

Analysis of sediment, fish and phytoplankton samples from Indawgyi Lake, Myanmar

ECRC Research Report Number 167

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Environmental Change Research Centre
University College London
Pearson Building, Gower St.
London, WC1E 6BT

List of contributors

Kernan, M. ENSIS Ltd, Environmental Change Research Centre, UCL

Turner, S. ENSIS Ltd, Environmental Change Research Centre, UCL.

Henderson, G. ENSIS Ltd, Environmental Change Research Centre, UCL.

Goodrich S. ENSIS Ltd, Environmental Change Research Centre, UCL.

Yang, H. Environmental Change Research Centre, UCL.

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1. INTRODUCTION AND PROJECT OBJECTIVES

1.1 Study Rationale

Fauna and Flora International are coordinating a management plan for Indawgyi Lake (under consideration as a Ramsar and UNESCO World Heritage Site) in Myanmar. Part of this process will be to set-up monitoring protocols for the inflow/outflow streams and the lake. Potential impacts on the lake include artisanal gold mining in the in-flow streams, farming around the lake (mostly rice) and some waste inputs from villages. There are further concerns related to the introduction of invasive fish (*Oreochromis niloticus* – Nile tilapia) and plant (*Eichhornia* sp. 'water hyacinth') species.

In 2015 the following samples were collected following advice from ENSIS:

i) water samples to measure phosphate, nitrates and sulphates (and other N, P, and S species that may be appropriate)*;
ii) river and lake sediments and biological material (fish biopsy from whole small fish or tissue from larger fish) to measure heavy metal concentrations (with key elements being mercury, arsenic, lead and copper). Fish samples were preserved in 100% ethanol. Samples were taken of sediment (in triplicate) from about 15 locations from tributary rivers and from the lake periphery (45 samples in total);
iii) water column samples from Indawgyi Lake (10 cm below the surface) to measure algae abundance and algal species composition. Samples were preserved in Lugol's iodine, initially from 1 l of water but siphoned to about 150 ml final volume.

* These samples were collected but subsequently not analysed by ENSIS.

1.2 Objectives

The purpose of this work is to provide information to support the generation of a management plan for Lake Indawgyi in Myanmar. The results will be used to help set-up monitoring protocols for the inflow/outflow streams and the lake. Fauna & Flora International will supply ENSIS with samples of sediment, fish remains and phytoplankton. ENSIS was tasked with the following:

i) undertake XRF analysis for elemental chemistry on 12 out of the 45 sediment samples;
ii) undertake Hg analysis on these 12 sediment samples;
iii) undertake ICP-MS analysis for As and other key elements (above) on 3 fish samples;
iv) undertake Hg analysis on 3 fish samples;
v) count 9 phytoplankton samples;
vi) provide Fauna & Flora International with a data report comprising a spreadsheet incorporating results from all analyses.

2. METHODS

2.1 XRF analysis for elemental chemistry on 12 sediment samples

Sediment samples were analysed for element abundances using a Spectro XLAB2000 X-ray fluorescence (XRF) multi-element spectrometer at University College London. Freeze-dried sediments were milled to a fine powder in a pestle and mortar. Nylon cups with a base of prolene foil (4 µm thickness) were filled with 4-7g (measured to 4 d.p.) of milled sediment. The samples were measured in one run and the spectra converted to element abundance/dry weight of sample by the Spectro software. Elements are reported as % or µg g^{-1} depending on their abundance.

Reference sediment samples (Buffalo River Sediment, National Institute of Standards and Technology (NIST) - RM8704;S-SP Soil Rendzina (12-1-09) KRCM, Slovak Institute of Metrology) were included in the sample run to identify machine drift error and assess measurement accuracy.

2.2 Hg analysis on 12 sediment samples and 3 fish samples

0.2 g fish and sediment samples were digested with 6 ml HNO_3 (nitric acid) and 8 ml aqua regia, respectively, at 100°C on a hotplate for 2 h in rigorously acid-leached 50 ml polypropylene digestion tubes. Two standard samples of standard reference material stream sediment GBW07305 (certified Hg value is 100 ± 10 ng g^{-1}; our measured values are 105 ng g^{-1} and 107 ng g^{-1}) and sample blanks were digested. Digested solutions were analysed for Hg using cold vapour-atomic fluorescence spectrometry (CV-AFS) following reduction with $SnCl_2$. Standard solutions and quality control blanks were measured in every five samples to monitor measurement stability.

