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MONOCLE

Multiscale Observation Networks for Optical monitoring of Coastal waters, Lakes and Estuaries

Deliverable 4.2

Report compiling test and validation site characteristics

Project Description

Funded by EU H2020 MONOCLE creates sustainable *in situ* observation solutions for Earth Observation (EO) of optical water quality in inland and transitional waters. MONOCLE develops essential research and technology to lower the cost of acquisition, maintenance, and regular deployment of *in situ* sensors related to optical water quality. The MONOCLE sensor system includes handheld devices, smartphone applications, and piloted and autonomous drones, as well as automated observation systems for e.g. buoys and shipborne operation. The sensors are networked to establish interactive links between operational Earth Observation (EO) and essential environmental monitoring in inland and transitional water bodies, which are particularly vulnerable to environmental change.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776480

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1 Executive Summary

Several validation sites were selected for MONOCLE to ensure they represent a broad range of biogeochemical properties and deployment conditions in which to validate innovative *in situ* sensors, platforms and methods. The validation sites include the inland waters Loch Leven (Scotland), Lake Balaton (Hungary), Lake Dunkern (Sweden) and Lake Tanganyika (Tanzania), as well as the Razelm-Sinoe coastal lagoon system (Romania). The MONOCLE project also has access to test sites, which are sites frequently used by MONOCLE partners for specific instrument development. Whilst no collective campaigns are planned around test sites, access to these sites provides an additional opportunity for testing by the MONOCLE consortium and can be organised locally.

All validation sites are subject to anthropogenic impacts, and many are of great economic value to the local areas. These water bodies also represent areas of the weakest performance in present Earth Observation (EO) capabilities for retrieval of water quality parameters. Some sites have been well characterised in terms of bio-geo-optical properties, in previous projects (e.g. Loch Leven and Lake Balaton), while others are in relatively data-poor regions with regard to optical properties (e.g. Lake Dunkern, Lake Tanganyika and the Razelm-Sinoe Lagoon). The validation sites cover a range of climates and geographic locations, as well as a range of trophic status (oligotrophic to eutrophic) and optical water types, as shown through processed EO data.

There are varying deployment opportunities at each site (e.g. boats, buoys, ferries, citizen science opportunities) to allow for sufficient validation approaches and capabilities for the MONOCLE systems. Also highlighted in this deliverable are the laboratory facilities available (or not) and the typical sampling locations for historic data at each site, which will aid implementation of each field campaign.

Ultimately, these five validation sites sufficiently cover a range of bio-geo-optical properties to provide robust validation campaigns for the MONOCLE sensors and systems. The site characteristics presented here will be supplemented with high-end bio-optical characterisation of each field site during the MONOCLE campaigns, including any seasonal and spatial variations.

2 Scope

The MONOCLE sites for sensor and system validation were selected to provide comprehensive comparative validation environments, including a wide range of optical-biogeochemical properties and deployment conditions. Validation sites which bring together all MONOCLE sensor developments are characterized in this report from archived data records, where available, and satellite remote sensing. In addition, an overview of the deployment opportunities is given for each of the field validation sites.

This report is intended to allow matching of MONOCLE testing requirements to validation sites and provide feedback for sensor/platform development requirements for **WP2** and **WP3**. This report is public in nature, because future users of the MONOCLE systems will benefit from knowing where the novel sensor solutions were initially developed and tested.

3 Introduction

The aim of MONOCLE Work Package 4 is to exploit a range of test environments to verify that cost effective sensors and sensing technologies for water quality data can sustainably provide reliable results. These data can add value to satellite missions for water quality monitoring, and in turn feed into the Global Earth Observation System of Systems (GEOSS), as well as provide more comprehensive datasets for Water Framework Directive (WFD; 2000/60/EC) and Marine Strategy Framework Directive (MSFD; 2008/56/EC) reporting purposes. However, in order to achieve these goals, it is vital that the validation sites chosen cover a broad range of water types so that the sensors and platforms are rigorously tested.

Thus, this document reviews in detail the site characteristics for each of the five MONOCLE validation campaigns in section 4 of this document. The preselected sites are characterised to ensure they together provide a full range of environmental settings, contrasting optical water types and a full range of deployment opportunities. This report uses pre-existing knowledge of each site, publications, archive data and preprocessed EO data.

There are a number of additional test sites which are used by sensor/platform developers in their development and testing strategy of individual systems. These are listed in Section 5 of this document.

4 Validation Sites

The MONOCLE validation sites include:

- Loch Leven (United Kingdom – visited in month 7)
- Lake Balaton (Hungary – month 17)
- Lake Dunkern (Sweden – month 29)
- The Razelm-Sinoe Lagoon System (Romania – month 32)
- Lake Tanganyika (Tanzania – month 38).

These sites are expected to provide sufficient variability over which to test and validate MONOCLE systems, therefore the range of site characteristics will be presented in this deliverable.

Each site is described in detail below, including climate, hydrology, geography, maps and sampling locations for each site. Lab facilities and deployment opportunities are also detailed, and a summary of the data archive available is presented. Earth Observation (EO) datasets processed through the *Calimnos* processing chain (v 1.04) are also provided. *Calimnos* implements global bulk processing of water quality algorithms for full resolution data from Medium Resolution Imaging Spectrometer (MERIS), Ocean and Land Colour Instrument (OLCI) and MultiSpectral Instrument (MSI). *Calimnos* was developed as part of the GloboLakes project (UK NERC NE/J024279/1) and is used for the Copernicus Global Land Service (CGLS). The processor has been tuned to a wide number of lakes distributed globally. Due to the wide optical diversity of these waterbodies, the processor is currently considered to offer a suitable approach for mapping water quality in inland and transitional waters.

4.1 Loch Leven, Scotland

Loch Leven (56°12’N 3°23’W) is the largest shallow lake in Great Britain, located to the east of Kinross, Scotland. The loch is located within the Loch Leven National Nature Reserve (NNR) and is managed by several stakeholders, including Scottish Natural Heritage (SNH), the Royal Society for the Protection of Birds (RSPB), Historic Scotland (Castle Island only) and the Kinross Estate. The loch is an important site for recreation, including the Loch Leven Heritage Trail (http://www.lochlevenheritagetrail.co.uk/), Loch Leven Fisheries (http://www.fishlochleven.co.uk/) and Historic Scotland boat tours to Castle Island (https://www.historicenvironment.scot/visit-a-place/places/lochleven-castle/). The wetlands on the southern shore also provide internationally important feeding, roosting and wintering sites for large numbers of swans, geese and ducks.

Loch Leven has a history of nutrient enrichment as result of phosphorus loading from a woollen mill (May et al., 2012), sewage treatment works (Bailey-Watts and Kirika, 1987) and diffuse agricultural inputs. However, in response to severe eutrophication, total phosphorus loading was reduced by 1995 and remained low in 2005 (May et al., 2012). High phosphorus loads still regularly induce spring and late summer phytoplankton blooms, with cyanobacteria blooms common in late summer and early autumn (Carvalho et al., 2012). Wind-driven resuspension of sediments is also common, resulting in deep mixing in shallow waters (May et al., 2012; Hunter et al., 2010).

4.1.1 Climate

Air temperatures at Loch Leven range from approximately -4 to 22°C (Met Office data from Leuchars, Scotland), with water temperatures of 0.1-23.6°C (Environmental Information Data Centre, Centre for Ecology and Hydrology (CEH)). Mean hours of sunshine are 1495 hours per year, with a mean rainfall of 682 mm per year (Met Office data from Leuchars, Scotland). The prevailing wind direction is from the SW with an average wind speed of approximately 10 knots (maximum gusts of 50-72 knots; Met Office data from Leuchars, Scotland).

4.1.2 Hydrology and Geography

Loch Leven is a eutrophic lowland lake, positioned 107 m above sea level, with an area of 13.3 km^2 and max length of 5.9 km. The loch is shallow, with a mean depth of 3.9 m and max depth of 25.5 m (Carvalho et al., 2012). Thermal stratification is therefore rare and typically of short duration, limited to the deep areas only.

There are 11 total inflows to the loch, with the six main inflows including Pow Burn, North Queich, South Queich, Gairney Water and Camel Burn. The main outflow is the sluice gate, which was installed in 1850 to regulate the loch outflow to the River Leven (May et al., 2017). The loch has a retention time of 140-180 days (Bailey-Watts and Kirika, 1999).

The Loch Leven catchment consists mainly of arable crops (38.6%) and improved pasture (31.5%), with some upland moor (11.6%), coniferous woodland (3.8%), heathland (3.5%), rough grazing (3.5%) and suburban/rural development (2.2%), and a small percentage of deciduous woodland, bog, bare ground or inland water (5.3%), according to data from the ENC Data Centre (http://data.ecn.ac.uk/sites/ecnsites.asp?site=L06).

Loch Leven has several designations as an international site for wildlife, including Site of Special Scientific Interest (SSSI), Special Protection Area (SPA), National Nature Reserve (NNR), RAMSAR and EU Natura 2000. Additionally, Loch Leven Castle and St Serf's Priory are Scheduled Monuments.

4.1.3 Map and Sampling Locations

The Centre for Ecology and Hydrology (CEH) typically monitors at three sites in Loch Leven (Reed Bower, RB6; South Deeps, SD6; Sluices, Sl8; Figure 1 and Table 1). They also maintain a buoy for instrumentation (met data and fluorometer) located in the middle of the loch.

The University of Stirling have collected biogeochemical and optical data at Loch Leven since 2007, with opportunistic campaigns for collection of phytoplankton pigments (including chlorophyll-a (Chl-a) and phycocyanin), total suspended matter (TSM), absorption by coloured dissolved organic matter (CDOM) and inherent and apparent optical properties (IOPs and AOPs). Indicative locations for the University of Stirling monitoring positions are shown in Figure 1 and Table 1.

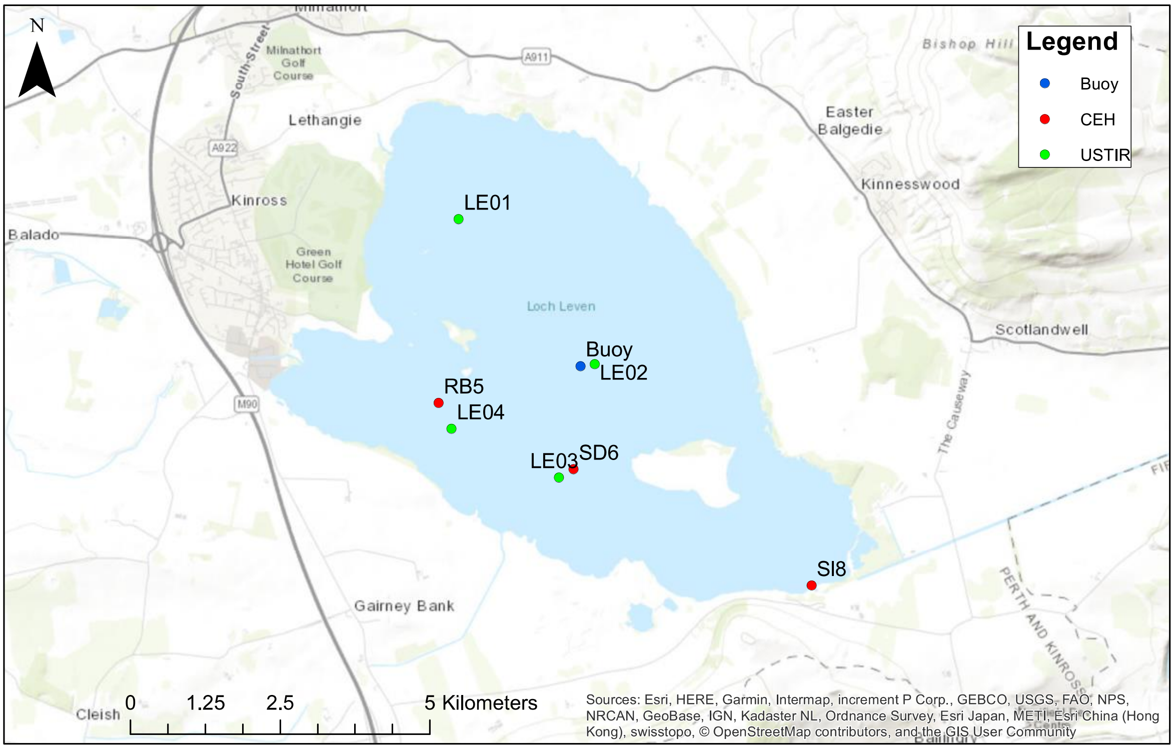


Figure 1. Map of Loch Leven, indicating typical sampling locations for the Centre for Ecology and Hydrology (CEH) and University of Stirling (USTIR)

Table 1. Coordinates of sampling stations and buoy in Loch Leven

Monitoring Body	Station	Latitude	Longitude
CEH	RB5 – Reed Bower	56.195006	-3.3944639
	SD6 – South Deeps	56.189490	-3.3742500
	SI8 – Sluices	56.179800	-3.3385583
	Buoy	56.198070	-3.3731900

Monitoring Body	Station	Latitude	Longitude
USTIR	LE01	56.210313	-3.3914583
	LE02	56.198225	-3.3710733
	LE03	56.188803	-3.3764183
	LE04	56.192863	-3.3925330

4.1.4 Deployment Opportunities

Deployment opportunities at Loch Leven include the University of Stirling research vessel (Predator 165 Sea Angler; Figure 2). Additionally, there are several small boats owned by Loch Leven Fisheries that can be hired for use.

There is a CEH buoy located in the middle of the loch, which presently has the fixed position WISP installed (since 5th June 2018). Permission from CEH is required for deployment of instruments on the buoy.

The harbour is located on the western shore of the loch, with access to mains power and dock facilities. The dock space is publicly accessible and can be used for shore deployment of drones and instrument testing in the harbour itself.

Figure 2. University of Stirling research vessel (Predator 165 Sea Angler)

4.1.5 Lab Facilities

There are no lab facilities at Loch Leven itself; however, there is a boathouse with access to mains power (via Leven Fisheries) and a small café onsite.

Laboratory facilities will be based at the University of Stirling, where a large laboratory space has been reserved for the MONOCLE campaign. There are refrigerators and a cold storage room (both +4°C) and freezers at -40°C and -80°C available for sample storage. Water filtration equipment is available, with 3-4 low vacuum filtration pumps, and at least 3 x 25 mm glass filtration and 3 x 47 mm glass filtration sets with clamps. One manifold is available for use with either size glassware. Additionally, a dual beam spectrophotometer with integrating sphere is available for use to conduct either CDOM absorption or particulate absorption measurements. Several analytical balances are also available.

4.1.6 Data Archive

There is a large archive of historic bio-geo-chemical data for Loch Leven (1985-2007) that are openly available on the NERC Environmental Information Data Centre (EIDC) website (http://eidc.ceh.ac.uk). Parameters include nutrients (phosphorus, nitrogen and silica), chlorophyll-a, Secchi depth and water temperature. Diatom count data (1968-2007) and crustacean zooplankton data (1972-2007) are also available on the EIDC website.

Data for inherent and apparent optical properties of Loch Leven have been collected in recent years (since 2007) by the University of Stirling. These include seasonal data for *in situ* IOPs (absorption, attenuation and backscattering properties) and AOPs (radiometry) as part of the NERC-funded GloboLakes project (http://www.globolakes.ac.uk) and EU-funded INFORM project (http://inform.vgt.vito.be). Radiometry data (using TriOS Ramses sensors) are also collected opportunistically alongside bio-geo-chemical parameters as part of the H2020 EOMORES project since 2017 (https://eomores-h2020.eu/). Additionally, airborne hyperspectral data with AISA Eagle and Hawk and CASI-2 were collected over Loch Leven in 2007 (Hunter et al., 2010) and with AISA Fenix in 2014 (Markelin et al. 2017, projects INFORM and GloboLakes).

Chlorophyll-a concentrations in Loch Leven ranged from 0.5 to 486 mg m^{-3} in the last decades, with peaks typically in early spring (Feb-Mar) and late summer (Aug) (Figure 3). Secchi depth ranged from 0.38 to 4.55 m, and water is typically clearest (greatest Secchi depth) in May-June (Figure 4). Soluble reactive phosphorus (SRP) ranged from 0 to 107.3 µg/L, with peaks in winter (Dec-Jan) and early autumn (Aug-Sept) (Figure 5).

