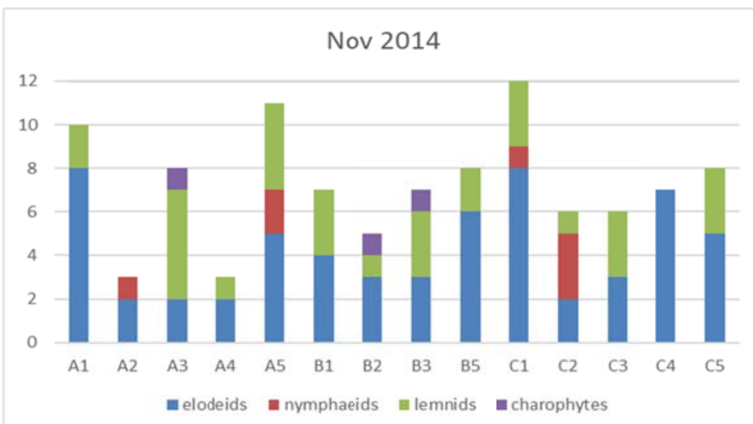
Figure 4.7. Frequency and abundance (sum semi-quantitative scale) for the dominating species in Inlay lake in 2014-2015.

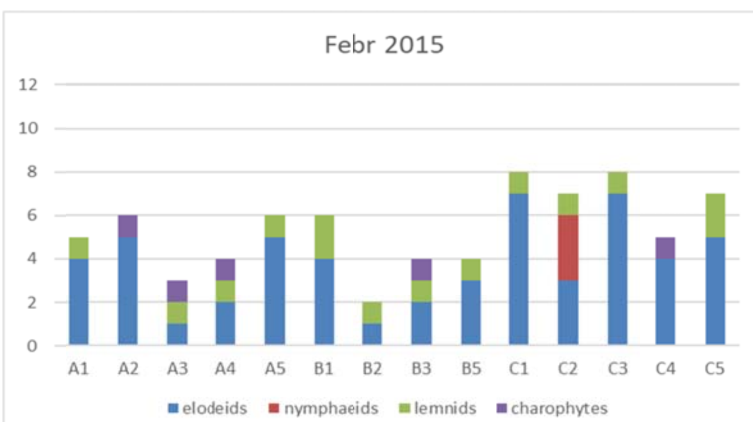
The growing season can vary between species, and some of the less frequent species are lacking or have small abundance in part of the year. To get a good overview of the diversity and abundance of aquatic macrophytes in tropical eutrophic lakes it seems to be necessary to survey twice a year, and some years in a row.

Figure 4.8. The dominating species in Inlay lake. Left: the lemnid *Eichornia crassipes*, middle: the elodeid *Potamogeton lucens,* and right: the elodeid *Nechamandra alternifolia.* Photos: Andreas Ballot.

The number of species in the different lifeform groups vary among transects and localities, and between year and seasons (Figure 4.8). In general, the localities in the middle of the lake, especially the localities B3 and B4, have fewer free-floating species (lemnids), mainly because of the wind erosion.

In February 2015, the number of species was low compared to November 2014 and November 2015. It is obviously that the macrophytes are in better condition after the wet season (i.e. November), compared to the dry period (February). In February 2015 and March 2017 (not shown here), the coverage of periphyton algae on sediment and plants was higher than in November. In addition, most localities had lower species number in November 2015 compared to November 2014. Also the number and abundance of sensitive species show a small, but not significant, decrease from 2014 to 2015.





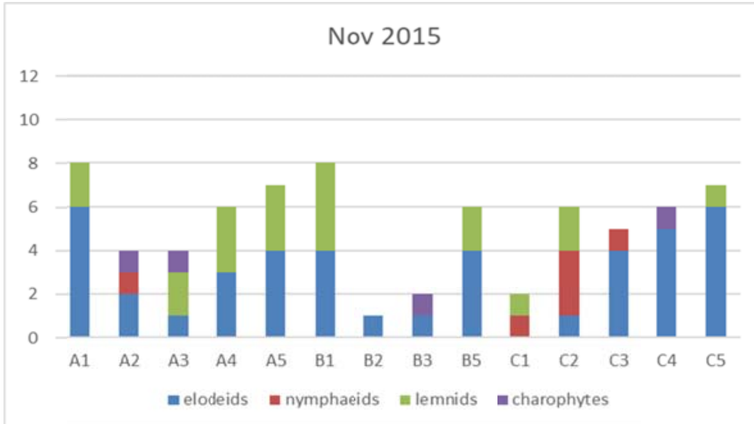


Figure 4.9. Aquatic macrophytes at the different localities and dates in Inlay lake. Number of species within each lifeform group.