2.3. ICP-MS analysis for As and other metals on 3 fish samples

0.2 g dried fish samples were digested in 6 ml HNO_3 for 2h at 100° C. Following this the c. 4 ml digested solution was diluted to 50 ml before analysis. Samples were run on a Varian/Bruker 820 ICP-MS against standards of 0 and 10 ppb, except for As at 50 ppb. Samples and standards were in 5% HNO_3. Concentrations of elements in the fish flesh are expressed as µg g^{-1} dry weight.

2.4. Counting of phytoplankton samples

The phytoplankton samples were analysed using sedimentation chambers following the Utermöhl counting technique. Counts were conducted using 'Whole chamber scans' (magnification x100), 'Transects counts' (magnification x200) and 'Field of View' analysis (magnification x400) using a Leica inverted microscope DMIL.

In general the samples were very dirty with large amounts of silt like material present. For this reason many of the samples had to be diluted back from their concentrated states (original samples were concentrated before being sent to UCL) and it was not possible to count the picoplankton (0.2 to 2 µm) due to the dirty nature of the samples. Overall the concentration of plankton was low with quite a few benthic taxa present (particularly benthic diatoms). The amount of silt in the samples meant they could not be concentrated further for the analysis which may have resulted in a higher taxonomic diversity. The presence of the benthic taxa and the amount of silt present in the samples could indicate possible contamination of the sample with benthic material during the sampling period. Alternatively benthic material may have been naturally present in the water column due to resuspension.

3. RESULTS

3.1 XRF analysis for elemental chemistry on 12 sediment samples

Metal concentrations in powdered sediment samples were measured by XRF. Concentrations were expressed as µg g^{-1} dry weight of sample. Values highlighted in red are above concentrations which harmful biological effects are likely to be observed (Consensus-Based Probable Effect Concentration (PEC) (MacDonald et al. 2000). Error is statistical machine measurement error with 1 sigma confidence interval.

Table 1: Concentrations of selected metals sediment samples

Sediment Sample	**Cr** µg g^{-1}	+/-	**Ni** µg g^{-1}	+/-	**Cu** µg g^{-1}	+/-	**Zn** µg g^{-1}	+/-	**As** µg g^{-1}	+/-	**Pb** µg g^{-1}	+/-
21#1	1372	22	209.5	4.2	20	1.1	34.5	1.2	4.7	0.6	9.5	0.9
22#1	475	14	63.5	2.2	16.8	1	29.6	1	1.6	0.5	12.7	0.8
22#2	342	12	111.7	3.2	33.7	1.4	49.6	1.4	4.7	0.7	15	0.9
22#3	100.2	7.8	47.7	2	16.2	1	29.2	1	1.3	0.6	17.3	0.8
22#4	123.1	8.1	56.3	2.3	33.8	1.4	53.5	1.4	3.7	0.6	13.9	0.8
23#1	4432	40	300.8	5.5	24.3	1.4	62	1.7	2.3	0.5	4.7	0.9
23#2	1547	23	458.5	6.6	96.4	2.6	101.1	2.2	5.7	0.7	8.7	1.1
25#1	226	11	46	2.2	24.2	1.2	54.9	1.5	3	0.6	13.9	0.8
25#2	204.8	9.8	34.6	1.9	28.4	1.2	54.3	1.4	2.8	0.6	13.3	0.8
25#3	177.6	9.4	74.5	2.7	43.5	1.6	86.7	1.8	4.5	0.7	15.8	0.9
26#7	288	11	149.2	3.7	55.1	1.8	73.1	1.7	4	0.8	22.9	1.1
26#9	711	16	291.7	4.8	32.3	1.4	47.6	1.4	2.9	0.6	12.2	0.9