(a)

(b)

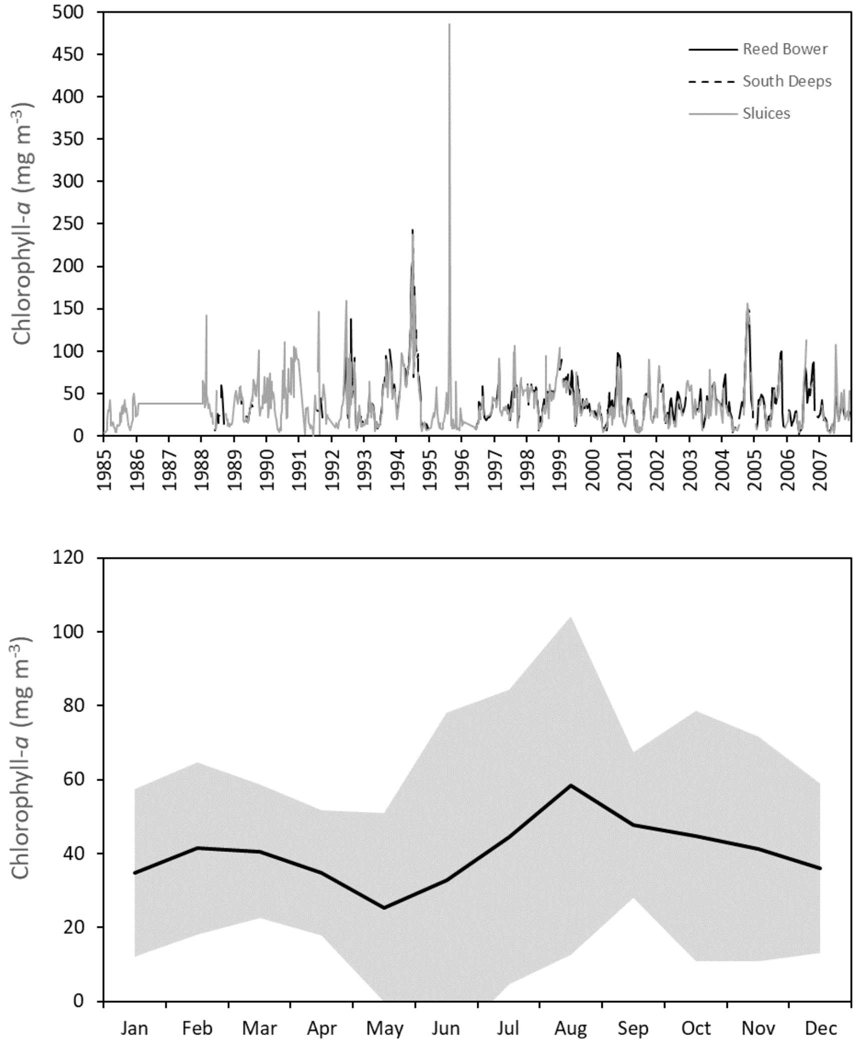
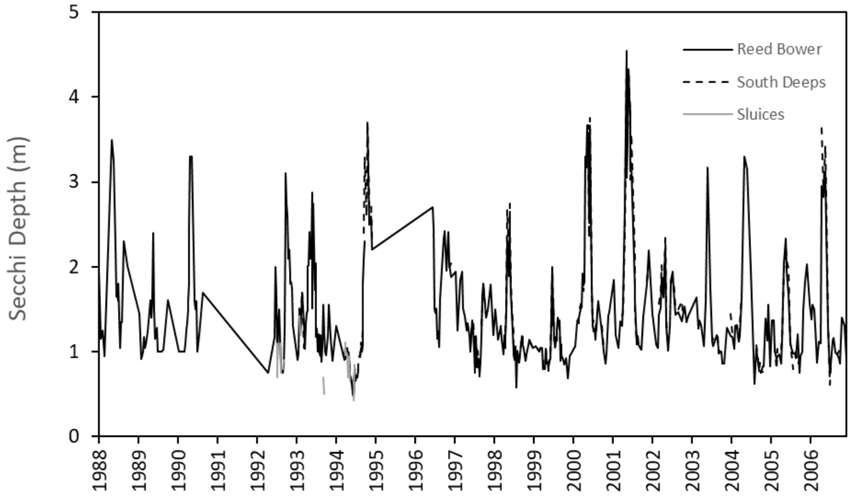


Figure 3. (a) Time series of Chl-a (mg m^{-3}) in Loch Leven (1985-2007) and (b) seasonal mean Chl-a from three sites (Reed Bower, South Deeps and Sluices). Shaded area indicates standard deviation. (Data from EIDC, CEH)

(a)



(b)

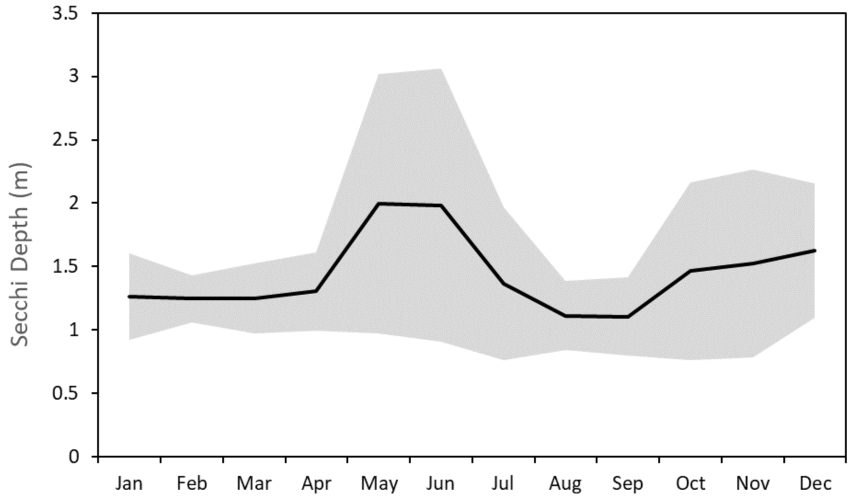
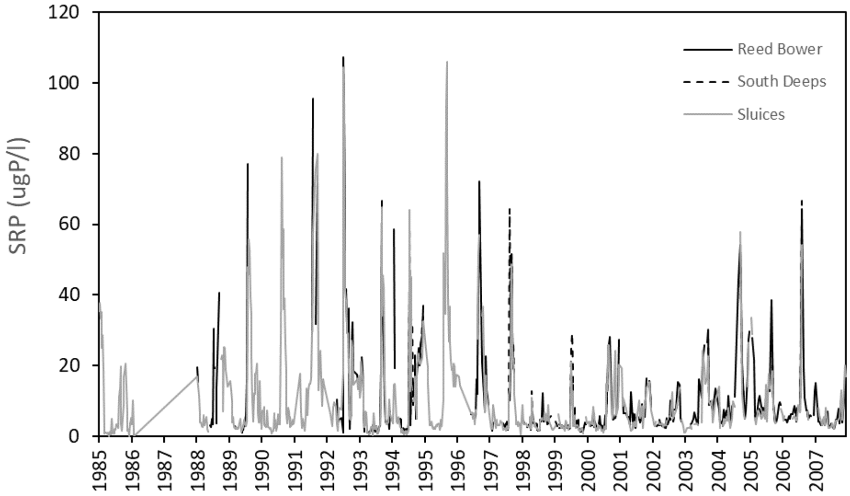


Figure 4. (a) Time series of Secchi depth (m) in Loch Leven (1988-2006) and (b) seasonal mean Secchi depth from three sites (Reed Bower, South Deeps and Sluices). Shaded area indicates standard deviation. (Data from EIDC, CEH)

(a)



(b)

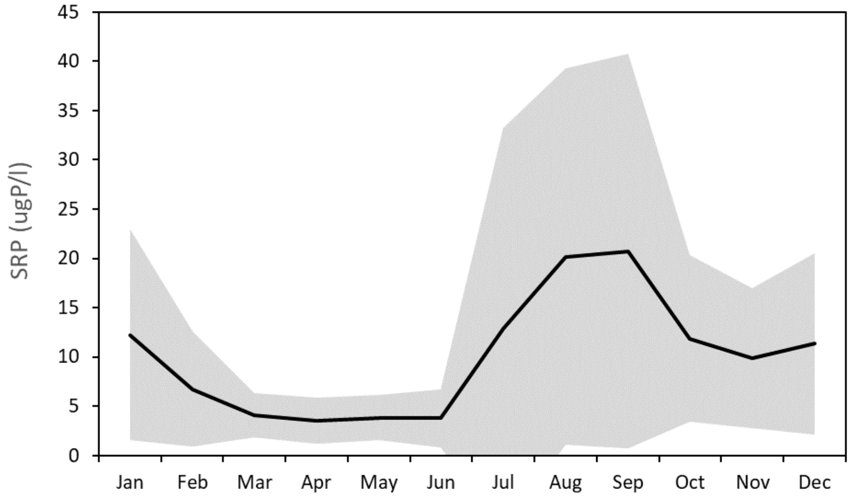


Figure 5. (a) Time series of Soluble Reactive Phosphorus (SRP) in Loch Leven (1988-2006) and (b) seasonal mean SRP from three sites (Reed Bower, South Deeps and Sluices). Shaded area indicates standard deviation. (Data from EIDC, CEH)

4.1.7 Earth Observation

Loch Leven is a relatively small lake, including two islands. Coverage of the lake by medium resolution imaging sensors (300m) is possible and the lake is sufficiently turbid to be observed by land-based sensors with a finer resolution (10-60m). Optical water types in Loch Leven were not well retrieved during highly turbid phases using *Calimnos*, which is the main cause for sparse valid observations in the time-series generated for Figure 6.

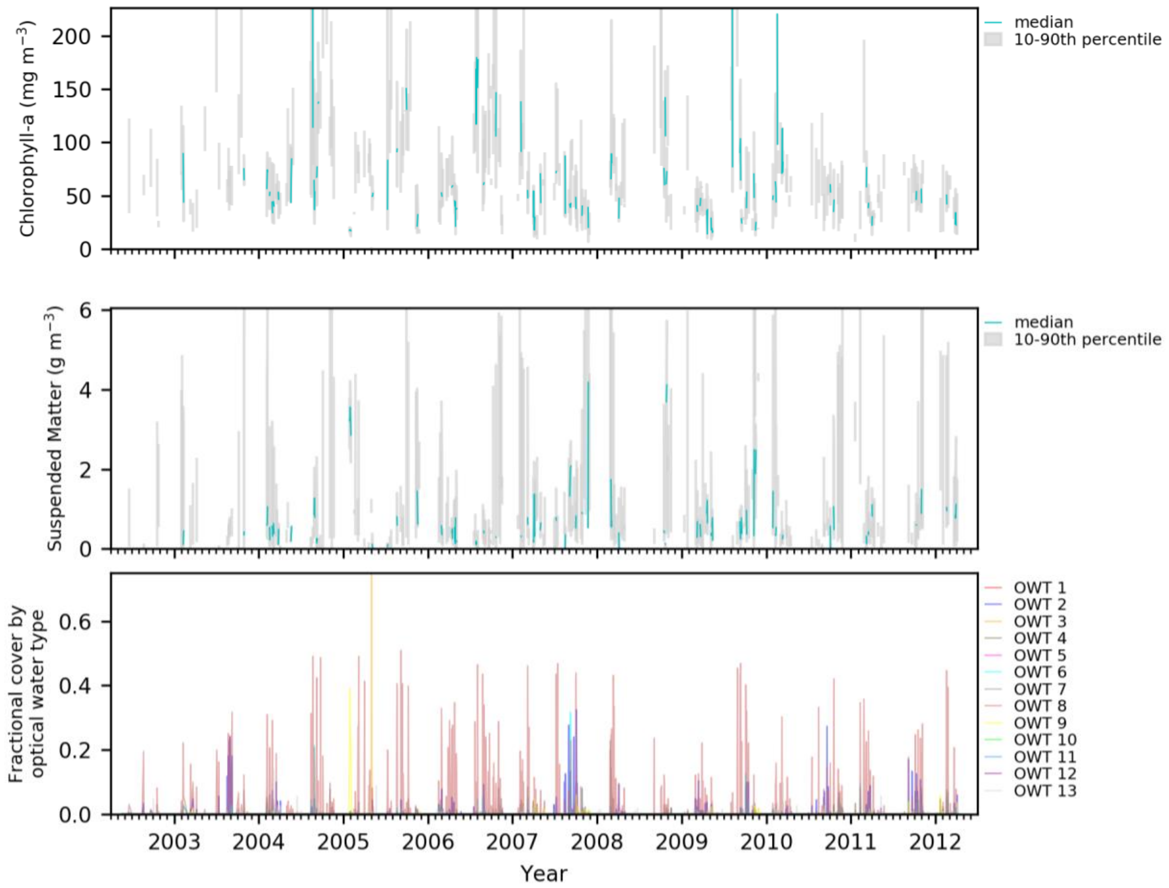


Figure 6. Earth Observation time-series of Chl-a, Suspended Matter and Optical Water Type (OWT) in Loch Leven (2002-2012, MERIS data)

4.2 Lake Balaton, Hungary

Lake Balaton is the largest shallow lake in Eastern Europe, located in the mid-western part of Hungary (46°52' N 17°50' E). While popular for recreation and tourism, the lake has historically been subject to eutrophic conditions and summer cyanobacteria blooms (Tyler et al., 2006; Horváth et al., 2013). Lake Balaton typically has a gradient in phytoplankton biomass, Chl-*a* and CDOM, with decreasing concentrations over increasing distance from the Zala River inflow in the westernmost basin (Riddick et al., 2015; Aullo-Maestro et al., 2017).

4.2.1 Climate

The surrounding air temperatures range from -20-40°C, with water temperatures ranging from 0-35°C, depending on the depth and season. The prevailing wind direction is NW, and wind speeds range from 0-45 m/s. Total sunshine hours are 2300-2500 per year, and total annual rainfall is approximately 550-650 mm (sum) per year.

4.2.2 Hydrology and Geography

Lake Balaton has a surface area of 596 km^2, and is shallow with a mean depth of 3.5 m (max depth = 11.2 m). The maximum lake length is 78 km, and the lake is located at 105 m above sea level.

Stratification does not generally occur, however on longer calm periods stratification has been reported for 6-14 days (although this is relatively rare).

The main inflow is the River Zala in the west, which is the main tributary of Lake and comprises more than 50% of the inflow, while the main outflow is the Sio Canal in the east. The Sio Canal is operated on a periodic basis depending on rainfall, with the canal generally remaining open in late winter or early spring. Lake residence time is 4.71 years.

The lake exhibits a trophic gradient, with status ranging from eutrophic to oligotrophic from west to east across the lake. The forming rocks in the lake are predominantly limestone and dolomite, which fundamentally control the chemistry of water discharging to and also stored in Lake Balaton (Ca^{2+}, Mg^{2+}, HCO^{3-} in high concentrations). The basalt mountains on the northern shore provide evidence of Pleistocene volcanic activity. Alluvial sediments predominate in the Zala River catchment, while loessial soils are commonly found in the southern sub catchment. Ploughed lands, meadows, pastures, vineyards and orchards cover 35, 8, 7 and 6% of the catchment, respectively.

Lake Balaton is a Natura 2000 site (https://www.bfnp.hu/en/natura-2000-areas) and Long-Term Socio-Ecological Research (LTSER) site (https://data.lter-europe.net/deims/site/lter_eu_hu_001).

4.2.3 Map and Sampling Locations

The MTA Centre for Ecological Research at Balaton Limnological Institute (BLI) routinely monitors 5 sampling stations, covering all 4 basins of Lake Balaton (Figure 7; Table 2).

The government body (KdKVI) also monitors routinely at 3 fixed platform locations and 12 buoy locations across the lake (Figure 8; Table 2).

Table 2. Coordinates of BLI sampling stations, fixed platform and buoy locations in Lake Balaton

Monitoring Body	Station	Latitude	Longitude
BLI	Balatonfűzfő - basin IV (namely Siófok)	46.985950	18.079117
	Tihany - basin IV (namely Tihany)	46.922117	17.927483
	Zánka - basin III (namely Szemes)	46.844350	17.743250
	Szigliget - basin II (namely Szigliget)	46.751867	17.419083
	Keszthely - basin I (namely Keszthely)	46.734917	17.276383
Government (KdKVI) – Fixed Platforms	Platform in basin I	46.733472	17.276310
	Platform in basin II	46.751283	17.412161
	Platform in basin IV	46.946353	18.011740
Government (KdKVI) – Buoys	1. Kelet T08	46.893371	17.919233
	2. Kelet	46.897761	17.918258
	3. Észak	46.901096	17.913898
	4. Észak1	46.896561	17.908268
	5. Észak T05	46.922450	17.889738
	6. Kelet T07	46.921847	17.890927
	7. Dél T03 (Csúcs s.)	46.920815	17.890753
	8. Dél T02	46.901876	17.905324
	9. Dél	46.897284	17.902255
	10. Dél T01	46.893309	17.898172
	11. Észak T06	46.887333	17.897254
	12. Észak T04	46.891901	17.902825

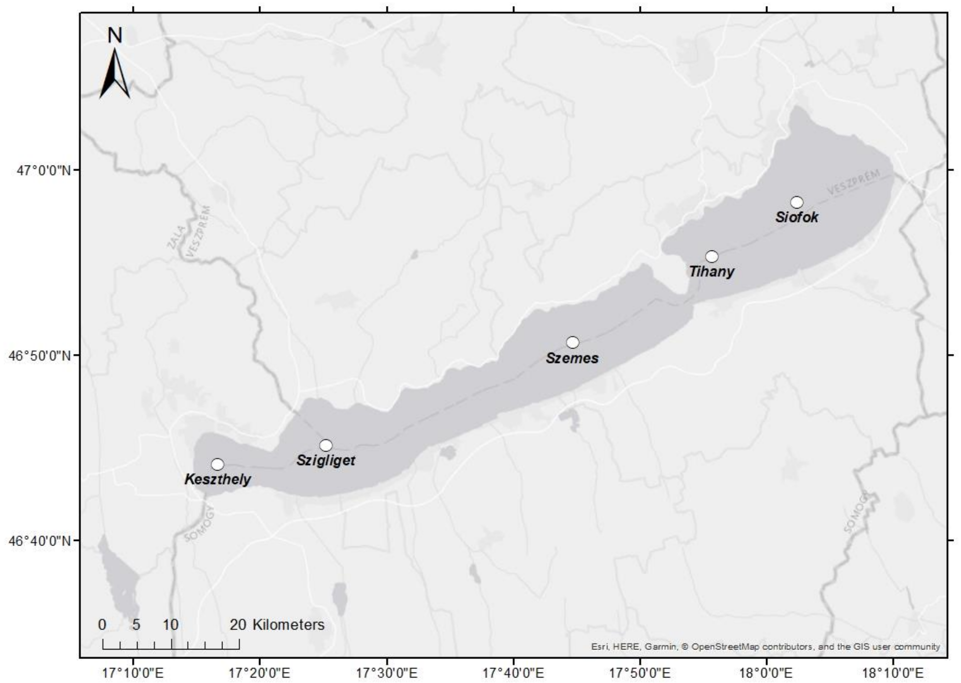


Figure 7. Map of Lake Balaton, indicating 5 typical sampling locations (BLI)

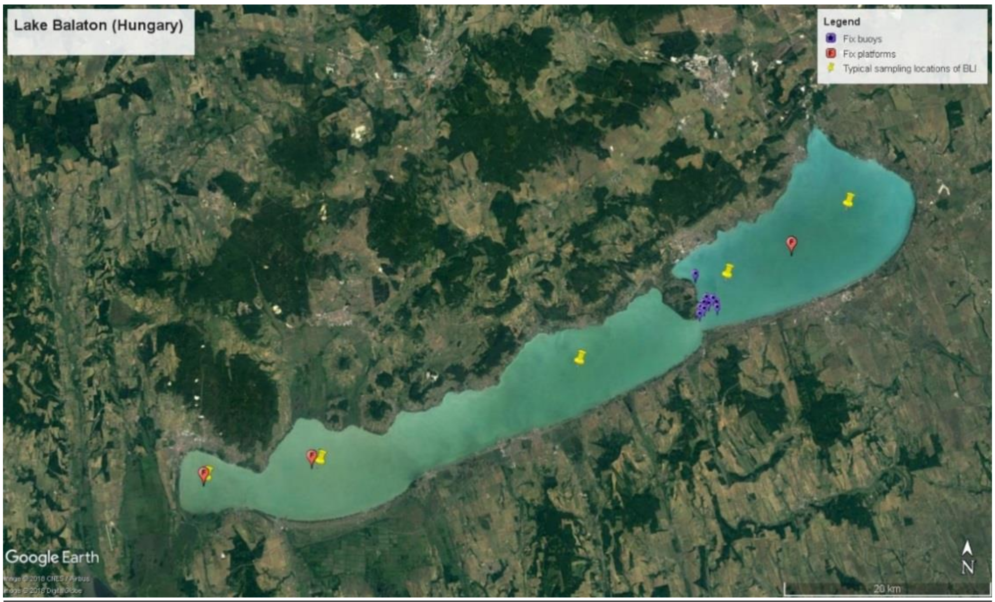


Figure 8. Map of Lake Balaton, indicating fixed platform and buoy locations.