4.4.2. Ecological status of Inlay lake based on aquatic macrophytes

The ecological status of aquatic macrophytes in Inlay lake, based on the three suggested indices is presented here. Indices and boundaries has to be evaluated and developed, soon as more data from Myanmar are available. The TIc-index indicates that the aquatic macrophytes in Inaly lake are dominated by tolerant species, which give a negative value, and poor status (based on Norwegian boundaries (Table 4.5). However, based on the relative abundance the status can be classified as moderate, with best status in February 2015 (Table 4.6). The SMC-index show good status, especially in February 2015 (Table 4.7).

Norwegian trophic index - TIc

Based on the preliminary species sensitivity, and using the suggested Norwegian trophic index and boundaries, the status of aquatic macrophytes in Inlay lake was classified as poor, see Table 4.5. In addition, the status seems to become worse from November 2014 to November 2015, however, still in the same status class.

Table 4.5. Ecological status of aquatic macrophytes in Inlay Lake in 2014 and 2015.

Based on the TIc-index and the boundaries in Table 3.9. Inlay lake is lake type 301:

high alkalinity, clear. Orange = poor status.

Period	TIc value	Status
November 2014	-13,0	poor
February 2015	-15,0	poor
November 2015	-21,1	poor

Relative abundance index

Based on the suggested relative abundance metrics, the status of aquatic macrophytes in Inlay lake was classified as poor in November 2014 and moderate in February and November 2015, see Table 4.6.

Table 4.6. Ecological status of aquatic macrophytes in Inlay Lake in 2014 and 2015.

Based on a RA-index (relative abundance), see Table 3.10. Yellow = moderate status,

orange = poor status.

Period	RA value	Status
November 2014	2,4	poor
February 2015	2,8	moderate
November 2015	2,5	moderate

Submerged macrophyte coverage

Based on submerged macrophyte coverage, the status of aquatic macrophytes in Inlay lake was classified as good status in all sampling periods, see Table 4.7.

Table 4.7. Ecological status of aquatic macrophytes in Inlay Lake in 2014 and 2015.

Based on a SMC-metric (submerged macrophyte coverage), see Table 3.10.

Green = good status.

Period	SMC value	Status
November 2014	3,9	good
February 2015	4,4	good
November 2015	4,1	good

5. Conclusions

Based on the available data and the suggested characterisation parameters, Inlay lake is characterised as a mid-altitude, very large and very shallow, calcareous, clear lake. The preliminary total assessment of physico-chemical status and ecological status for phytoplankton and aquatic macrophytes in Inlay lake are based mainly on Norwegian indices and boundaries (Table 5.1).

Regarding phytoplankton, Inlay lake clearly showed a deterioration from good status to moderate status from 2014 until 2015. However, Inlay lake is dominated by an intensive growth of aquatic macrophytes, and most likely, a large amount of the available nutrients (TP and TN) is used and stored in the macrophyte biomass, and is not available for phytoplankton growth. The relatively low phytoplankton biomasses found in Inlay lake in 2014 and 2015 are therefore the consequence of the massive macrophyte growth. Without aquatic macrophytes the phytoplankton biomass would most likely be much higher, and lead to a poorer evaluation of Inlay lake.

Table 5.1. Preliminary assessment of ecological and physico-chemical status in Inlay lake 2014-2015.

	Quality elements	Status class
1.	**Biological quality elements**	
	Phytoplankton	
	- Total algal biomass (mg/l)	good - moderate
	- PTI	moderate
	- Cyanobacterial biomass (mg/l)	high
	Total assessment phytoplankton	*
	Aquatic macrophytes	
	- Trophic index (TIc)	poor
	- Relative abundance index (RA)	moderate
	- Submerged macrophyte coverage (SMC)	good
	Total assessment aquatic macrophytes	*
2.	**Total assessments all biological elements**	*
3.	**Physico-chemical elements**	
	Total phosphorus TP µg/l	moderate (high - bad)
	Total nitrogen TN µg/l	good (high - good)
	Ammonium NH4 µg/l	good (good - moderate)
4.	**Total assessments all physico-chemical elements**	*
5.	**Total assessment for Inlay lake**	*

*: since data from reference lakes are not available, it is not possible to calculate the EQR (Ecological Quality Ratio) which allow us to compare the different indices and metrics and give a total assessment for all biological elements.

The data and assessment in Table 5.1 should be used as an example of an assessment for Inlay lake. Establishing a correct classification system for Myanmar requires information about species distribution in country, and their sensitivity to pressures, in addition to data about existing lake types and water chemistry.

It is recommended to collect data from other lakes in different regions of Myanmar. The chosen lakes should represent different lake types (natural lakes and reservoirs, high and low alkalinity lakes, etc.) with expected different biodiversity of phytoplankton and aquatic macrophytes, and representing different water quality. Data from these additional lakes will give important information about the distribution of species along the main gradients, such as alkalinity, nutrient, latitude, altitude, etc. Together with data from Inlay lake, these data will essential to establish indices and boundaries for assessing ecological status for phytoplankton and aquatic macrophytes in lakes in Myanmar.

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