Standards	**Cr** µg g^{-1}	+/-	**Ni** µg g^{-1}	+/-	**Cu** µg g^{-1}	+/-	**Zn** µg g^{-1}	+/-	**As** µg g^{-1}	+/-	**Pb** µg g^{-1}	+/-
S-SP at UCL	82.4	7.2	36.9	2.1	31.1	1.4	117.6	2.2	15.1	1.1	46.1	1.4
SSP Reported[1]	75.3	3.2	37.4	3.3	30.9	1.9	119	7	14	1.4	41.3	4.4
% recovery	*91.4*		*101.4*		*99.4*		*101.2*		*92.7*		*89.6*	
BRS at UCL	110.5	7.5	42.2	2.2	86.5	2.3	368.3	3.7	15	1.7	147	2.1
RM-8704 Reported[2]	121.9	3.8	42.9	3.7	n	n	408	15	17*	n*	150	17
% recovery	*110.3*		*101.7*				*110.8*		*113.3*		*102.0*	

[1,2] Reference Materials

1. S-SP Soil Rendzina (12-1-09) KRCM, Slovak Institute of Metrology
2. RM-8704 'Buffalo River Sediment'. National Institute of Standards & Technology, 2008. * The arsenic value in RM 8704 is given for information only because there is insufficient information to assign an uncertainty (NIST, 2008).

3.2 Hg analysis on 12 sediment samples and 3 fish samples

Mercury concentrations in the samples are shown in Table 2. Mercury concentrations in the sediments are low, varying from 8.1 ng g^{-1} to 53.4 ng g^{-1}, while two fish samples have low Hg, one has a relatively higher level at 163 ng g^{-1}.

Table 2: Mercury concentrations in dried fish tissue and sediment samples

Sample ID	Hg (ng g^{-1})
Fish	
26#5	163
26#6a	14.9
26#6b	7.8
Sediment	
21#1	13.3
22#1	11.9
22#2	25.2
22#3	12.4
22#4	9.2
23#1	8. 1
23#2	43.3
25#1	19.5
25#2	27.1
26#7	38.8
25#3	53.4
26#9	33.8

3.3. ICP-MS analysis for As (Arsenic), Cd (Cadmium), Cu (Copper), Ni (Nickel) and Zn (Zinc) on 3 fish samples

Table 3: Results from ICP-MS analysis of fish and photo of one of the fish (26#6) used for flesh biopsy. Hg results added for comparison.

Sample	As $\mu g\ g^{-1}$	Cd $\mu g\ g^{-1}$	Cu $\mu g\ g^{-1}$	Ni $\mu g\ g^{-1}$	Pb $\mu g\ g^{-1}$	Zn $\mu g\ g^{-1}$	Hg ng g^{-1}
25#5	*0.224*	*0.011*	*2.042*	*0.362*	*0.017*	*87*	*163*
26#6a	*0.126*	*0.451*	*5.003*	*1.137*	*0.023*	*51*	*14.9*
26#6b	*0.150*	*0.019*	*4.852*	*0.668*	*0.007*	*63*	*7.8*

Fish 26#6 – Small insectivorous/planktiferous species
Photo – Steven Lowe

3.4. Counting of phytoplankton samples

The results are presented as numbers per ml and due to the nature of this concentration scaling some species can be listed as having a concentration of 0 in the results sheet (despite the fact that the species may have occurred many times in the raw counts). If this occurs it indicates that those species were present but exist only at trace numbers within the sample (i.e. less than 1 per ml).
Two samples had particularly high levels of suspended silt present (26 # 9 and 26 # 7) which left a layer of silt on the slide when the sample was settled out which completely obscured any plankton present. These samples were therefore not counted and the two reserve samples were counted instead (26 # 8 and Nyan Pim Jetty).

Table 4: Summary observations of phytoplankton samples

26#1 Some benthics present (*Cocconeis, Navicula, Epithemia* and *Gomphonema* spp diatoms seen). No picoplankton counted.

26#3 Some benthics present (*Navicula* and *Epithemia* spp. diatoms seen). Picoplankton not counted.

26#5 Some benthics present (*Navicula* and *Epithemia* spp diatoms seen). Picoplankton not counted.

26#6 Some benthics present (*Epithemia, Gomphonema* , *Cocconeis* and *Navicula* spp diatoms present). Picoplankton not counted. Very low plankton concentrations.

26#8 Very dirty sample. Picoplankton not counted. Some benthics present (*Navicula, Achnanthes* and *Epithemia* spp diatoms seen).

28#1 Some benthics present (*Epithemia* and *Navicula* spp. diatoms present). Picoplankton not counted.

28#3 Picoplankton not counted. Very sparse plankton. Some benthic diatoms present (*Epithemia* spp.).