4.2.4 Deployment Opportunities

There are fixed platforms, buoys, ferry boats and a small cruiser boat available for instrument deployment in Lake Balaton. There are three fixed platforms located in Basins I, II and IV (Table 2; Figure 9) as well as 12 fixed buoy locations across the lake (Table 2; Figure 10), all run by the government monitoring organisation (KdKVI). The fixed platforms are single metal columns fixed into the sediment (diameter = 219.2 mm, height = 1.1 m above surface level or 3 m above surface level with tail piece). The platforms are operational on a seasonal basis, typically installed in spring (March or April) and removed in late autumn (November). Platforms are removed in the winter to avoid ice damage. The buoys are fixed in the coordinate positions, however these do move slightly depending on wave action.

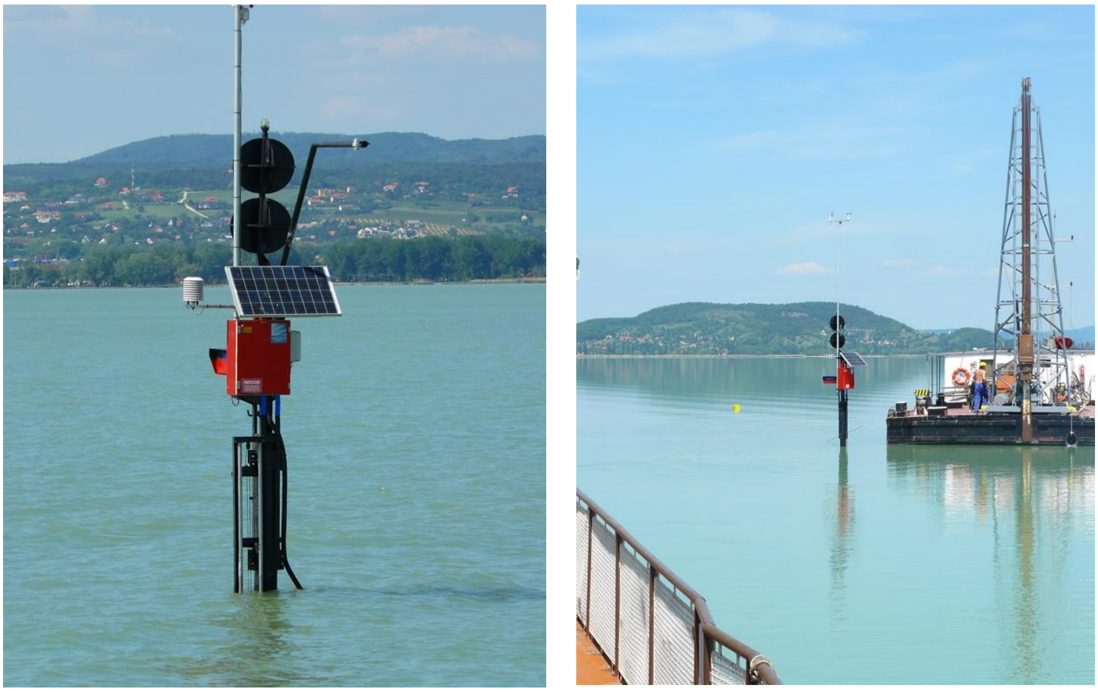


Figure 9. Photos of the fixed platforms in Lake Balaton

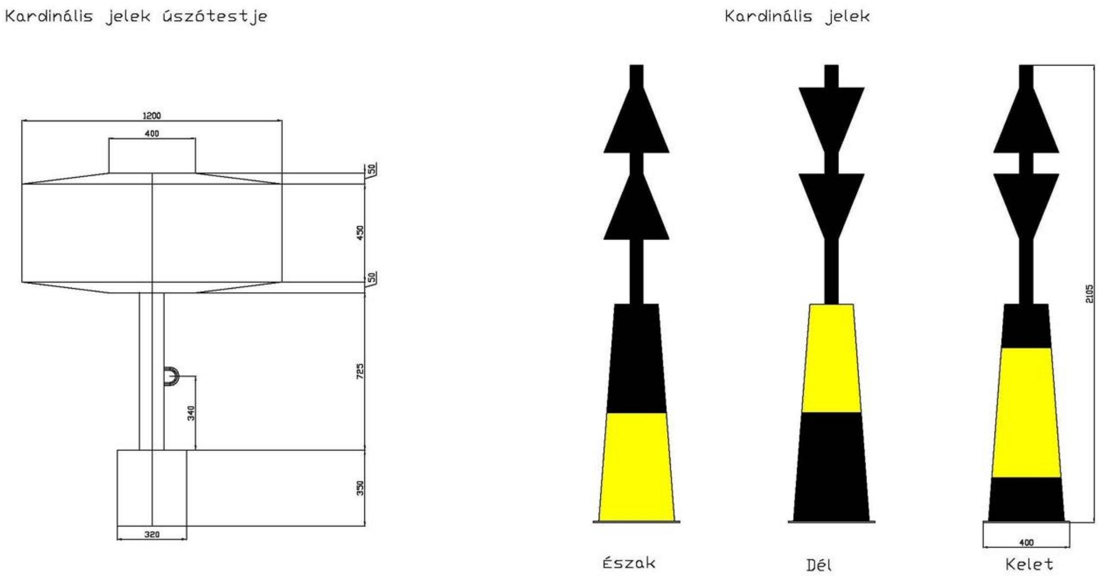
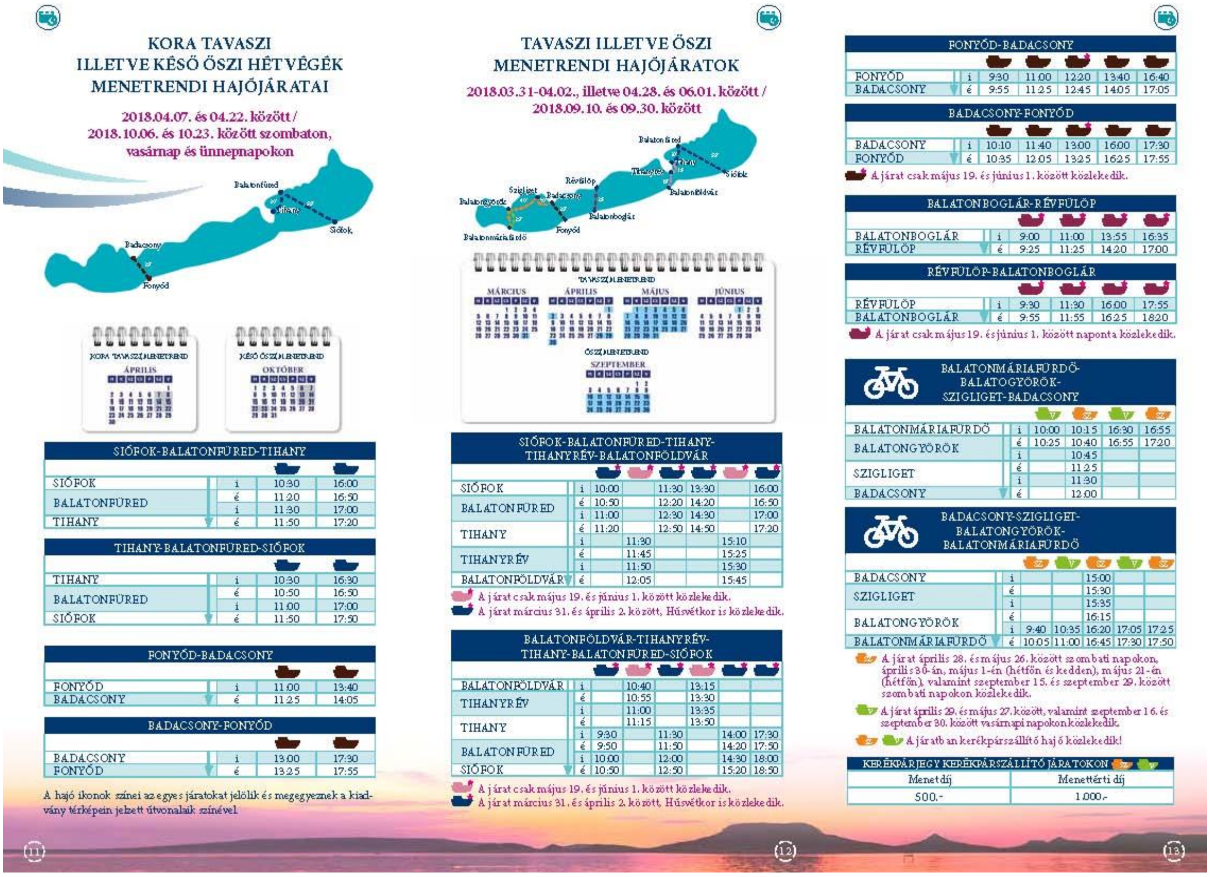
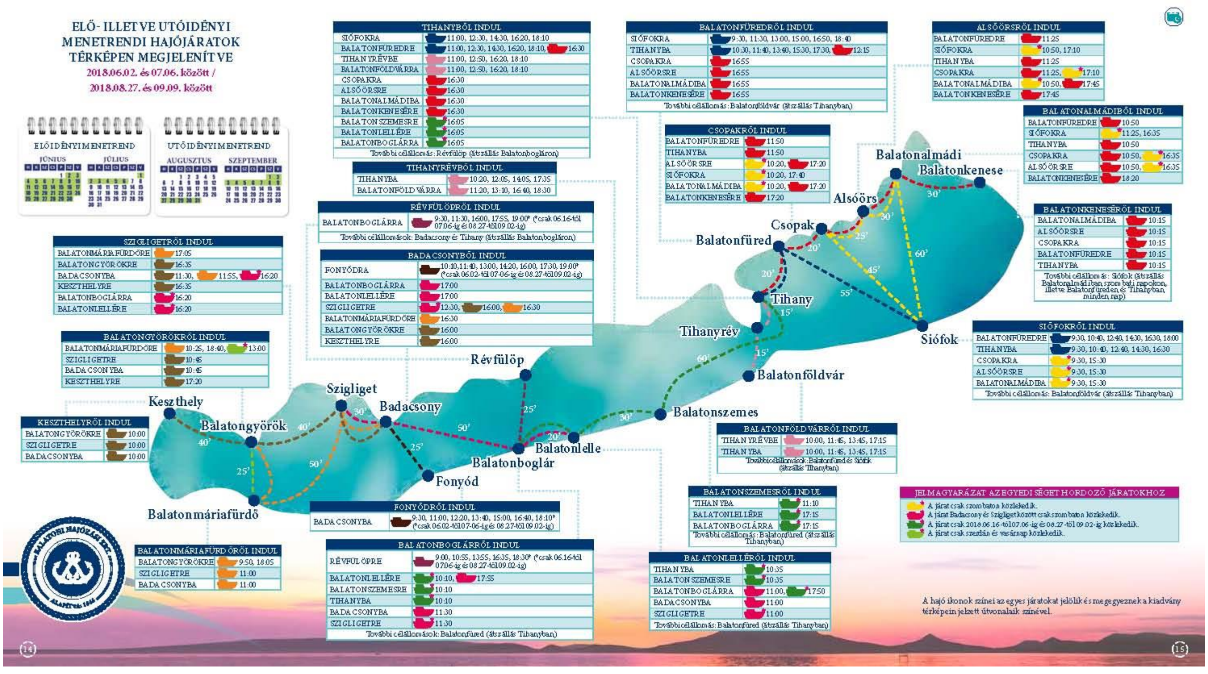


Figure 10. Design of the buoy installations in Lake Balaton

Passenger ferries operate on varying seasonal schedules between March and October (Figure 11). These would provide a deployment opportunity for equipment fixed on board a ferry along designated routes. Operators have been positive about the use of their vessels for monitoring, awaiting further technical discussions.





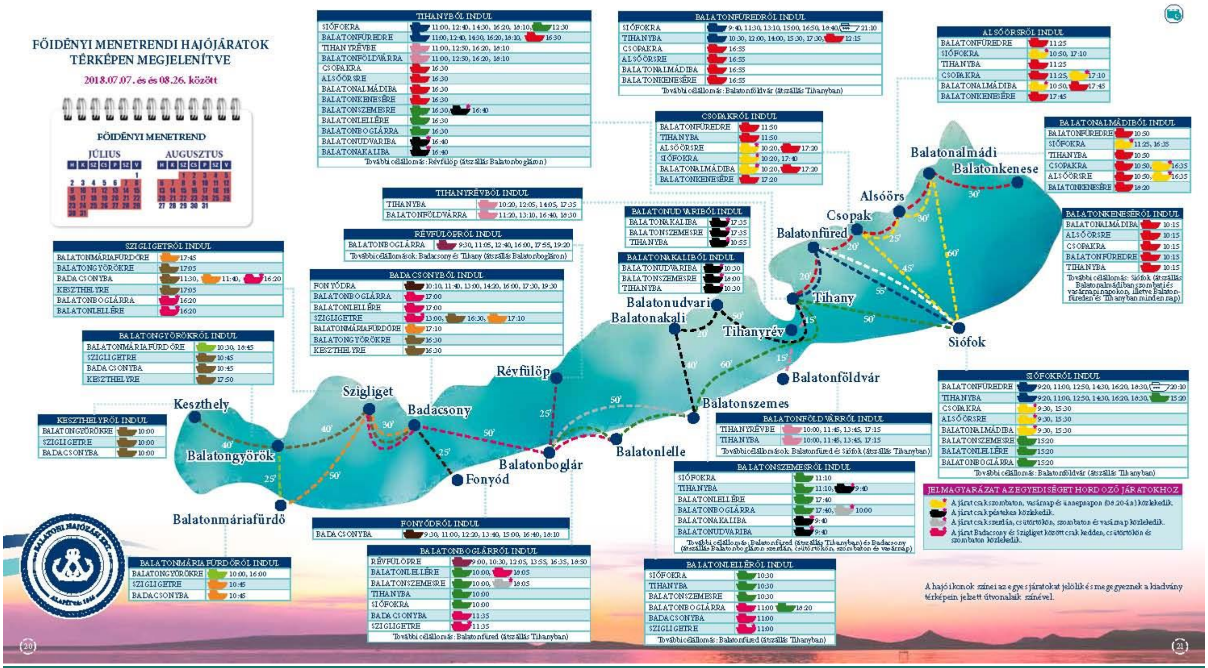


Figure 11 (previous page and above). Seasonal ferry maps and schedules for Lake Balaton

Figure 12 Car ferry connecting Tihanyrév and Balatonföldvár

4.2.5 Lab Facilities

Sample storage facilities at BLI comprise refrigerator (4°C), freezers set to -20°C and -80°C, and liquid nitrogen. Three sets of filtration equipment (including 25 or 47 mm glassware, clamps and pumps), two spectrophotometers (Shimadzu UV-1601 and Hitachi U-2900) and four analytical balances [Sartorius Handy (0-400 g, readability to 0.001 g), Metler ME30 (readability to 0.001 mg), Sartorius

Mpack (0-220 g, readability to 0.0001 g), Sartorius Handy (0-31 g, readability to 0.0001 g)] are available.

4.2.6 Data Archive

Due to routine monitoring, there is an extensive dataset for Lake Balaton from 1998. Water samples are collected by BLI on a biweekly or monthly basis at five stations (Table 2).

The lake itself typically has a gradient in phytoplankton biomass and Chl-a, with the highest Chl-a concentrations occurring in the western Keszthely basin (3-45 mg m^{-3}), and lower phytoplankton biomass and Chl-a in the eastern Siófok basin (3-20 mg m^{-3}; Figure 13). Cyanobacteria biomass tends to peak in late summer (anywhere from June-October), with phycocyanin concentrations up to 60-100 mg m^{-3} in the westernmost basins (Horváth et al., 2013). In recent years, summer cyanobacteria populations in Lake Balaton are dominated by nitrogen-fixing species, and during a bloom cyanobacteria often contribute to >70% of the total phytoplankton biomass (Horváth et al., 2013).

Despite the frequently high concentrations of phytoplankton that occur in Lake Balaton during the summer, light attenuation is largely determined by the frequent wind-driven resuspension of mineral particles from the lake bottom. TSM in the lake is mostly of inorganic origin, with concentrations typically in the order of 18-28 mg L^{-1} (2010 annual mean), but can exceed 100 mg L^{-1} during windy periods (Figure 14).

The light attenuation coefficient (K_d) in Lake Balaton is also typically higher in the western basin (Keszthely) as compared to the eastern basin (Tihany), with values ranging from 0.28 to 17 m^{-1} (Figure 15).

Lake Balaton also demonstrates highly localised concentrations of CDOM. CDOM absorption coefficients ($a_{CDOM}(440)$) typically ranging from 0.09–1.4 m^{-1}, with the highest CDOM absorption observed at the mouth of the Zala River ($a_{CDOM}(440)$ up to 9.5 m^{-1}) where water rich in dissolved organic carbon produced in the reservoir system Kis-Balaton discharges into the western portion of the lake (Riddick et al., 2015; Figure 16). However, CDOM is rapidly diluted and bleached through photodegradation as water passes through the system (Aullo-Maestro et al., 2017).

Phytoplankton absorption coefficients ($a_{ph}(\lambda)$) vary over a broad range in Lake Balaton (Figure 17). However, seasonal variability appears high, likely related to changes in both phytoplankton abundance and community composition.

High concentrations of mineral particles contribute significantly to light absorption and scattering in Lake Balaton; absorption by non-algal particles ($a_{NAP}(440)$) is typically 0.2 m^{-1} and particulate backscattering ($b_{bp}(532)$) varies between 0.04-0.2 m^{-1} (Riddick et al., 2015; Figure 18). These fine particles have a high backscattering efficiency (b_{bp}:b_p up to 0.03) and thus contribute strongly to the water-leaving radiative signal and impart the lake with its characteristic turquoise colour.

In situ remote sensing reflectance ($R_{rs}(\lambda)$) data were collected in 2010 and 2014 over Lake Balaton, with a broad range of spectral values collected over the lake (Figure 19).

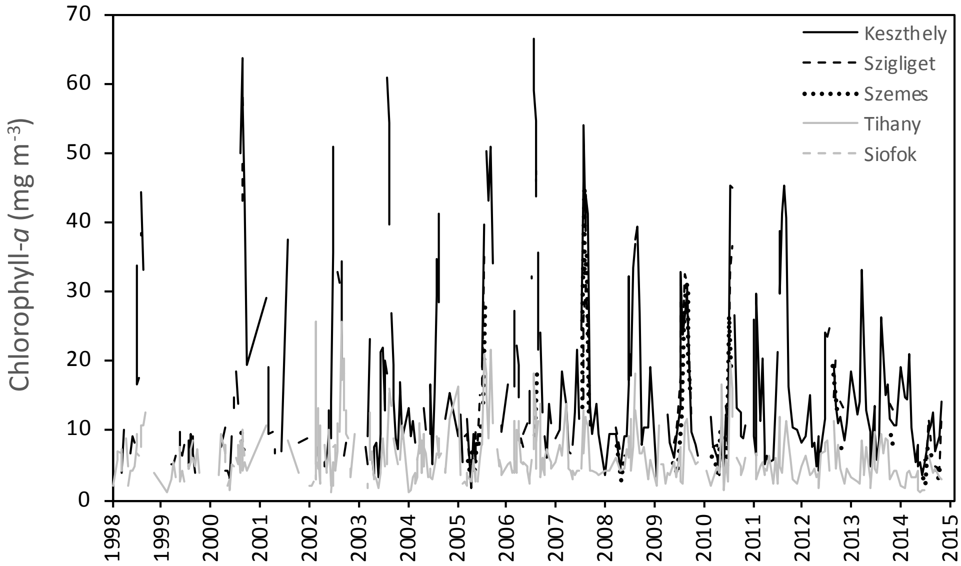


Figure 13. Time series of Chl-a in Lake Balaton (BLI data, 1998-2015)

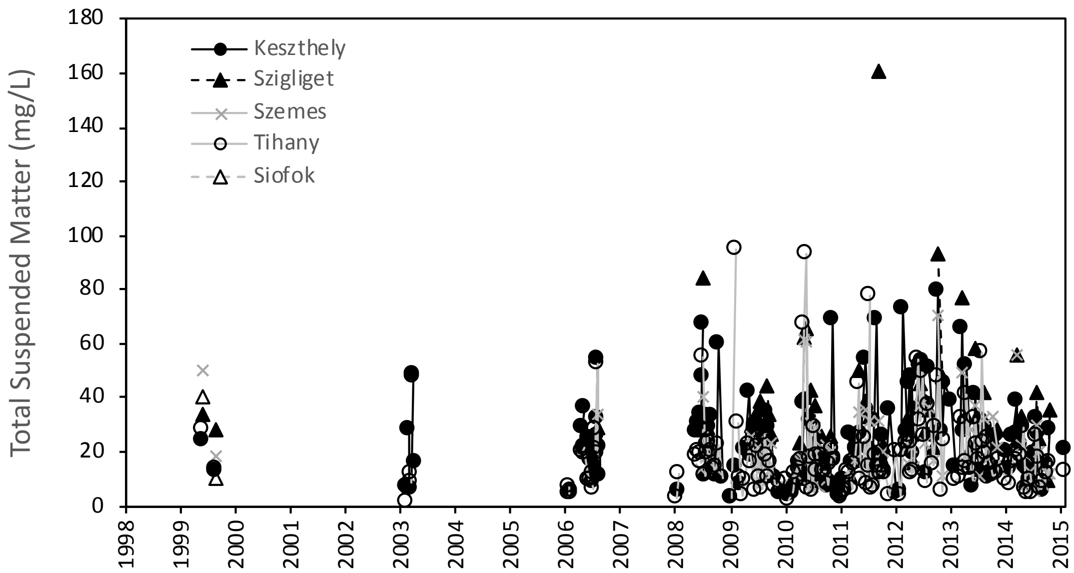


Figure 14. Time series of TSM in Lake Balaton (1998-2015)

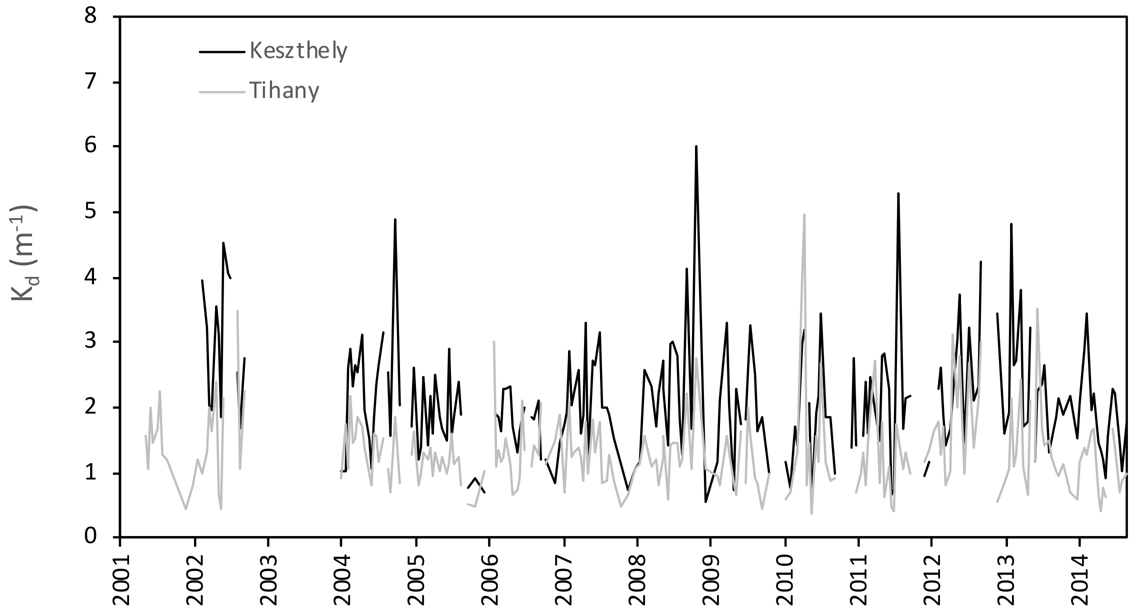


Figure 15. Time series of K_d in Lake Balaton (2001-2014)

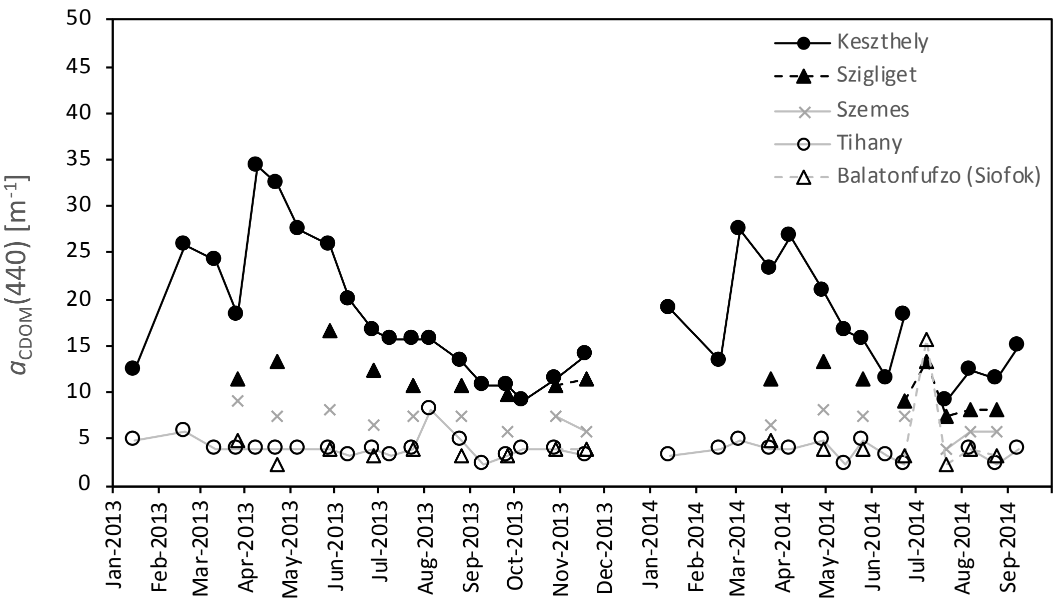


Figure 16. Time series of CDOM absorption in Lake Balaton (2013-2014)

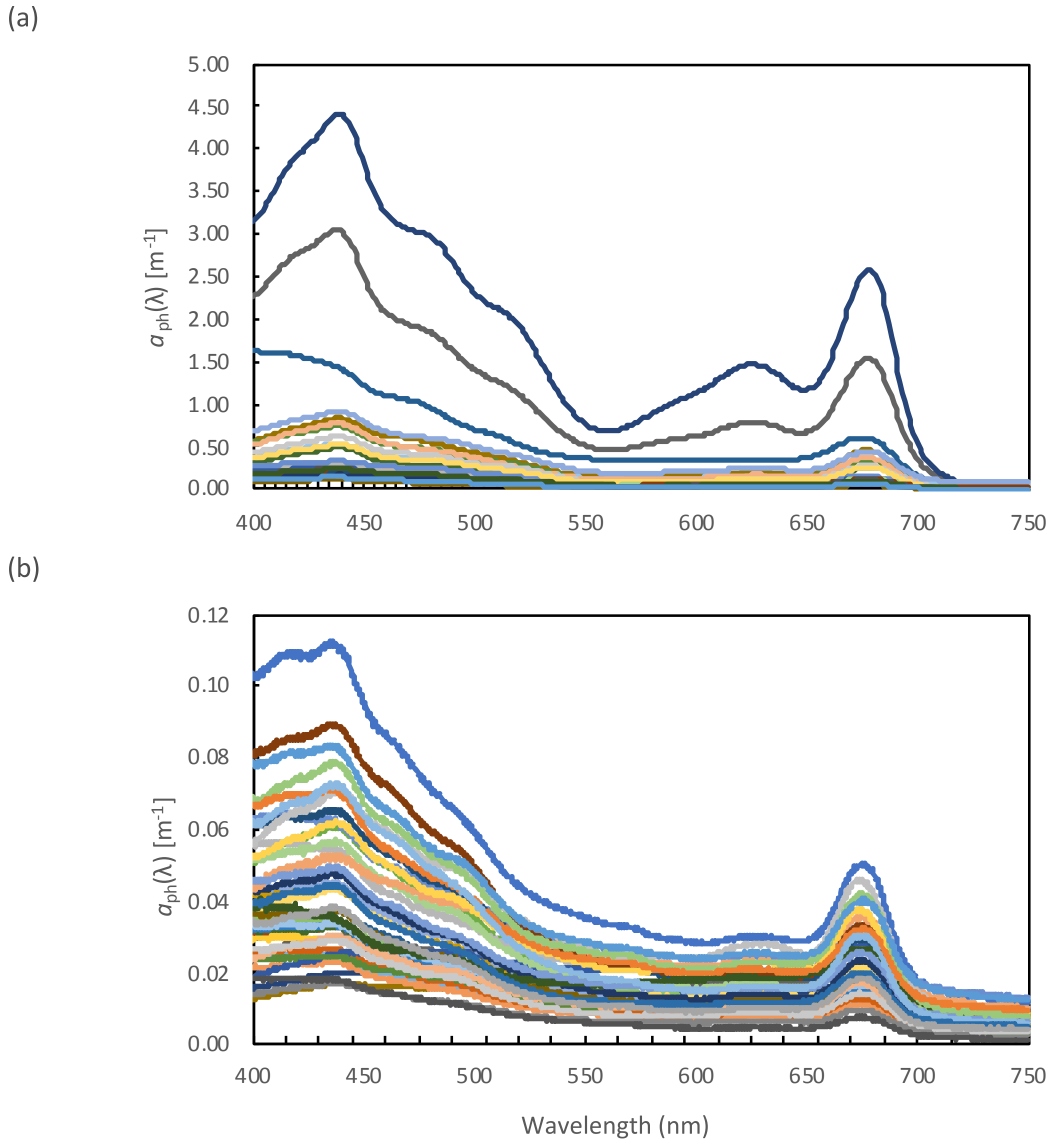
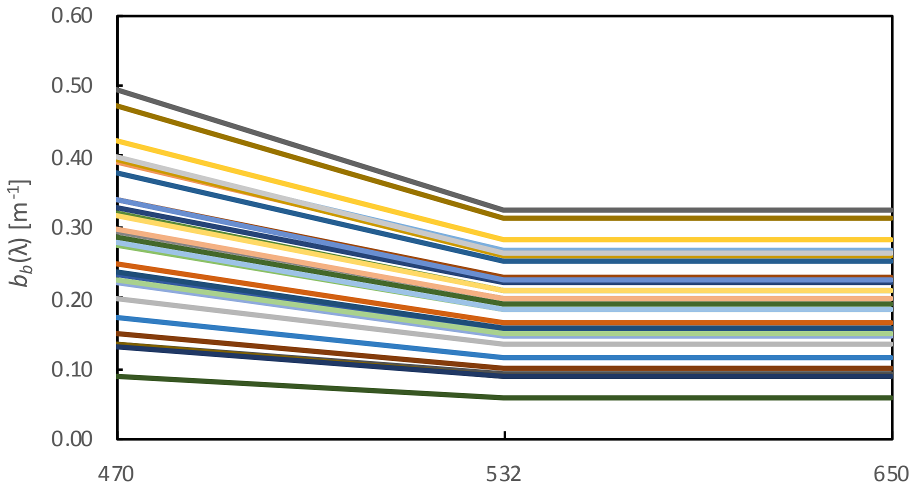


Figure 17. $a_{ph}(\lambda)$ in Lake Balaton for (a) 19-26th August 2010 and (b) 9-25th July 2014 (dual beam spectrophotometer, University of Stirling). Note different y-axis ranges.

(a)



(b)

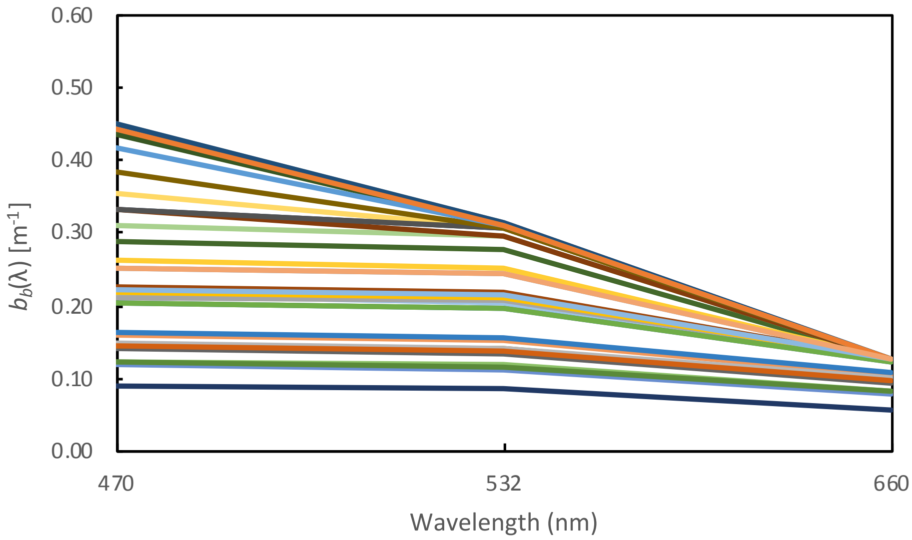


Figure 18. $b_b(\lambda)$ in Lake Balaton for (a) 19-26th August 2010 and (b) 9-25th July 2014 (Wetlabs Eco-BB3, University of Stirling).

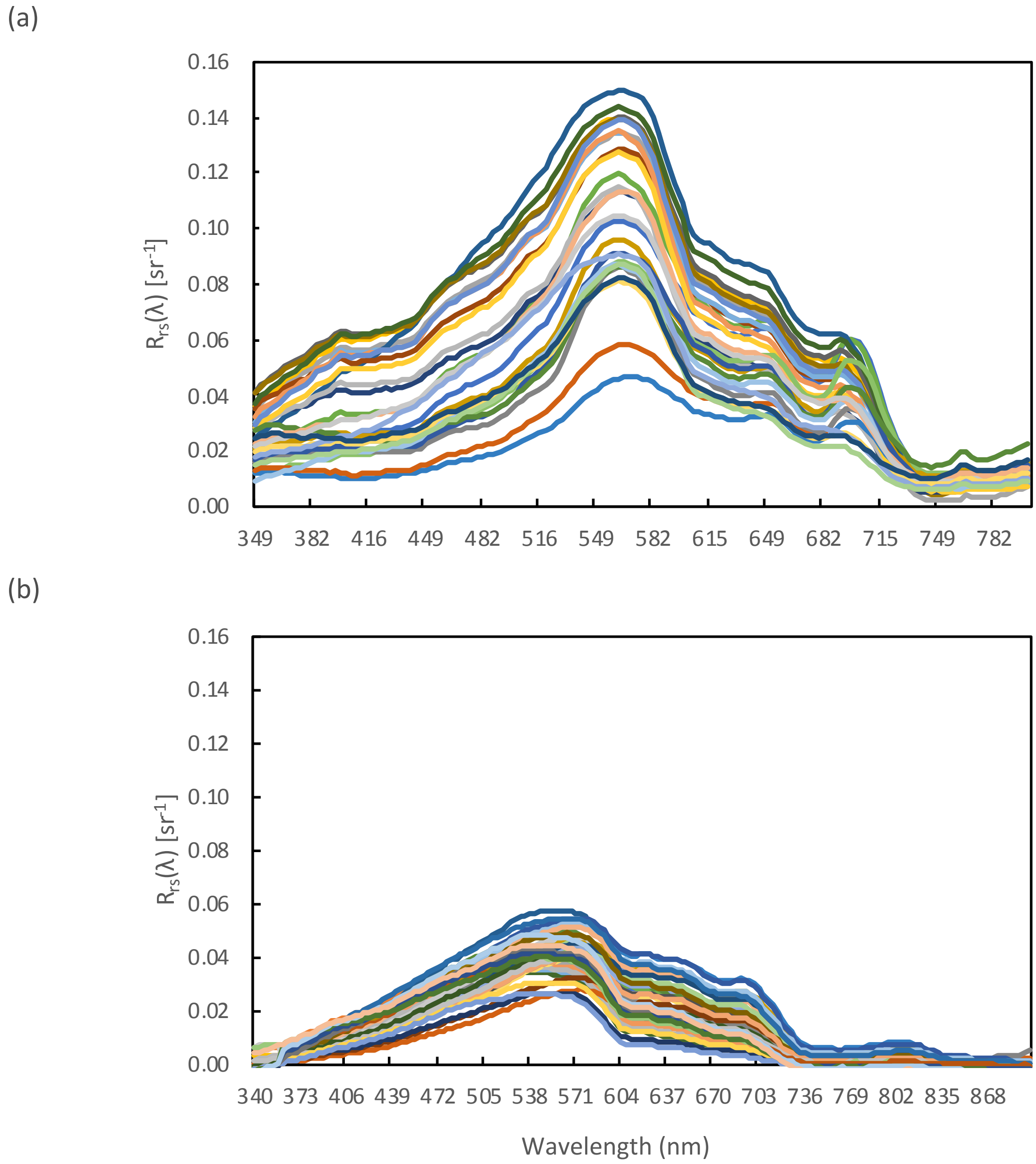


Figure 19. $R_{rs}(\lambda)$ in Lake Balaton for (a) 19-26th August 2010 and (b) 9-25th July 2014 (HyperSAS, University of Stirling). Note different wavelength ranges between the two panels.