28#4 Some benthics present (*Cocconeis, Achnanthes* and *Epithemia* spp. diatoms present). Picoplankton not counted.

Nyam Pim Jetty - Picoplankton not counted. Some benthics present (*Epithemia, Gomphonema* and *Cocconeis* spp. diatoms present). The relatively abundant ‘blue green individual cells’ present could be *Microcystis* spp. but no whole colonies seen.

Results for each sample/site are presented in Tables 5 to 13.

Table 5: Phytoplankton counts - Sample 26 #1

Sampling date	Species Code	Species name	Concentration Units Code	Concentration (No's per ml)	Biovolume Type Code	Biovolume (µm^3 per ml)
Unknown	01040000	Aphanizomenon	FI	2	FI	1,493
Unknown	04100000	Trachelomonas	CE	2	CE	2,487
Unknown	05040001	Cryptomonas (small) Length <20 µm	CE	1	CE	345
Unknown	05040002	Cryptomonas (medium) Length 20-30 µm	CE	2	CE	5,233
Unknown	12030000	Aulacoseira	CO	2	CE	828
Unknown	13540000	Nitzschia	CE	205	CE	24,293
Unknown	13540000	Nitzschia	CE	39	CE	47,926
Unknown	13810000	Synedra	CE	1	CE	1,757
Unknown	16060000	Carteria	CE	10	CE	3,029
Unknown	17680030	Pediastrum boryanum	CO	0	CO	3,965
Unknown	17680090	Pediastrum tetras	CO	1	CO	971
Unknown	17810160	Scenedesmus communis	CO	29	CE	5,111
Unknown	17960030	Tetraedron minimum	CE	10	CE	857
Unknown	27040000	Closterium	CE	0	CE	613
Unknown	27050000	Cosmarium	CE	1	CE	8,679

Table 6: Phytoplankton counts - Sample 26 #3

Sampling date	Species Code	Species name	Concentration Units Code	Concentration (No's per ml)	Biovolume Type Code	Biovolume (µm^3 per ml)
Unknown	01040020	Aphanizomenon flos-aquae	FI	10	FI	5,990
Unknown	01490020	Microcystis flos-aquae	CO	0	CE	215
Unknown	04100000	Trachelomonas	CE	0	CE	2,038
Unknown	05040002	Cryptomonas (medium) Length 20-30 µm	CE	1	CE	906
Unknown	06020030	Ceratium furcoides	CE	0	CE	7,697
Unknown	06110000	Peridinium	CE	1	CE	1,529
Unknown	06110100	Peridinium willei	CE	0	CE	764
Unknown	12000001	Small centric diatom (5 - <10 µm diam.)	CE	8	CE	1,538
Unknown	12000004	Very small centric diatom (<5 µm diam.)	CE	12	CE	532
Unknown	12030000	Aulacoseira	CO	0	CE	143
Unknown	13540000	Nitzschia	CE	4	CE	702
Unknown	17170010	Closteriopsis acicularis	CE	1	CE	306
Unknown	17580030	Monoraphidium convolutum	CE	36	CE	52
Unknown	17640050	Oocystis lacustris	CO	24	CE	4,220
Unknown	17970050	Tetrastrum staurogeniaeforme	CO	4	CE	465
Unknown	25010010	Elakatothrix gelatinosa	CO	2	CE	104
Unknown	27040030	Closterium aciculare	CE	0	CE	361
Unknown	27370000	Staurastrum	CE	0	CE	125
Unknown	27380330	Staurastrum cingulum	CE	3	CE	3,660