4.2.7 Earth Observation

Lake Balaton is highly suitable for satellite observation at 300m resolution, providing a dense time series of chlorophyll-a and suspended matter through optical water type-specific mapping (Figure 20 and Figure 21). Satellite data analysis with *Calimnos* v1.04 show seasonality in the phytoplankton Chl-a with occasional blooms, represented by a typological shift between water types 9 and 2. Yearly maps of the 90th percentile of Chl-a show that blooms are restricted to the western basins and the highest concentrations are found in the westernmost parts (Figure 21).

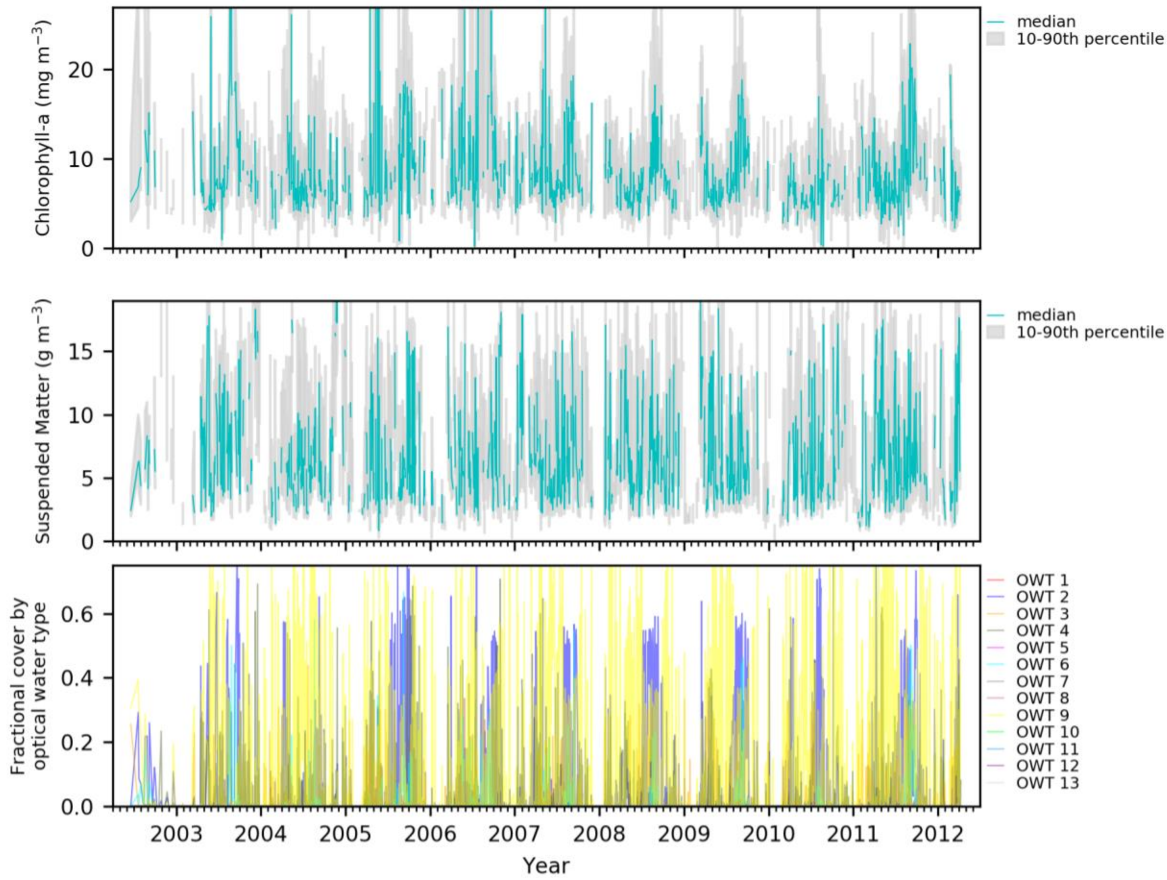


Figure 20. Earth Observation time series of Chl-a, Suspended Matter and Optical Water Types (OWT) in Lake Balaton (2002-2012, MERIS data)

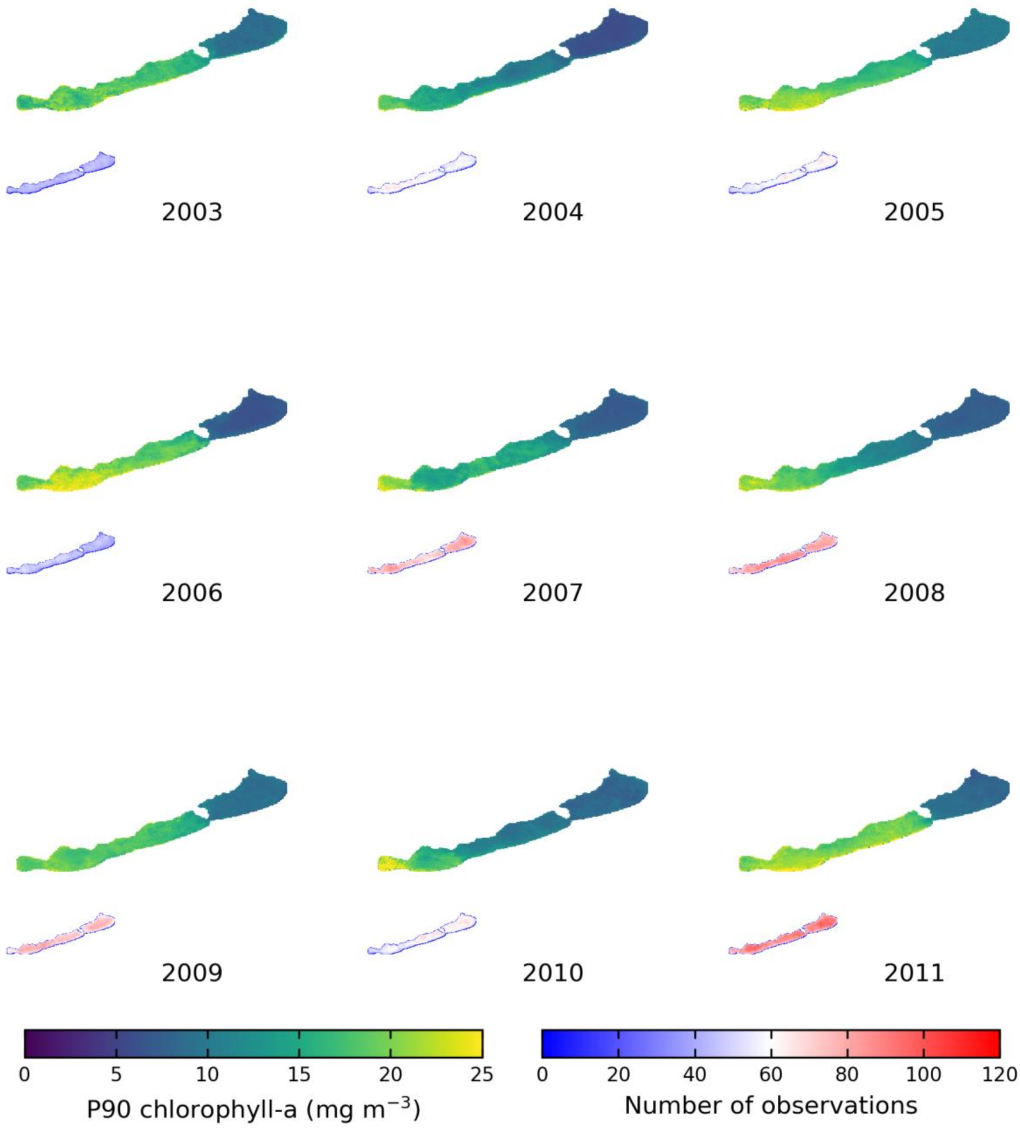


Figure 21. Yearly 90th-percentile maps of Chl-a in Lake Balaton (2003-2011, MERIS data)

4.3 Lake Dunkern, Sweden

Lake Dunkern (59.155003°N, 16.880921°E) is a small mesotrophic lake (4.46 km^2) located 100 km from Stockholm, Sweden. There are few measurement data available for Lake Dunkern.

4.3.1 Climate

Air temperatures range from -5° to 17°C on average near Lake Dunkern. The mean wind speed is 9 km/h. The wind is most often from the west for 11 months. Annual total sunshine hours are 1900 hrs, while total annual rainfall is 600 mm.

4.3.2 Hydrology and Geography

Lake Dunkern has a surface area of just 4.46 km^2, with a maximum length of 2.5 km. The mean depth is 15.6 m, with a maximum depth of 40 m, and stratification occurs in summer. The lake is located 24.1 m above sea level.

The main inflow to Lake Dunkern is Vadsbroån and the main outflow is Husbyån. It is a mesotrophic lake, with the surrounding landscape comprised of 60% forest and 16% agricultural land.

Lake Dunkern is a Natura 2000 designated site.

4.3.3 Map and Sampling Locations

Available bio-geo-optical data has been collected from a single station in the centre of Lake Dunkern (59.155003°N, 16.880921°E) (Figure 22).

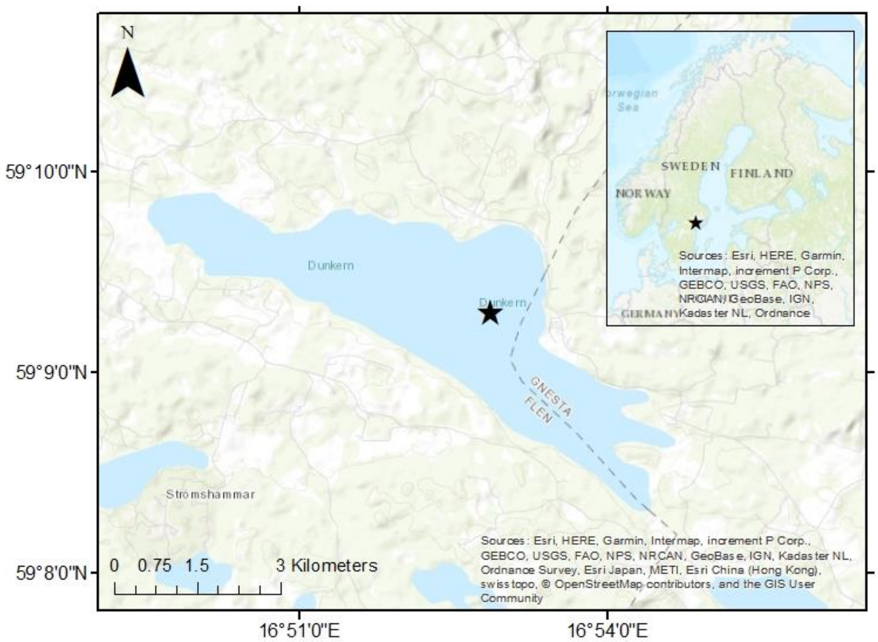


Figure 22. Map of Lake Dunkern, indicating the single sampling location (star).

4.3.4 Deployment Opportunities

Deployment opportunities at Lake Dunkern include citizen science (CS), boats and platforms. Buoys are present, however availability of these needs to be checked prior to the MONOCLE field campaign.

4.3.5 Lab Facilities

Sample storage facilities can be organised through the existing links between Earthwatch (CERT) and Stockholm University. No laboratory equipment or instruments are available at the site, although there are possibilities to arrange these with local universities and partners.

4.3.6 Data Archive

Lake Dunkern has been monitored as part of several projects under the Sötvatten program since 1962 on a seasonal basis (Table 3, [external link]). The data archive includes phytoplankton community composition since 2013, and nutrients, Secchi depth and dissolved organic carbon (DOC) absorption (Abs_F436) data from 1998. Samples were mainly taken from surface waters (0.5 m), with two bottom water samples taken in March and August 2003.

Table 3. Dunkern monitoring projects

Projekt	Provtagningsår
Södermanlands län	2006 - 2017
Södermanlands län	2006 - 2017
Södermanlands län, sjöinventering	1999 - 2006
Södermanlands län, vattenkemi i sjöar	1998 - 2015
Stockholms län	1968 - 2018
Stockholms län	1968 - 2018
Stockholms län, sjöinventering	2013 - 2017
Nyköpingsåarnas vattenvårdsförbund	1962 - 2016

Chlorophyll-a concentrations ranged from 3 to 10 mg m^{-3} (Figure 23) and turbidity values ranged from 1 to 3 in Formazin nephelometric units (FNU) (Figure 24), however it is noted that these data are from a small sample size (chlorophyll n=7, turbidity n=5), with samples taken in late summer months only (August or September).

Nutrient concentrations in Lake Dunkern have generally decreased in recent years, with total phosphorus (TP) concentrations of 11-40 µg/l and total nitrogen (TN) concentrations of 400-900 µg/l (Figure 25 and Figure 26). These chlorophyll-a and nutrient levels in surface waters are indicative of a mesotrophic lake. However, two bottom samples taken in 2003 contained markedly higher TP (40-300 µg/l) and TN concentrations (800-1600 µg/l), suggesting a legacy of nutrient enrichment in this lake.

In relation to water colour, the absorption of dissolved organic carbon (water sample filtered through a 0.45 µm pore size filter) at 436 nm ranged from 0.05 to 0.09 cm^{-1} (Figure 27).

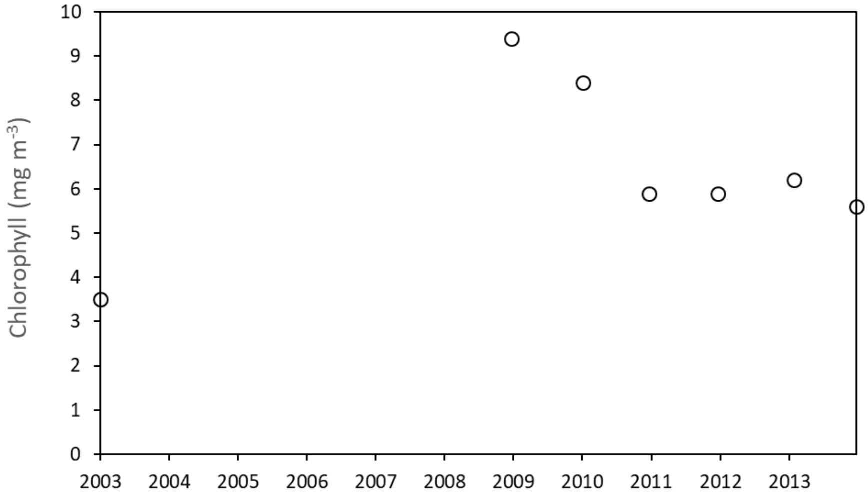


Figure 23. Time series of Chl-a in Lake Dunkern (2003-2014)

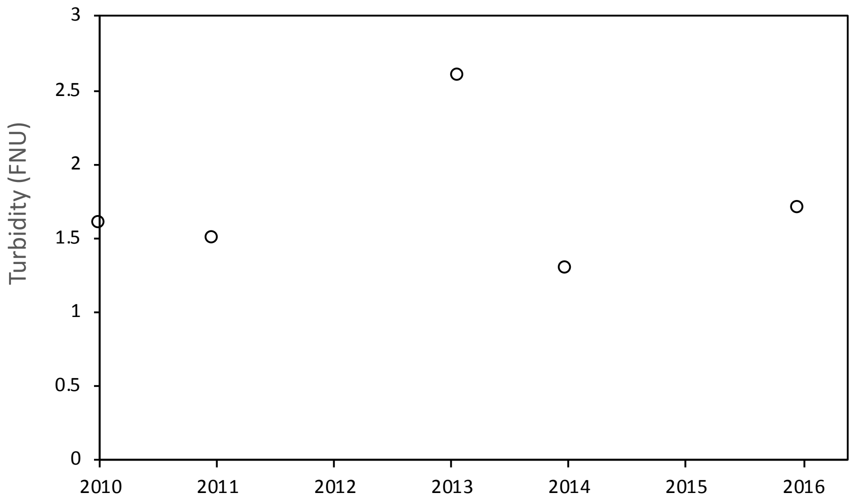


Figure 24. Time series of turbidity in Lake Dunkern (2010-2016)

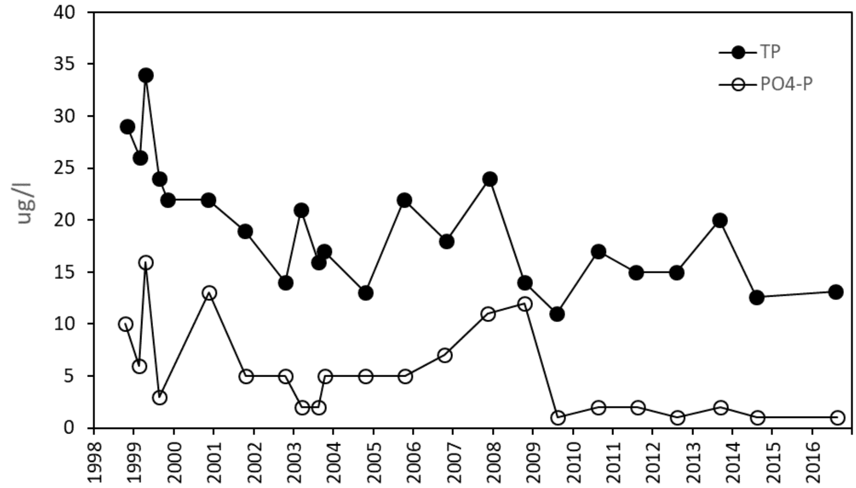


Figure 25. Time series of phosphate as P (PO_4-P) and total phosphorus (TP) in Lake Dunkern (1998-2016)

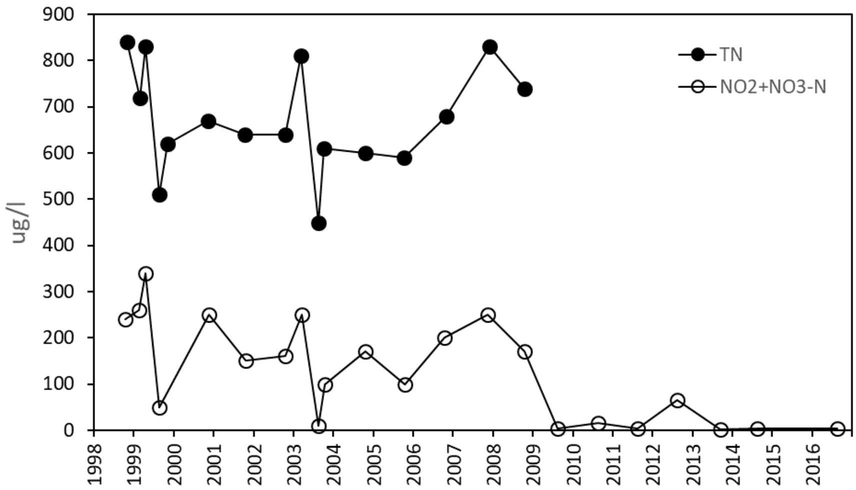


Figure 26. Time series of nitrate + nitrite as N (NO_2 + NO_3-N) and total nitrogen (TN) in Lake Dunkern (1998-2016)

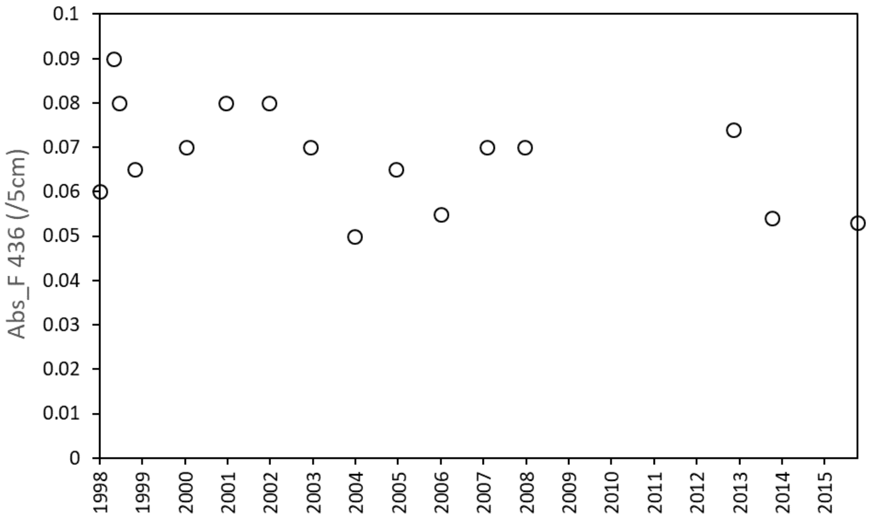


Figure 27. Time series of dissolved organic carbon (DOC) absorption at 436 nm in Lake Dunkern (1998-2015). Samples are filtered through a 0.45 um pore size prior to measurement of absorption by spectrophotometry.

4.3.7 Earth Observation

Remote sensing observations by MERIS and OLCI at 300-m resolution can be used in Lake Dunkern. The MONOCLE project will additionally employ observations from the MSI (Multispectral Imager) on board Sentinel 2 over Lake Dunkern, as this sensor has a much higher spatial resolution (10 m^2) and will therefore provide more detailed information than MERIS/OLCI for a small lake.

4.4 Razelm-Sinoe Lagoon System, Romania

The Razelm-Sinoe Lagoon is a coastal lagoon system attached to the southern part of the Danube Delta, located on the Romanian shoreline of the Black Sea (44°53’ N, 28°58’ E). Originally a marine bay (the former Halmyris Gulf), the lagoon system became isolated from the sea by accumulation and redistribution of sand bars (Dinu et al., 2015). Due to the complex evolution of the interaction between the Danube and the Black Sea, the area has been fragmented into many semi-independent lakes. The Razelm lagoon consists of: Razelm Lake (41500 ha), Golovita Lake (11800 ha), Zmeica Lake (5550 ha), Babadag lake (2370 ha) (with two components: Tauc Lake and Topraichioi Lake), Sarichioi-Sarnasuf lake (2070 ha) and Cosnei lake (3550 ha). The Sinoe Lagoon consists of: Sinoe Lagoon (17159 ha), Nuntasi Lake (1050 ha), Istria Lake (560 ha) and Edighiol Lake (1070 ha). The lagoon system has historically been significantly impacted by anthropogenic interventions, including dredging and substantial physical modifications that have affected the course of its natural evolution (Stănică, 2012).

4.4.1 Climate

Air temperatures near the Razelm-Sinoe Lagoon range from -23 to 40 °C, and the highest frequency of strong winds tend to be from the N (15 m/s). Annual sunshine in the region is 220 hours per year, while rainfall averages 350-400 mm per year.

4.4.2 Hydrology and Geography

The surface area of Razelm-Sinoe Lagoon System is 863 km^2, with a maximum length of 50 km. The lagoon is shallow and has a mean depth of just 1.5 m (max depth 3.2 m), therefore stratification is not known to occur. The lagoon system is classed as freshwater to oligohaline, with salinity levels near the inlets from the Sinoe Lagoon ranging between 8.93 and 18.77 psu (Dinu et al., 2015).

The Sf. Gheorghe tributary of the Danube Delta discharges into the Razelm Lagoon via 3 channels (the Dunavăt, Mustaca and Dranov channels). Water discharge from the Razelm Lake to the Sinoe Lake then occurs through two artificial canals, and circulation between the Black Sea and the Sinoe Lagoon occurs via the Periboina and Edighiol inlets. Sea water level at the lagoon system varies between 0.5 and 0.92 m above sea level (Dinu et al., 2015).

In the area of the Razelm-Sinoe Lagoon System, there are also several islands, including Popina Island, Bisericuta Island and Gradistea Island. Littoral bars (active and relict) separate the lakes and lagoons, consisting of Danube-sourced fine sands, and occupy lengths of tens of kilometres. These include Grindul Chituc, Grindul Lupilor, Edighiol, Periboina, Portita and Periteasca.

The surrounding landscape consists of agricultural lands, intensive forestry and abandoned land proposed for ecological reconstruction as part of the Danube Delta Biosphere Reserve Authority Development/investments programme.

The Razelm-Sinoe Lagoon System forms part of the Danube Delta Biosphere Reserve (DDBR) and was declared as both a Natural World Heritage and Ramsar site in 1991. The DDBR is ranked as having the third ecological significance among the 300 UNESCO reserves in the world. Due to its international importance, the DDBR was listed (1990) among the world network of biosphere reserves under the Man and Biosphere Programme (MAB). Under the RAMSAR Convention, of which Romania is a party since 1991, the DDBR was singled out as wetland of international value as a major water bird habitat.

4.4.3 Map and Sampling Locations

There are no typical or set locations for water quality measurements in the Razelm-Sinoe Lagoon System, however available data have been collected at various locations in Razim (also called Razelm), Goloviţa, Zmeica, Ceamurlia, Leahova Mică, Istria, Babadag and Sinoie (also called or Sinoe) (Figure 28).

A map of the lagoon system is shown in Figure 29, indicating the inflows to Razelm Lagoon, canal connecting Razelm and Sinoe lagoons, and the inlets from the Sinoe to the Black Sea.

4.4.4 Deployment Opportunities

If the water level is high enough during the MONOCLE field campaign, then the research vessel (RV) Istros owned by GEOECOMAR can be used for instrument deployment. This RV can be used together with smaller boats for deployment, and can form a “base camp” for the field campaign.

Additionally, the Popina and Bisericuta islands can be used as deployment points for fixed position instruments.

4.4.5 Lab Facilities

In autumn 2018, the RV Istros will be modernised and will include fridges and freezers for sample storage. There are no filtration equipment, spectrophotometers or analytical balances available for use on the RV Istros or in the vicinity of the field site, therefore any required laboratory equipment will need to be transported to the site.

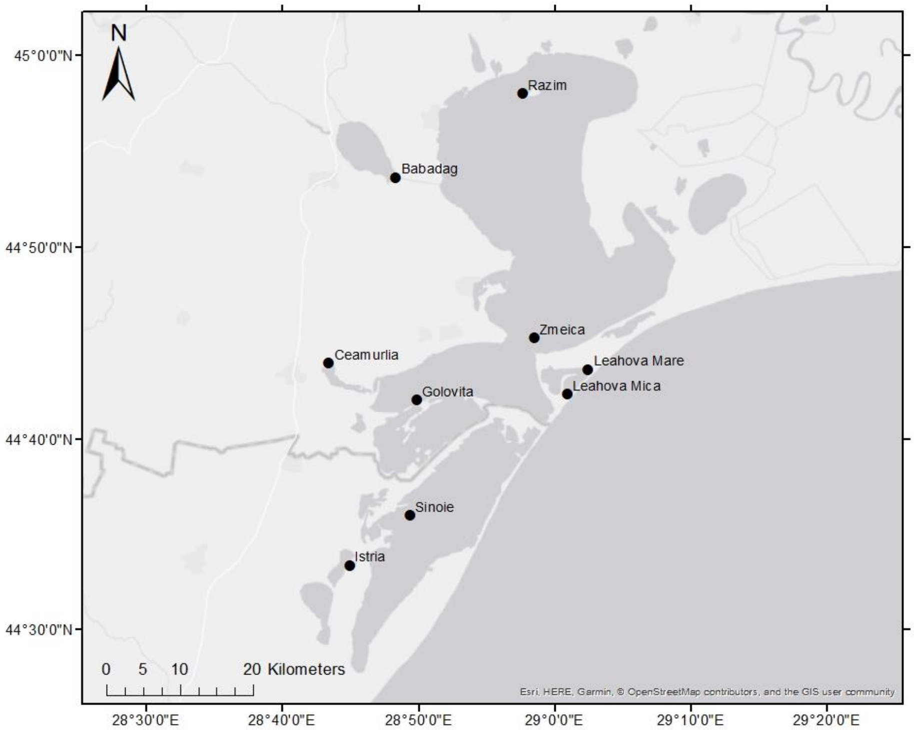


Figure 28. Example sampling locations for the Razelm-Sinoe Lagoon System

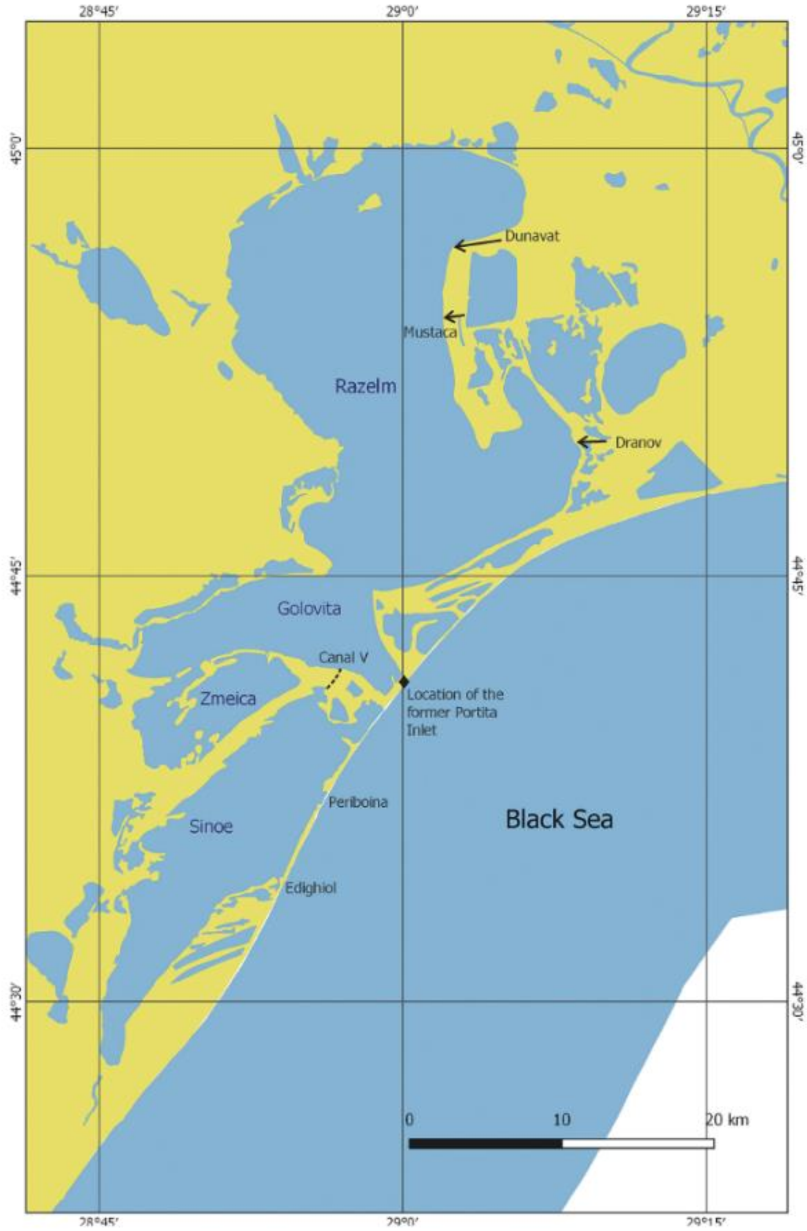


Figure 29. Map of the Razelm-Sinoe Lagoon System (from Dinu et al., 2015)

4.4.6 Data Archive

Available data for the Razelm-Sinoe Lagoon System include water depth, Secchi depth, temperature, chemistry (Dissolved Oxygen, Conductivity, pH, salinity, turbidity), total dissolved solids, total suspended solids, nutrients (nitrite, nitrate, phosphate, sulphate, silicate). Data were collected in July 2010 and 2011, October-November 2014, April and October 2015, May-June and August 2016, May-June 2017 and May 2018. Chl-a data are available for May 2016, May 2017 and May 2018 only.

Chl-a concentrations varied from 2 to 96 µg/l across the lagoon (note all data are from May-June only), with the highest annual mean concentrations recorded in Razim (2017) and the lowest annual mean concentrations reported in Golovita (2016; Figure 30). Concentrations were highly variable within each lake/lagoon, however, with standard deviation ranging from 2.9-26.1 µg/l.

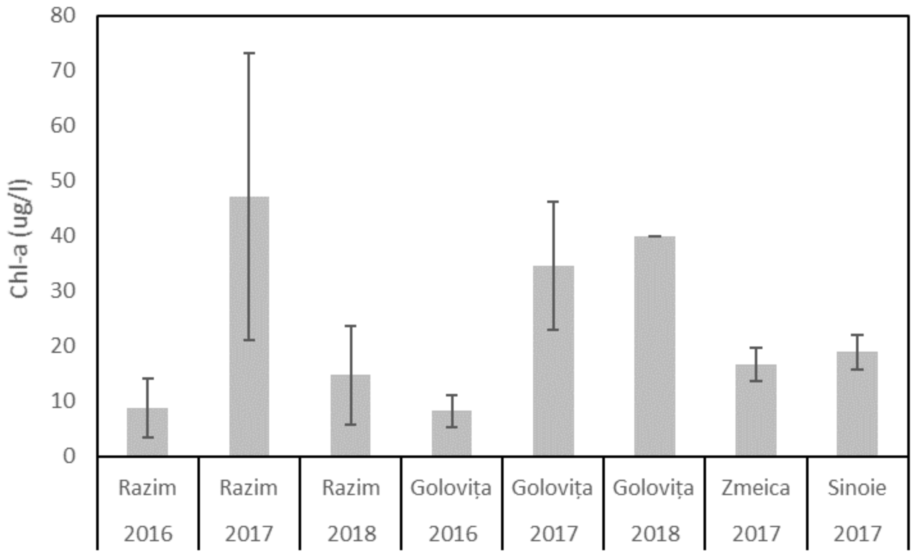


Figure 30. Mean Chl-a (μg/l) in Razelm-Sinoe Lagoon System (error bars indicate standard deviation)

TSM ranged from 2 to 221 mg/l in the Razelm-Sinoe Lagoon System, with the highest mean TSM frequently in Goloviţa (Figure 31). There is also a large variability in the relative composition of sand, silt and clay in the Razelm-Sinoe Lagoon System sediments, indicating the highly heterogeneous nature of the lagoon system (Figure 32).