Table 7: Phytoplankton counts - Sample 26 #5

Sampling date	Species Code	Species name	Concentration Units Code	Concentration (No's per ml)	Biovolume Type Code	Biovolume (µm^3 per ml)
Unknown	01000000	Unidentified cyanophytes - single cell < 6 µm diameter.	CE	27	CE	2,516
Unknown	01040020	Aphanizomenon flos-aquae	FI	4	FI	2,539
Unknown	01530000	Oscillatoria	FI	0	FI	114
Unknown	01750000	Snowella	CO	4	CE	719
Unknown	04100000	Trachelomonas	CE	1	CE	3,511
Unknown	05040001	Cryptomonas (small) Length <20 µm	CE	1	CE	796
Unknown	06020030	Ceratium furcoides	CE	0	CE	3,838
Unknown	06110000	Peridinium	CE	3	CE	7,306
Unknown	06110100	Peridinium willei	CE	1	CE	4,978
Unknown	12000001	Small centric diatom (5 - <10 µm diam.)	CE	12	CE	2,724
Unknown	12030000	Aulacoseira	CO	0	CE	314
Unknown	13540000	Nitzschia	CE	20	CE	2,283
Unknown	17170010	Closteriopsis acicularis	CE	1	CE	140
Unknown	17580030	Monoraphidium convolutum	CE	12	CE	22
Unknown	17640050	Oocystis lacustris	CO	8	CE	1,977
Unknown	27040030	Closterium aciculare	CE	0	CE	115
Unknown	27380330	Staurastrum cingulum	CE	2	CE	2,523
Unknown	27381460	Staurastrum tetracerum	CE	4	CE	198

Table 8: Phytoplankton counts - Sample 26 #6

Sampling date	Species Code	Species name	Concentration Units Code	Concentration (No's per ml)	Biovolume Type Code	Biovolume (µm^3 per ml)
Unknown	01530000	Oscillatoria	FI	1	FI	2,211
Unknown	04100000	Trachelomonas	CE	1	CE	288
Unknown	05040001	Cryptomonas (small) Length <20 µm	CE	1	CE	549
Unknown	12000002	Medium centric diatom (10-20 µm diam.)	CE	8	CE	6,187
Unknown	12000003	Large centric diatom (>20 µm diam.)	CE	4	CE	11,863
Unknown	12030000	Aulacoseira	CO	1	CE	3,268
Unknown	13370000	Fragilaria	CO	28	CE	32,994
Unknown	13540000	Nitzschia	CE	529	CE	3,851,234
Unknown	13540000	Nitzschia	CE	974	CE	293,398
Unknown	13810180	Synedra ulna	CO	1	CE	23,117
Unknown	17810160	Scenedesmus communis	CO	2	CE	13,618

Table 9: Phytoplankton counts - Sample 26 #8

Sampling date	Species Code	Species name	Concentration Units Code	Concentration (No's per ml)	Biovolume Type Code	Biovolume (µm^3 per ml)
Unknown	01040020	Aphanizomenon flos-aquae	FI	4	FI	4,270
Unknown	01050000	Aphanocapsa	CO	0	CE	52
Unknown	04020000	Euglena	CE	0	CE	3,680
Unknown	04100000	Trachelomonas	CE	1	CE	1,243
Unknown	05040001	Cryptomonas (small) Length <20 µm	CE	1	CE	1,725
Unknown	05040002	Cryptomonas (medium) Length 20-30 µm	CE	1	CE	4,105
Unknown	06110000	Peridinium	CE	6	CE	25,237
Unknown	06110100	Peridinium willei	CE	1	CE	1,678
Unknown	12000001	Small centric diatom (5 - <10 µm diam.)	CE	20	CE	3,915
Unknown	12000002	Medium centric diatom (10-20 µm diam.)	CE	5	CE	7,047
Unknown	12030000	Aulacoseira	CO	0	CE	682
Unknown	12110080	Melosira varians	CO	0	CE	607
Unknown	13540000	Nitzschia	CE	31	CE	6,995
Unknown	16330000	Gonium	CO	5	CE	3,654
Unknown	17170010	Closteriopsis acicularis	CE	1	CE	403
Unknown	17580030	Monoraphidium convolutum	CE	25	CE	55
Unknown	17580080	Monoraphidium minutum	CE	5	CE	114
Unknown	17640000	Oocystis	CO	5	CE	1,403
Unknown	25010010	Elakatothrix gelatinosa	CO	0	CE	49
Unknown	27040030	Closterium aciculare	CE	0	CE	98
Unknown	27380330	Staurastrum cingulum	CE	0	CE	642
Unknown	27381460	Staurastrum tetracerum	CE	0	CE	63

Table 10: Phytoplankton counts - Sample 28 #1

Sampling date	Species Code	Species name	Concentration Units Code	Concentration (No's per ml)	Biovolume Type Code	Biovolume (µm^3 per ml)
Unknown	01040000	Aphanizomenon	FI	2	FI	862
Unknown	01060000	Aphanothece	CO	0	CE	27
Unknown	04100000	Trachelomonas	CE	6	CE	14,934
Unknown	05040001	Cryptomonas (small) Length <20 µm	CE	2	CE	1,173
Unknown	05040002	Cryptomonas (medium) Length 20-30 µm	CE	2	CE	7,837
Unknown	06110000	Peridinium	CE	1	CE	2,042
Unknown	06110100	Peridinium willei	CE	1	CE	4,380
Unknown	12000001	Small centric diatom (5 - <10 µm diam.)	CE	28	CE	5,335
Unknown	12030000	Aulacoseira	CO	0	CE	283
Unknown	13540000	Nitzschia	CE	9	CE	1,014
Unknown	13540000	Nitzschia	CE	18	CE	6,974
Unknown	17580030	Monoraphidium convolutum	CE	9	CE	23
Unknown	17640000	Oocystis	CO	0	CE	422
Unknown	17680090	Pediastrum tetras	CO	0	CO	241
Unknown	17810160	Scenedesmus communis	CO	9	CE	1,992
Unknown	27050000	Cosmarium	CE	0	CE	142
Unknown	27380330	Staurastrum cingulum	CE	0	CE	388
Unknown	27381460	Staurastrum tetracerum	CE	1	CE	83

Table 11: Phytoplankton counts - Sample 28 #3

Sampling date	Species Code	Species name	Concentration Units Code	Concentration (No's per ml)	Biovolume Type Code	Biovolume (µm^3 per ml)
Unknown	01040020	Aphanizomenon flos-aquae	FI	0	FI	314
Unknown	04100000	Trachelomonas	CE	0	CE	2,256
Unknown	05040002	Cryptomonas (medium) Length 20-30 µm	CE	1	CE	2,384
Unknown	06110000	Peridinium	CE	2	CE	4,758
Unknown	13540000	Nitzschia	CE	13	CE	3,751
Unknown	17170010	Closteriopsis acicularis	CE	1	CE	377
Unknown	17580030	Monoraphidium convolutum	CE	25	CE	55
Unknown	25010010	Elakatothrix gelatinosa	CO	0	CE	9
Unknown	27040030	Closterium aciculare	CE	0	CE	436
Unknown	27370000	Staurastrum	CE	1	CE	35
Unknown	27380330	Staurastrum cingulum	CE	1	CE	677

Table 12: Phytoplankton counts - Sample 28 #4

Sampling date	Species Code	Species name	Concentration Units Code	Concentration (No's per ml)	Biovolume Type Code	Biovolume (µm^3 per ml)
Unknown	01130000	Chroococcus	CO	0	CE	768
Unknown	01530000	Oscillatoria	FI	1	FI	1,912
Unknown	04100000	Trachelomonas	CE	1	CE	1,800
Unknown	05040001	Cryptomonas (small) Length <20 µm	CE	10	CE	10,081
Unknown	05040002	Cryptomonas (medium) Length 20-30 µm	CE	4	CE	12,183
Unknown	05100000	Rhodomonas	CE	16	CE	685
Unknown	06110000	Peridinium	CE	8	CE	19,574
Unknown	06110100	Peridinium willei	CE	2	CE	5,185
Unknown	12000001	Small centric diatom (5 - <10 µm diam.)	CE	16	CE	1,446
Unknown	12030000	Aulacoseira	CO	1	CE	842
Unknown	13540000	Nitzschia	CE	179	CE	18,364
Unknown	13540020	Nitzschia acicularis	CE	1	CE	367
Unknown	13810000	Synedra	CE	0	CE	4,126
Unknown	17170010	Closteriopsis acicularis	CE	0	CE	144
Unknown	17330040	Dictyosphaerium pulchellum	CO	0	CE	146
Unknown	17580010	Monoraphidium arcuatum	CE	16	CE	94
Unknown	17580030	Monoraphidium convolutum	CE	16	CE	47
Unknown	17680030	Pediastrum boryanum	CO	0	CO	8,939
Unknown	17680050	Pediastrum duplex	CO	0	CO	2,235
Unknown	17680090	Pediastrum tetras	CO	0	CO	993
Unknown	17810000	Scenedesmus	CO	16	CE	4,685
Unknown	17810000	Scenedesmus	CO	33	CE	11,479
Unknown	17810000	Scenedesmus	CO	16	CE	4,685
Unknown	17810160	Scenedesmus communis	CO	82	CE	28,346
Unknown	17960030	Tetraedron minimum	CE	16	CE	1,432
Unknown	27380330	Staurastrum cingulum	CE	2	CE	1,985