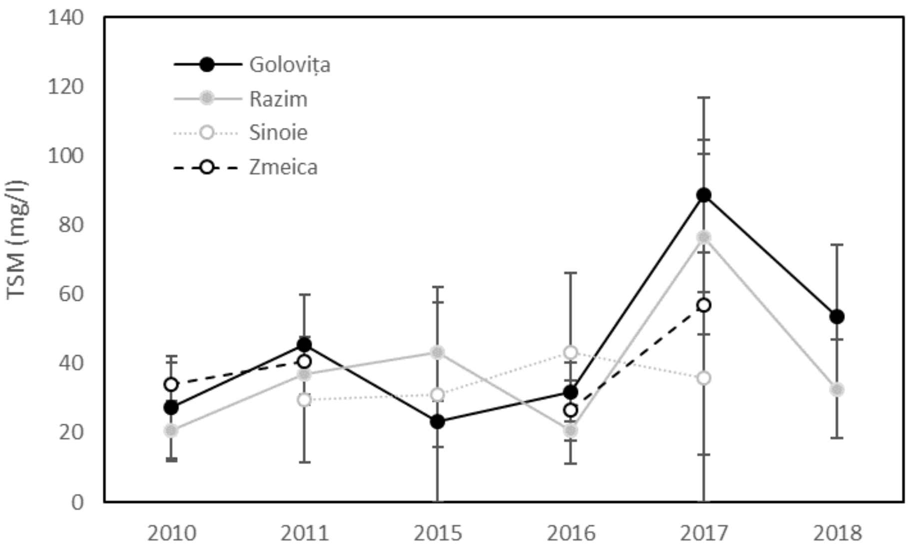


Figure 31. Mean TSM (mg/l) in Razelm-Sinoe Lagoon System (error bars indicate standard deviation)

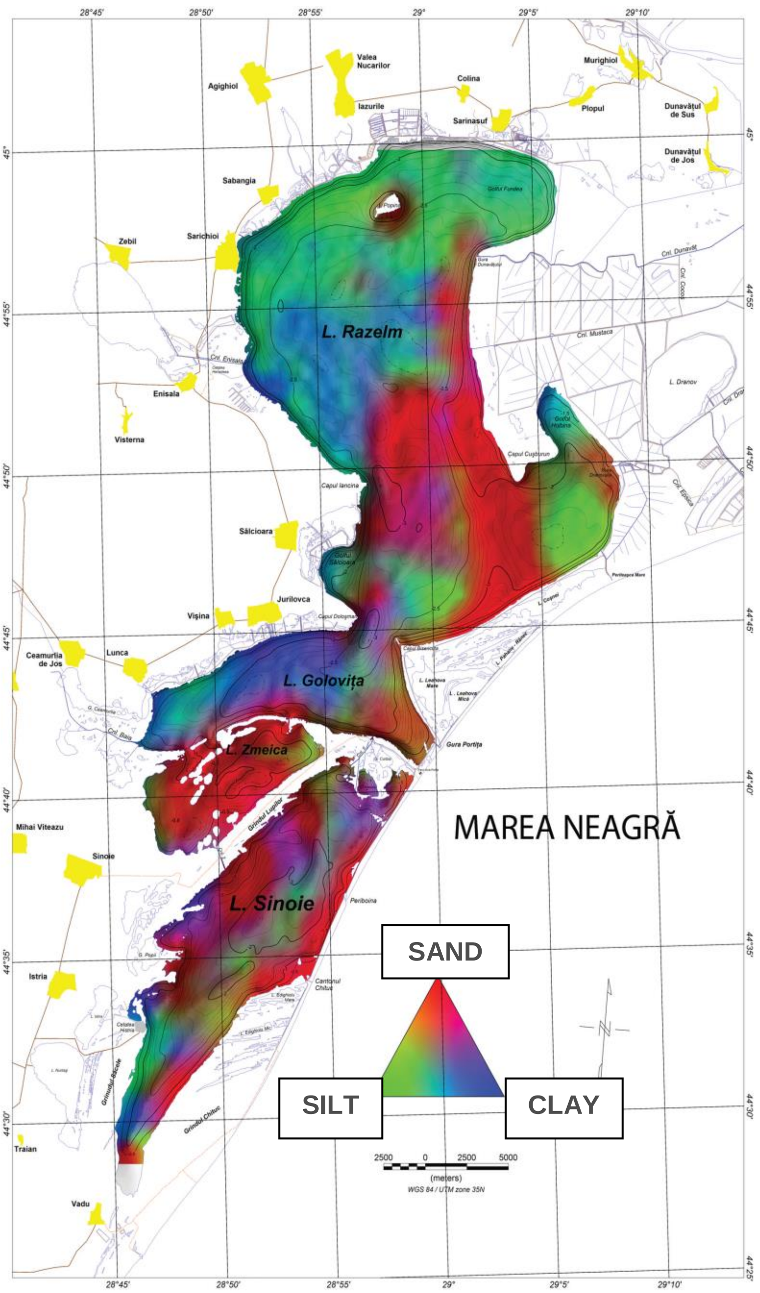


Figure 32 Sediment composition map of the Razelm – Sinoe Lagoon System

Phosphate (PO_4^{3-} as P) concentrations ranged from 0 to 6.75 mg/l in the Razelm-Sinoe lagoon system. Annual mean phosphate concentrations were typically highest in Razim or Golovita, which is likely due to the vicinity of these lagoons to the discharges into the system (Figure 33). Phosphate concentrations were markedly higher in 2015, however mean phosphate concentrations in other years remained <1 mg/l.

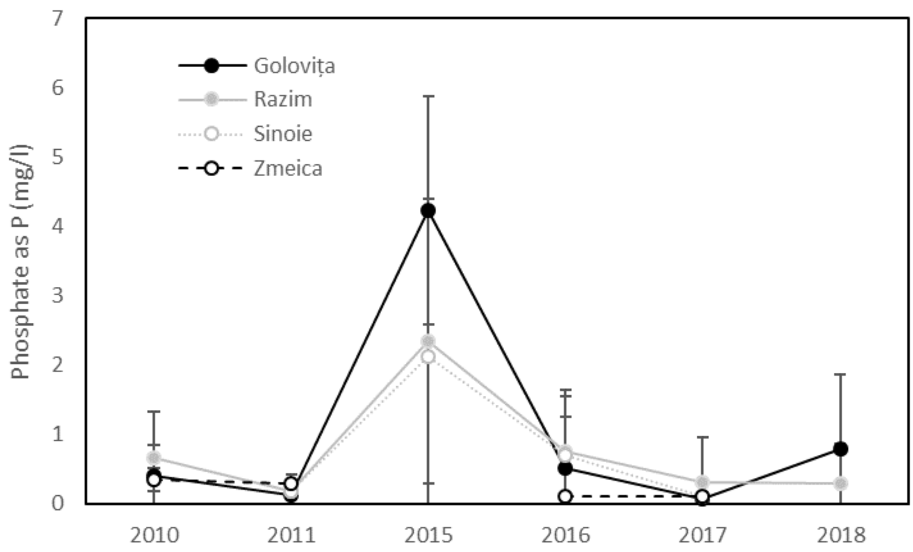


Figure 33. Mean phosphate concentrations (P-PO_4^{3-}; mg/l) in Razelm-Sinoe Lagoon System (error bars indicate standard deviation)

4.4.7 Earth Observation

Earth observation data from the MERIS sensor (2002-2012, Figure 34) show a highly dynamic pattern in phytoplankton Chl-a, with concentrations characteristic of a eutrophic water body. The optical water typology centres around types 2 and 10, associated with a strong influence of CDOM. This may also influence the accuracy in the retrieval of Chl-a concentrations. Suspended matter time-series derived from the satellite data also show a highly dynamic pattern with a continuous high load, indicating turbid water. 90th percentile maps of Chl-a indicate that high concentrations of phytoplankton are most commonly associated with the bays in the east and northeast parts of the lagoon system (Figure 35).

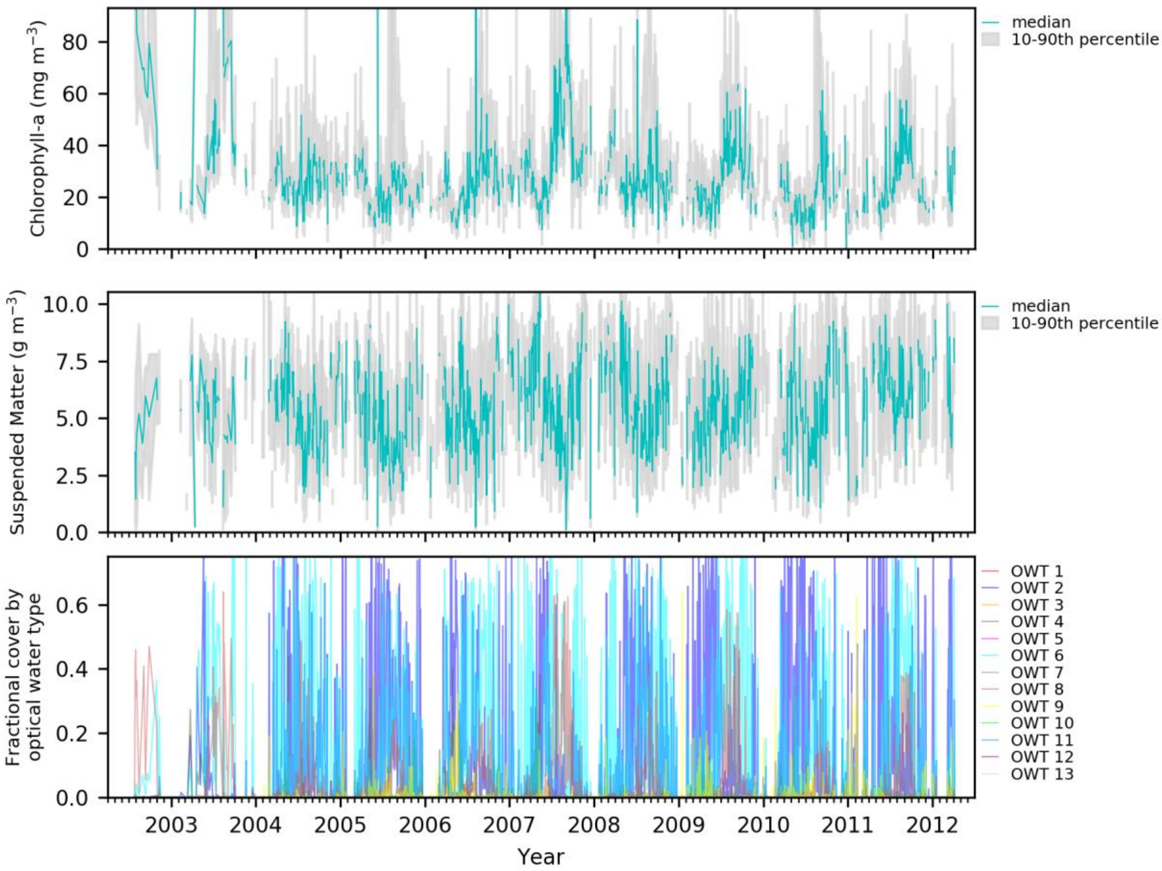


Figure 34. Earth Observation time series of Chl-a, Suspended Matter and Optical Water Types (OWT) in the Razim Lagoon (2002-2012, MERIS data)

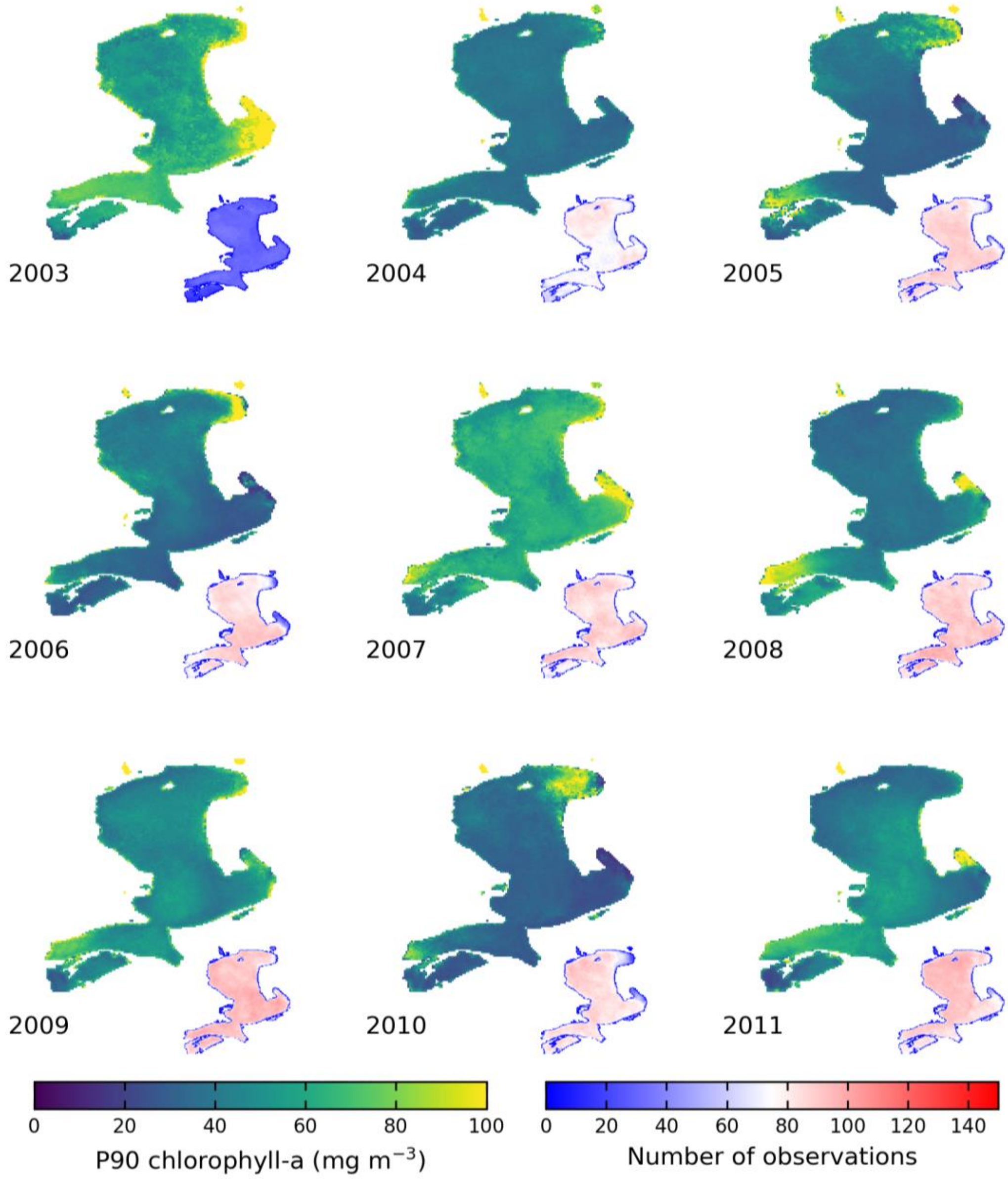


Figure 35. Yearly 90th-percentile maps of Chl-a in the Razim Lagoon (2003-2011, MERIS data)

4.5 Lake Tanganyika, Tanzania

Lake Tanganyika is an African Great Lake and rift lake, located across the four countries of Tanzania, Democratic Republic of the Congo, Burundi and Zambia (6°30’ S 29°50’ E). It is the longest freshwater lake in the world, and the second largest by volume and second deepest after Lake Baikal (Russia). The volume of freshwater held in Lake Tanganyika accounts for approximately 16% of freshwater in the world the lake is an important source of food, water and transport for over 10 million people. The lake is also a biodiversity hotspot, with an estimated >1,500 aquatic species present of which approximately 600 are endemic to the lake (Coulter, 1991).

4.5.1 Climate

Surrounding air temperatures range from 16-32°C, with water temperatures ranging from 20-30°C. The prevailing wind direction is SE/NE (monsoon winds), with speeds of 3-10 m/s recorded. Typical hours of sunshine are 2836 hours per year, and total annual rainfall is 900 mm per year.

4.5.2 Hydrology and Geography

The lake surface area is 32,600 km^2, with a mean depth of 570 m (maximum depth 1,470 m). The maximum lake length is 670 km, with a surface elevation of 773 m above sea level. Lake Tanganyika is oligotrophic and frequently subject to stratification, with a residence time of 440 years.

The main inflow is the Malagarasi River, and the main outflow is the Lukuga River, which flows into the Congo River and ultimately into the Atlantic Ocean. The surrounding landscape comprises mountains, wetlands, agricultural fields and woodlands. Lake Tanganyika is also a Natura 2000 site.

4.5.3 Map and Sampling Locations

Routine monitoring of Lake Tanganyika is undertaken by the Tanzania Fisheries Research Institute (TAFIRI) at 16 stations on a monthly basis (Table 4; Figure 36). However more recently (since June 2018), LT6-LT9 and LTM (Mahale) are no longer sampled.

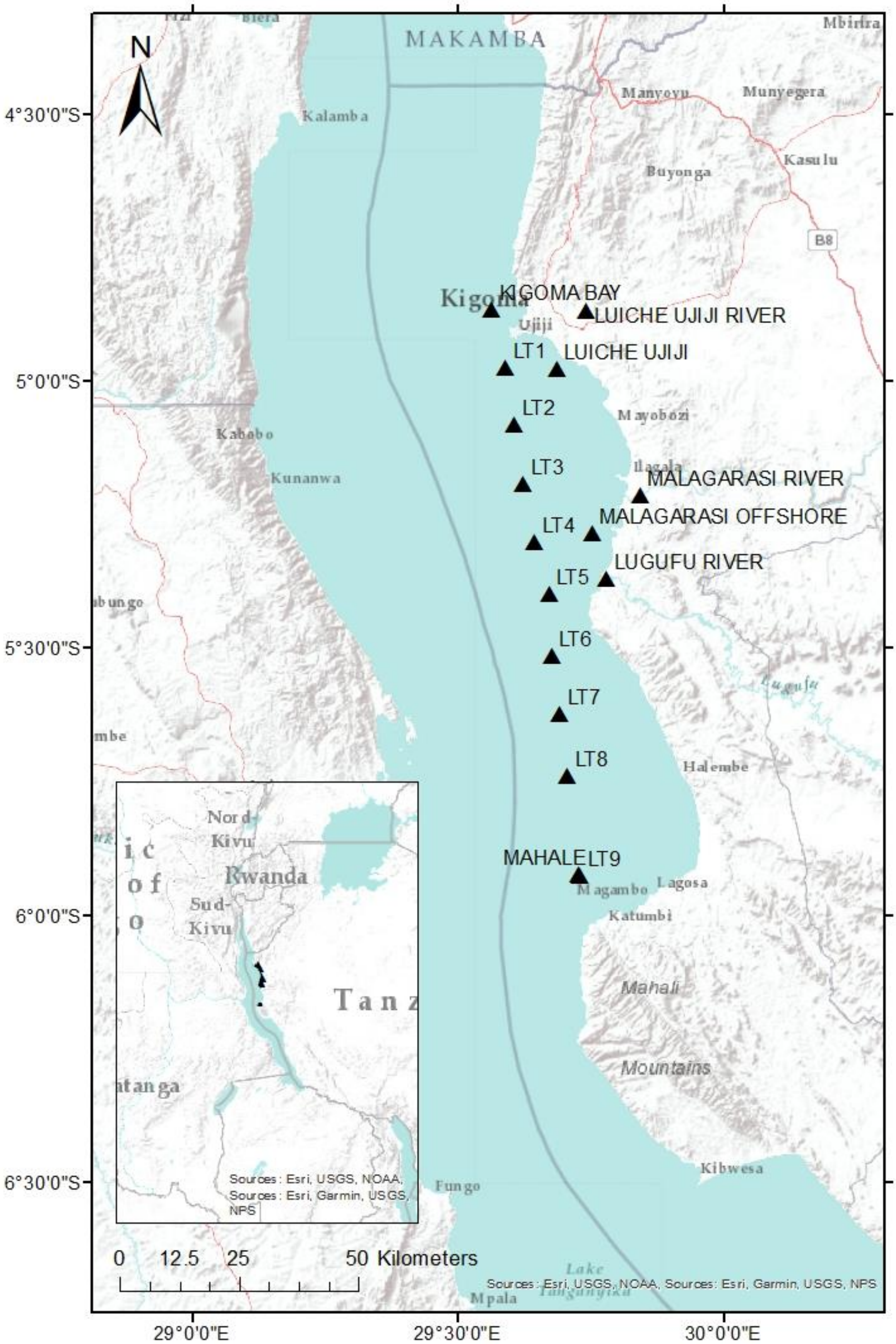


Figure 36. Map of Lake Tanganyika, indicating TAFIRI sampling locations

Table 4. Coordinates of TAFIRI sampling stations and buoy in Lake Tanganyika

Monitoring Body	Station	Latitude	Longitude
TAFIRI Buoy	KIGOMA BAY	-4.86505	29.5637167
	LUICHE UJIJI	-4.9751	29.6856833
	LUICHE UJIJI RIVER	-4.8681	29.7411667
	LUGUFU RIVER	-5.37015	29.7803833
	MALAGARASI RIVER	-5.21225	29.8426
	MALAGARASI OFFSHORE	-5.2836333	29.75305
	MAHALE	-5.9236	29.7277
	LT1	-4.9731100	29.588790
	LT2	-5.0807100	29.6063
	LT3	-5.1925300	29.62239
	LT4	-5.3005800	29.64384
	LT5	-5.3979200	29.67138
	LT6	-5.5141900	29.67646
	LT7	-5.6235700	29.69238
	LT8	-5.7387500	29.70597
	LT9	-5.9260900	29.72909
	Buoy	-4.931917	29.5807

4.5.4 Deployment Opportunities

Deployment opportunities at Lake Tanganyika include a buoy, which is located at Kigoma (4.931917° S, 29.5807° E; Figure 37). TAFIRI also has a boat with inboard engine that can be used for sensor deployment. Additionally, there are ferries on Lake Tanganyika that travel to Congo, Zambia and Bujumbura, however it is not yet established whether these can be used for MONOCLE sensor deployment.