Table 13: Phytoplankton counts - Nyam Pim Jetty

Sampling date	Species Code	Species name	Concentration Units Code	Concentration (No's per ml)	Biovolume Type Code	Biovolume (µm^3 per ml)
Unknown	01000000	Unidentified cyanophytes - single cells < 6 µm diameter.	CE	4940	CE	191,650
Unknown	01020000	Anabaena	CO	1	CE	4,842
Unknown	01530000	Oscillatoria	FI	2	FI	7,616
Unknown	04100000	Trachelomonas	CE	23	CE	32,909
Unknown	05040001	Cryptomonas (small) Length <20 µm	CE	18	CE	21,518
Unknown	05040002	Cryptomonas (medium) Length 20-30 µm	CE	33	CE	88,547
Unknown	05040003	Cryptomonas (large) Length >30 µm	CE	1	CE	3,228
Unknown	06110000	Peridinium	CE	9	CE	41,004
Unknown	06110100	Peridinium willei	CE	1	CE	3,825
Unknown	12000001	Small centric diatom (5 - <10 µm diam.)	CE	28	CE	5,356
Unknown	12000002	Medium centric diatom (10-20 µm diam.)	CE	14	CE	19,281
Unknown	13540000	Nitzschia	CE	139	CE	29,214
Unknown	13810000	Synedra	CE	1	CE	690
Unknown	17260000	Crucigeniella	CO	14	CE	5,758
Unknown	17330040	Dictyosphaerium pulchellum	CO	1	CE	447
Unknown	17580030	Monoraphidium convolutum	CE	209	CE	600
Unknown	17580040	Monoraphidium griffithii	CE	14	CE	225
Unknown	17580080	Monoraphidium minutum	CE	153	CE	3,437
Unknown	17640000	Oocystis	CO	2	CE	1,210
Unknown	17680050	Pediastrum duplex	CO	1	CO	1,932
Unknown	17680090	Pediastrum tetras	CO	5	CO	4,904
Unknown	17810000	Scenedesmus	CO	14	CE	5,758
Unknown	17810000	Scenedesmus	CO	14	CE	5,758
Unknown	17810160	Scenedesmus communis	CO	70	CE	19,309
Unknown	17960030	Tetraedron minimum	CE	42	CE	5,733
Unknown	25010010	Elakatothrix gelatinosa	CO	2	CE	209
Unknown	27040000	Closterium	CE	1	CE	915

Table 13 Continued.

Sampling date	Species Code	Species name	Concentration Units Code	Concentration (No's per ml)	Biovolume Type Code	Biovolume (µm^3 per ml)
Unknown	27050000	Cosmarium	CE	28	CE	3,942
Unknown	27370000	Staurastrum	CE	2	CE	3,633
Unknown	27380330	Staurastrum cingulum	CE	1	CE	741
Unknown	27381460	Staurastrum tetracerum	CE	2	CE	1,055
Unknown	27430000	Xanthidium	CE	2	CE	1,587
Unknown	90000005	Nanoplankton - unidentified flagellates 2–20 µm diameter	CE	14	CE	2,499

4. RESULTS and DISCUSSION

The purpose of this work is to provide information to support the generation of a management plan for Lake Indawgyi in Myanmar. An assessment of the ecological status of the lake from the samples collected in 2015 is however limited by the number analysed.

With the limited number of sediment samples, it would appear that only Cr (Chromium) and Ni (Nickel) show significantly elevated levels, with a potential of causing ecological effects (MacDonald *et al.* 2000). Other metal elements (Hg included) are lower and suggest that metal contamination currently only poses an ecological risk. As the analysed samples were surface sediments, it is difficult to assess whether the values represent background environmental levels (there are significant Nickel and Chromite ore deposits in Myanmar) or are due to recent exploitation of metalliferous deposits. For some context, the concentration of Ni and Cr found in these Indawgyi Lake sediments are higher and/or comparable to values found in urban lakes in the UK by the authors (ST&HY) that have a known history of industrial inputs (Turner et al. 2013). The extent of Ni and Cr elevation in the sediments can be appreciated also by surface sediments found in Lake George, Uganda (Lwanga *et al.* 2000) downstream of significant mining, where Ni and Cr values of 28-42 and 119-168 µg g^{-1} respectively are found compared with Ni and Cr values (34-458 and 100-1372 µg g^{-1} respectively) in the analysed samples from Lake Indawgyi. More data from Lake Indawgyi and comparisons with analogous Asian lakes are essential for a proper assessment of metal contamination in the lake.

The results from the 3 fish samples indicate that for the particular species, flesh metal concentrations appear not to be significantly high. The Hg values for the presumed non-piscivorous fish (26#6) are in the low range, compared to similar trophic level species, found, for example, in catchments of the Amazon where Hg contamination occurs from gold mining (Dorea, 2003) and in fish ponds in the Pearl River delta (Zhou and Wong, 2000) subject to chronic urban pollution. Hg uptake is modulated significantly by an organism's trophic level and in terms of its effect on humans, from which level/s the dietary intake occurs. Although comparatively low concentrations, it would be unwise on the basis of the limited sample size to elaborate further.
For the other metals, without a bigger sample a broad statement cannot be given. However an interesting comparison can be given with flesh concentrations of Ni, Zn and Cu found in fish from Lake George, Uganda where metals are mined in the catchment and many lake species are eaten (Lwanga et al. 2000), including *O. niloticus*. Flesh concentrations of copper (2-5 µg g^{-1} dw flesh) and zinc (51-87 µg g^{-1}) in Lake Indawgyi are higher than in Lake George. Uptake of trace metals into fish are modulated by their trophic level and in terms of their effect on humans, from which level/s the dietary intake occurs, although less so than for mercury due to its bioaccumlative properties.

Due to the nature of the samples, which in general had low species diversity and low algal concentrations, added to the fact that the samples were just spot samples rather than seasonal monitoring it would be unwise to make any concreate ecological interpretations or recommendations from the phytoplankton data. Some samples were higher in species numbers (26#8, 28#3, 28#4 and Nyam Pim Jetty) possibly suggesting that growing conditions were more suitable in these areas due to either nutrient supply, water depth or light penetration (lower suspended sediment). None of the algal numbers suggested any form of algal blooms present within the lake.

All the samples did have limited numbers of Cyanophytes (these consisted of 'Unidentified cyanophytes - single cells < 6 µm diameter', *Anabaena, Snowella, Aphanizomenon flos-aquae, Microcystis flos-aquae, Aphanocapsa, Aphanothece, Chroococcus* and *Oscillatoria*) present. For the filamentous cyanophytes all of these were in numbers < 4 per ml. The Nyam PIm Jetty sample contained a larger number of individual cyanobacterial cells (4940 per ml) which had possibly come from broken *Microcystis* colonies. Their presence may indicate that this site might be higher in nutrients than some of the less productive samples (for example sample 28#3 had a very low species count).

Assessment of current nutrient status and potential sources of inputs would be greatly assisted by a spatial and temporal survey of nutrients in lake and inflow waters, as initially advised.

5. RECOMMENDATIONS

- Expand number and range of samples measured for metals (especially broaden range of fish species across trophic levels that are commonly consumed, i.e. *Tilapia*) and other organisms (turtles/piscivorous bird species). The fish/fishes sampled appear to have been only mid-level phyto/zooplanktivore so larger, higher predatory fish and other organisms may have higher concentrations, particularly for Hg.
- Collect and analyse lake and inflowing water for metals and nutrients. Base sampling on gathering data from upstream and downstream potential sources of metal contaminants and wastewater inputs.
- Collate existing data on concentration of metals/Hg in sediment, fish and biota in Myanmar or similar contexts (references used in Results section below).
- Establish a monitoring programme on seasonal/annual variability of nutrients, organisms and chemical properties, tailored to the lake and feasibility of continued monitoring.
- Consider a palaeolimnological study to assess whether the metal loadings indicated by the surface sediment are a recent departure from background concentrations. Similarly, a palaeolimnological (macrofossil, palaeobotanical) study may assist in understanding the ecological impacts of introduced fish (*Tilapia*) and plant (water hyacinth) species, as well as, nutrient changes to the lake.

6. REFERENCES & FURTHER READING

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