Figure 37. Buoy at Kigoma in Lake Tanganyika

4.5.5 Lab Facilities

Sample storage facilities include a refrigerator (4°C) and deep freezer (-18°C). Filtration equipment is limited and includes two pumps and glassware (>50 flasks, beakers and burets).

Two spectrophotometers [Shimadzu scanning spectrophotometer and Thermospectronic (UV-VIS 1280 and UV-VIS 2401)] and one analytical balance (4 decimal places with 0.0001 accuracy) are available for use.

4.5.6 Data Archive

Samples are routinely analysed by TAFIRI for nutrients (nitrate, nitrite, ammonium, total nitrogen, total phosphorus, soluble reactive phosphorus), alkalinity, conductivity, dissolved oxygen (DO), pH, temperature, zooplankton, phytoplankton, total suspended solids (TSS) and Secchi depth. There are also primary production data for stations LTK and LTM only.

Recent Chl-a data for five sites in Lake Tanganyika show very low concentrations in surface waters indicative of oligotrophic conditions throughout the lake (Figure 38). Secchi depths ranged from 1-17.5 m, with offshore locations demonstrating increased water clarity (Figure 39). Total dissolved solids in surface waters ranged from 44-628 mg/l, with most values around 435 mg/l (median value) showing little spatial or seasonal variability (Figure 40).

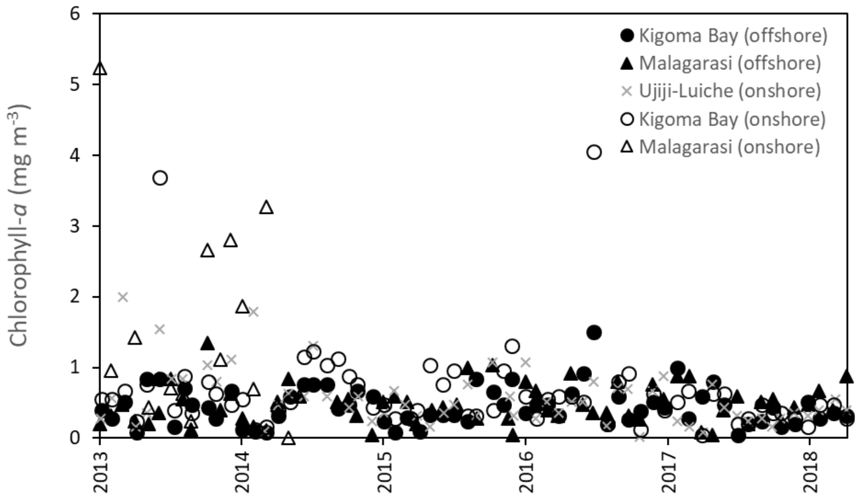


Figure 38. Time series of Chl-a in surface waters for 5 locations in Lake Tanganyika (2013-2018)

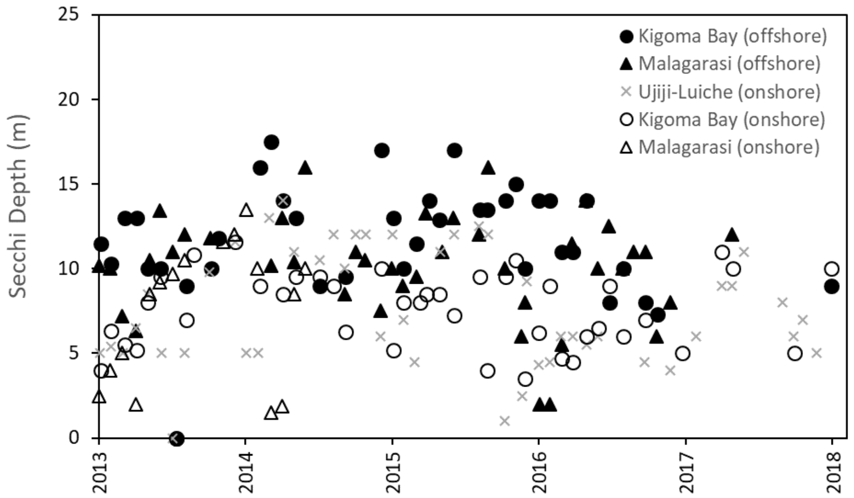


Figure 39. Time series of Secchi depth at 5 locations in Lake Tanganyika (2013-2018)

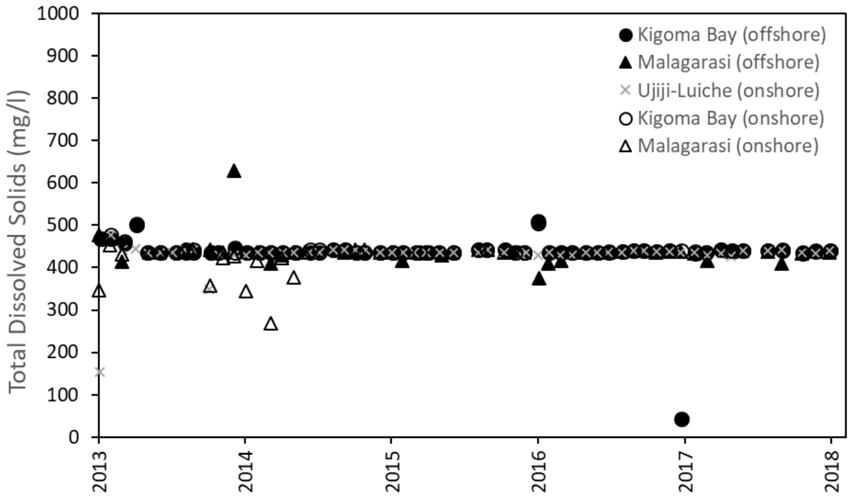


Figure 40. Time series of Total Dissolved Solids (TDS) in surface waters for 5 locations in Lake Tanganyika (2013-2018)

4.5.7 Earth Observation

The 300-m satellite imagery from MERIS analysed through the *Calimnos* v1.04 processing chain indicate conditions for oligotrophic to mesotrophic waters, with retrieved concentrations varying around 5 mg Chl-a m^{-3} (Figure 41). This is likely an overestimation due to relatively poor performance of Chl-a retrieval algorithms in clear inland waters. Higher Chl-a concentrations can occur in the mid to north of the lake (e.g. 2006), with some marginally elevated concentrations in the south end of the lake in recent years (Figure 42). Optical water type 13 (very clear water) dominates the observations as expected. Without globally validated Chl-a retrieval algorithms for oligotrophic inland waters, the typology is a better indication than the retrieved Chl-a concentration for this lake. It is, however, useful to note that there is no clear trend in the retrieved phytoplankton Chl-a concentrations over the 10-year observation period shown in Figure 41.

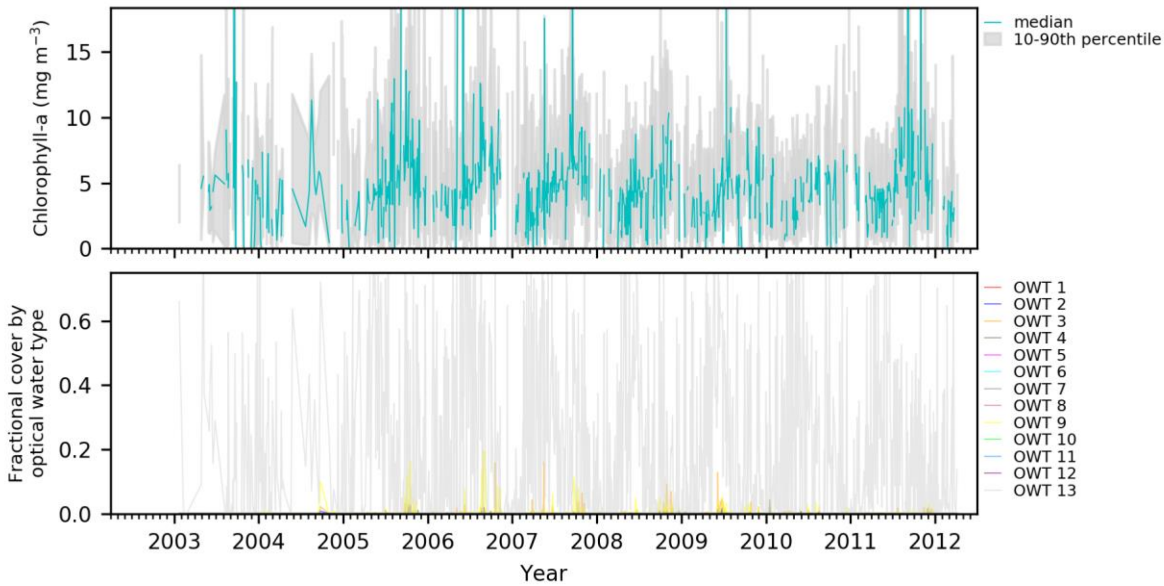


Figure 41. Earth Observation time-series of chlorophyll-*a* and optical water types (OWT) of Lake Tanganyika (2002-2012, MERIS data).

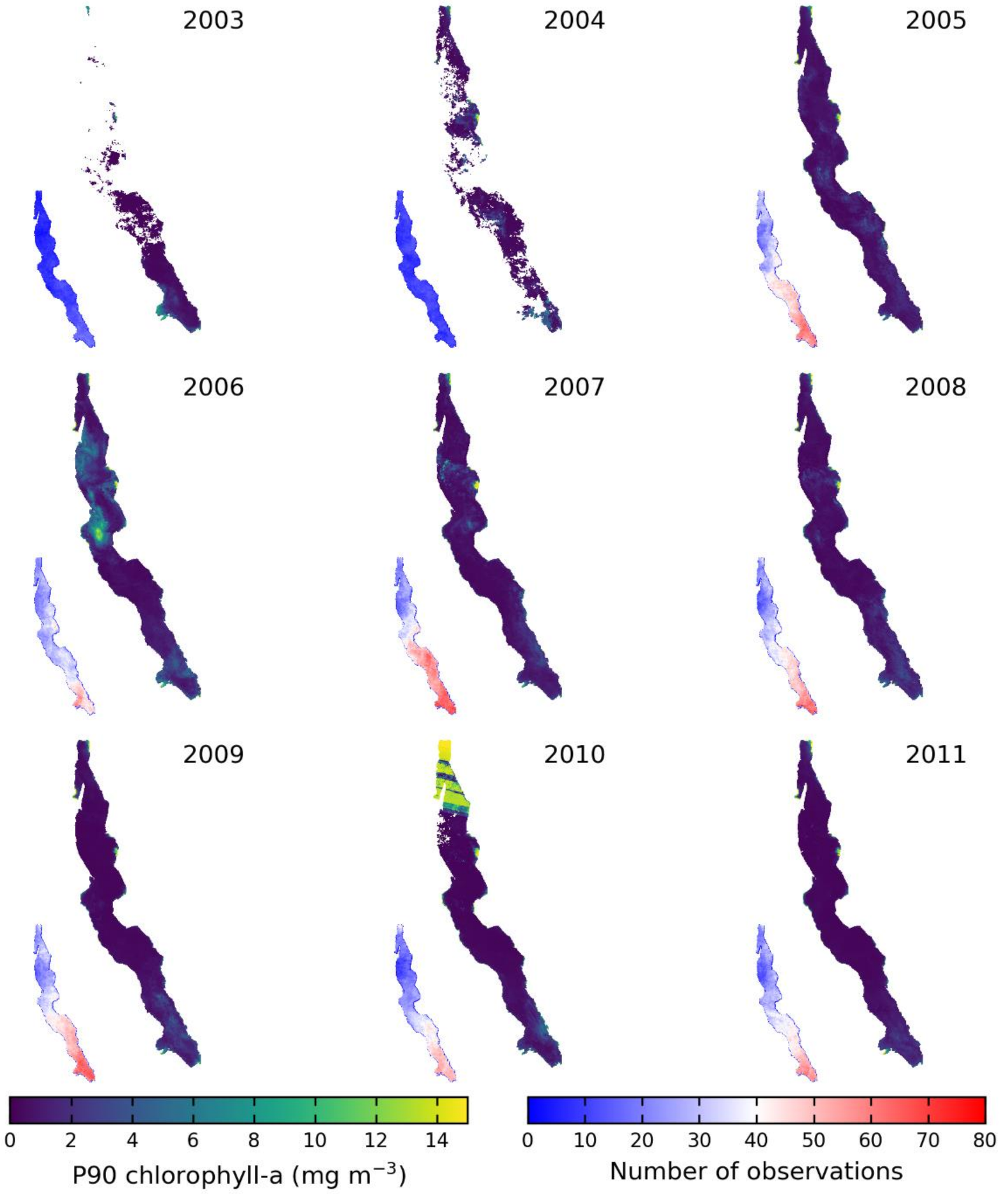


Figure 42. Yearly 90th-percentile maps of Chl-a in Lake Tanganyika (2003-2011, MERIS data). The pattern observed in the north part of the lake in 2010 is an artefact of calculating the 90th percentile and should be ignored.

5 List of Test Sites

The following table lists the sites routinely used for the deployment and testing of sensors by MONOCLE consortium members. Although no formal joint campaigns are planned at these sites, access is available to the consortium through the local site contacts.

Table 5. List of MONOCLE test sites

Site	Characteristics	EO Resolution	Infrastructure and scope	Lead and contact
Plymouth Sound & Western Channel Observatory	Western Channel Observatory, SPM gradients, long time-series of atmospheric and water quality observations, weekly visits	Med	Two offshore buoys, Rame Head and PML rooftop atmospheric observatory, AERONET, research vessels. Regular deployment and recovery. Ship-of-opportunity port for France and Spain.	PML: Stefan Simis
Pyrenees	Lake Closell, Lake Naorte. Eight lakes in total. Low accessibility, personnel on site. Natura2000 site, strong shifts in water transparency.	High	Citizen Scientists (low-cost buoys, biodiversity observation projects). Solar panels / batteries. Thermistors and light sensors, weather station <3km. Caravan on shore. Sampled 2-5 times/yr.	CSIC: Jaume Piera
Banyoles lakes	Lake Banyoles, Lake Vilar. Natura 2000 and RAMSAR site. Largest karstic lake complex on Iberian peninsula.	High	Accessible site with power supply. Weather station <1km. Laboratory on shore, personnel on site.	CSIC: Jaume Piera
River Scheldt	Highly turbid and dynamic, high economic value, dredging activities	High	Primary drone flight test site	VITO: Ils Reusen
Belgian lakes near Mol	Diverse water quality, algal and cyanobacterial blooms.	High	Primary drone flight test site	VITO: Ils Reusen
Sao Paolo reservoirs	Periurban reservoirs, massive algal bloom problems,	High	Ongoing citizen observatory, online GIS and database platform, use of smartphone apps.	CERT: Steven Loiselle

Site	Characteristics	EO Resolution	Infrastructure and scope	Lead and contact
Thames Valley Rivers and lakes	Citizen science infrastructure, eutrophication, Good tech support, links to H2020 and NERC funded Citizen Observatory projects	Med, High	Smartphone app, disposable kits, online GIS, feedback mechanisms to end-users.	CERT: Steven Loiselle
Lake Stechlin Lab	World's largest mesocosm facility	High	Cross-project collaboration (see Letter of Support) to test sensors in controlled experimental settings. A large scale experiment is currently planned for June-July 2019, in which several MONOCLE partners plan to participate.	IGB: external (via PML/ Stefan Simis)

6 Exploitation and Dissemination

Although this is not a dedicated exploitation deliverable, the information in this deliverable can also be used in **WP8** (Project Dissemination and Exploitation) by contributing validation site characteristics and data, particularly in data-poor regions.

This report contains a number of graphical results from long-term data analysis, which the MONOCLE project may re-use in dissemination activities and scientific papers. For any other use, please contact the authors.

7 Future activities/recommendations

This deliverable will allow the matching of MONOCLE testing requirements to validation sites to ensure appropriate deployment opportunities and resources are available for each sensor/platform. This deliverable also provides feedback on site characteristics to aid sensor/platform development for **WP2** (Novel Sensors and Sensing Methods) and **WP3** (Acquisition and Deployment Techniques).

Importantly, results of this deliverable confirm that the five MONOCLE field campaigns will cover a sufficient range of climatic conditions, geographic locations and bio-geo-optical properties for testing the novel sensors and systems. The MONOCLE validation campaigns will add value through the evolution of system standards and innovative *in situ* observation platforms, particularly in data-poor regions where no previous such campaigns have been undertaken.

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